Development and Evaluation of an Electronic Guide for Introductory Microbiology Skills

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To increase the quality of instruction, enhance student learning, and decrease laboratory time spent on laboratory safety, basic skills, and the use of equipment, we developed the Micro eGuide website. We compared the performance of students who used the Micro eGuide to students provided more traditional instruction in both an upper-level introductory microbiology course for biology majors and in a lower-division introductory microbiology course for nonmajors. Assessment of student learning included written pretests and posttests, practical testing of laboratory skills, and for the major's class, a review of poster presentations of independent projects. Students who used the Micro eGuide showed a statistically significant increase in performance on written examination in the introductory microbiology courses for both biology majors and nonmajors. Use of the Micro eGuide in the sophomore-level course for nonbiology majors resulted in a statistically significant improvement in laboratory skills. Though the increase in laboratory skills in the majors courses was not statistically significant, instructors were able to use the site as an effective learning source and decrease the time spent in class on topics covered in the Micro eGuide. While the number of student independent research projects was too small for statistical analysis on the quality of the poster presentations, the improvement in student attitude and the increase in the diversity in topics selected suggests that students using the Micro eGuide had increased comfort with microbiology and increased interest in exploring microbiology.

We view science laboratories as essential for developing students' higher-order thinking skills, including science process skills (problem solving, creativity, generating and testing hypotheses, data analysis), and to a lesser extent, for conveying and reinforcing content. For our goal of enhancing students' understanding of science as a process, student projects and investigative laboratories are particularly applicable (6). Theory and research on student motivation suggest that challenging, intrinsically interesting assignments are helpful for both self-confident and self-doubting students, especially when an absolute grading system is used to provide feedback (2). Although instructors may be concerned that investigative laboratories decrease "coverage," investigative laboratories increase student learning of difficult concepts in introductory biology (3, 5, 8). In our experience, it is very difficult for students to grasp an exercise that requires them to learn new skills and explore content areas simultaneously. However, simply practicing skills without collecting analyzable data focuses on skill acquisition at the expense of cognitive learning. To assist students in gaining necessary skills quickly and with minimal use of precious laboratory time, we developed a website to introduce microbiology laboratory safety, basic skills, and some laboratory equipment. Other investigators have shown that web-based instruction is effective for teaching complex ideas in biology and microbiology (7).

We developed an online multimedia laboratory guide for microbiology and molecular biology. The guide was intended to replace neither the laboratory experience nor the traditional laboratory manual; rather it served as an introduction to

laboratory techniques designed to enhance time spent in the laboratory and to give students increased confidence in their laboratory skills. Hypermedia is especially appropriate for providing students with technical information as they need it (1). Hypermedia is very efficient, as it allows nonlinear access to information, and the information can be presented in the most effective manner (text, diagrams, photographs, video). For example, students were first exposed to the use of the spectrophotometer by viewing, before coming to lab, a website that included a simulation and photographs demonstrating the correct use of the instrument and by completing an associated quiz. Video clips provided preclass instruction in streaking plates and making smears. The guide was designed to introduce techniques and equipment in introductory courses and as a review for students needing these techniques in advanced courses or in research projects. Our goal was to enhance student competence in the laboratory, allowing more opportunity for independent exploration.

METHODS

Description of the website. We developed a modular electronic multimedia laboratory guide to provide students with directions for use of equipment in the laboratory and some common microbiological techniques. This Micro eGuide includes video-clips, graphics, text, interactive features, and an associated quiz for many of topics (Table 1). Three sections of the guide have been published on the web: Laboratory Safety, Laboratory Skills, and Laboratory Equipment (graphic menu shown in Fig. 1). The Micro eGuide is available at <http://www.microeguide.com>.

Assessment of student learning. The impact of the Micro eGuide on student learning was assessed in two microbiology classes; Micro 20 and Micro 140. Micro 20 is a sophomore-

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TABLE 1. Micro eGuide components and content

Topic	Pages	Videos	Interactive features	Quizzes
Laboratory safety				
1. Good lab practice	6	2		1
2. Cleanup	8	1		1
3. Protective procedures	4	1	3	1
4. Emergency procedures	11	4		1
5. Safety contract	1			
Laboratory skills				
1. Aseptic techniques				
a. Broth transfers	2	1		1
b. Streak plates	3	1	3	1
c. Pipette transfers	2	1	1	1
2. Slide preparation				
a. Simple smear	2	2		1
b. Direct stain	2			1
c. Wet mount	2	1		1
3. Enumerating microbes				
a. Viable counts	3		1	2
b. Dilution arithmetic	1		1	
c. Pipetting	4	1		
d. Spread and pour plates	3	2		
e. Turbidimetry	1			
Laboratory equipment				
1. Bunsen burner	2	1		1
2. Micropipettors	5		2	
3. Water baths	3		2	1
4. Microscope	18	1	6	2
5. Spectrophotometer	8		6	1

level introductory microbiology course for nonbiology majors, made up primarily of prenursing students. Laboratory sessions in Micro 20 meet twice a week for 1.5 hours. Micro 140 is a junior or senior-level general microbiology course for biology majors with a prerequisite of organic chemistry. Laboratory sessions in Micro 140 meet for 2 hours three times a week, or 90 hours total each semester. Micro 140 has two laboratory sessions each semester; assessment data was gathered over four semesters. In the Fall 2002, the Spring 2003, and the Fall 2003 semesters, the laboratory sessions were taught by long-time instructors. A new faculty member taught one of the laboratory sections during the Spring 2003 semester and worked closely with an experienced instructor to ensure that the labs were taught identically and that the same procedures were used.

The study was explained to the students; students were asked to voluntarily take part in the study and asked to sign an informed consent form. One hundred percent of the students agreed to participate, and they were assured that their identities and individual performance would remain confidential. Students were taken to a computer laboratory the first day of class, taught to log onto and navigate the Micro eGuide, and given the opportunity to complete the safety portions of the Micro eGuide. Students using the Micro eGuide were required to take online quizzes associated with the individual topics. Students were required to take quizzes in the week before coming to the laboratory in which

that skill or equipment was first used and were awarded points that could comprise 2.5% of the total grade in Micro 20 (13 quizzes) and 4% of the course grade in Micro 140 (17 quizzes). No points were awarded for quizzes taken late.

Knowledge of laboratory skills, safety, and equipment was assessed using a written pretest and posttest consisting of 40 true-false questions (Fig. 2). The gain or the average effective improvement in the scores was determined, pretest compared to posttest, and is calculated: $\text{Gain} = (\% \text{post} - \% \text{pre}) / (100\% - \% \text{pre})$. Where angle brackets < . . . > indicate the class average for students who have taken both the pre- and posttests (4). The pretest was given to students the first day of class before any instruction. The identical posttest was given the last week of classes. Students were told to do their best but that the pretest would not affect their grade. The posttest was graded and students in Micro 20 were told that the posttest would not affect their grade; however, students in Micro 140 could earn 10 points out of the total 1,000 points in the course (1%). Competence in laboratory skills (aseptic tube transfer, plate streaking, and making a simple smear) was assessed near the end

of the semester through observation by trained graduate student observers. Training for the observers included reading the checklist that would be used to indicate student performance, discussions about not providing students any hints (positive or negative), and practice observations. The checklist they used for streak plating is provided in Fig. 3; on this sheet observers chose the action they observed from a list. A correct procedure was given one point; an incorrect procedure did not receive any points. For the streak plating lab practical, 28 points were possible. When the observer could not decide if the action taken by the student was correct or not, the observer noted the action and discussed it later with the professor. Single factor analyses of variance (ANOVAs) were used to compare student scores on these practical examinations. Practical examination results were part of the student's grade in the laboratory portion of the course. Test results from students who used the eGuide were compared to the results from students who did not use the Micro eGuide. Both students who used the Micro eGuide and those who did not received traditional training including in-class lectures and demonstrations; however, in the fall 2003 semester, when all of the students in the Micro 140 course used the Micro eGuide, the instructors decreased the time spent in class demonstrating and lecturing material covered in the Micro eGuide. In order to measure the impact of the Micro eGuide on the use of class time, the Micro 140 instructor maintained a log of instructional activity over two

semesters, the Fall 2002 semester before the Micro eGuide was used and the Fall 2003 semester. The log recorded the time spent by the instructor introducing laboratory experiments and demonstrating techniques. The log did not include one-on-one instruction, explanations, and demonstrations given by the instructor to individual students during the course of the laboratory sessions.

We also examined if using the Micro eGuide allowed students to feel more comfortable with independent projects. Independent projects have been a feature of our introductory course for majors for many years. Students prepared for the project throughout the semester and devoted six laboratory periods (2 weeks) to the actual bench work. The students worked in groups of four, wrote a formal report, and presented their results to the class in a poster session. Independent project posters were assessed using a Primary Trait-Based Scale for Biology: Original Scientific Experiment, a scoring rubric developed by Virginia Johnson Anderson (8). To gain an understanding of how students felt about laboratory activities, the students were surveyed each semester about which experiments or activities they enjoyed most in the laboratory.

RESULTS

Testing in nonbiology majors sophomore-level introductory microbiology course. Microbiology students in the nonmajors course (Micro 20) improved their knowledge of laboratory safety, skills, and equipment each semester as indicated by pre- and posttest scores, and these improvements were statistically significant ($P < 0.00005$). This improvement was achieved whether or not students used the Micro eGuide, showing that the students learn the material after being taught with both the traditional techniques and with the Micro eGuide. Micro eGuide users and nonusers earned equivalent scores on the pretest ($P = 0.34$) and on final lecture grades, suggesting that the two classes were equivalent in ability and in preparation for the course. Students who used the Micro eGuide scored better on the posttest than students who received only traditional instruction (statistically significant, $P < 0.00005$) and showed a higher percent improvement or gain (statistically significant, $P < 0.0023$). Near the end of the semester, students using the Micro eGuide earned statistically significant higher scores on a practical examination of skills than students in the control group ($P < 0.0005$). These results are summarized in Table 2.

Graphic Table of Contents - Laboratory Equipment

FIG. 1. Graphic table of contents for the laboratory equipment section of the Micro eGuide. The Microscope subheading is expanded. On the website, selection of any of the above squares opens a content page or menu of pages associated with the topic. Similar subheadings are available under Laboratory Safety and Laboratory Skills.

Testing in an upper-division introductory microbiology course for biology majors.

In the Spring 2003 semester, the class of 44 students in Micro 140 was split in half alphabetically. Half of the class was instructed to use the Micro eGuide (21 students) and the other half was instructed not to use the Micro eGuide (22 students), serving as the control group. Pretest scores and final lecture grades of the two groups were equivalent, showing that they did not differ in preparation or ability. Both groups received traditional instruction in class, including in-class demonstrations of techniques. Students who used the Micro eGuide scored higher on written posttests of their knowledge of laboratory safety, skills, and equipment (statistically significant, $P = 0.0279$) and showed a greater improvement or gain than students who were taught only with traditional techniques (statistically significant, $P = 0.0104$), but did not improve significantly in performance on the laboratory practical (Table 3). We examined the performance of the students in individual skills to determine if the Micro eGuide was more helpful in teaching some of the skills. The average scores for students who used the Micro eGuide were higher than the average scores for students who did not in all of the skills tested except work area preparation; however, none of

Name _____

Micro 140. For each of the following statements please indicate whether the statement is true or false.

True	False	Statement
		Never pipette by mouth.
		It is okay to have drinks in the lab as long as you return the drink to your book bag after every use.
		Lab benches should be cleaned at both the beginning and end of every lab.
		Petri plates should be incubated agar side down.
		In lab we follow Environmental Protection Agency guidelines for handling infectious materials.
		You should consult your physician before taking this course if you are pregnant.
		Beer's Law relates concentration and absorbance.
		Syringes should be disposed of in the red sharps container that is used to dispose of needles even if the syringe was used to measure buffer.
		All marks and labels must be removed from glassware before it is put aside for washing.
		Before glassware is placed in the tub to be washed, chemicals or culture in the glass container should be poured down the drain at the designated sink.
		After washing your hands, dispose of the paper towel in the hazardous waste container just in case there are still bacteria from class on your hands.
		You should take your lab coat home once a month to wash it.
		Bunsen burners should only be lit by the instructor.
		A spectrophotometer measures light given off by a substance.
		Ultraviolet light is measured at 350 to 600 nm.
		It is possible to determine the approximate number of bacteria in a gram of soil.
		When using the microscope, the working distance increases when the magnification increases.
		Gloves should be worn at all times in the laboratory.
		Some procedures in the lab require a face mask or goggles.
		A countable range used to determine the number of bacteria on a plate is 5 to 15.
		Safety controls on water baths prevent the temperature of the water bath from getting too high.
		You do not need to check the temperature of a newer water bath with digital controls.
		The flame from a Bunsen burner is very uniform in temperature.
		The purpose of streaking a plate is to isolate bacteria.
		It is necessary to flame your loop between sections of a streak plate.
		The eyepieces of a microscope magnify the image 100 times.
		In using a spectrophotometer it is possible to determine both the transmission and absorption from one reading.
		The microscope should be cleaned with "Kim" wipes—never with paper towel.
		Hands should be washed for 1.5 minutes using soap after each lab.
		CFU stands for colony forming unit.
		It is possible to adjust the flame on a Bunsen burner three ways.
		The lid of a Petri plate should be placed on a section of just disinfected laboratory bench while streaking a plate.
		The nose piece of the microscope holds the objectives.
		You should consult your instructor before using the eye wash station.
		Resolution and resolving power are inversely related.
		Turbidimetry readings may be used to estimate cell numbers in a culture.
		Phase contrast microscopy is used to study stained bacterial cells.
		Using oil immersion microscopic techniques increases the resolution.
		Heat fixing a slide weakens the bacterial cell walls allowing the stain to penetrate the cells.
		Micropipettor tips should be wetted before using them to measure 1 to 10 microliters.

FIG. 2. Pre- and posttest given to students in the major's introductory microbiology course. Students were to indicate if the statement was true or false.

Student Name: _____

Lab Section – Monday 10, 12 or 2 OR Thursday 8:30, 10 or noon

Instruct students: “Act as you would if you were coming into this lab to perform two tasks: to streak a plate and to prepare a smear for a Gram stain (get the smear ready for the primary stain).” Do not prompt them or remind them in any way about the techniques or about steps they might forget or mistakes they make.

Prep

- Bench disinfected/not disinfected
- Paper towel from disinfecting bench thrown in normal trash/thrown in biohazard bag
- Hair tied back/hair and/or ties and/or jewelry dangling

Bunsen burner

- Gas turned on immediately before lighting/gas turned on a minute or more before lighting
- Gas flow adjusted/gas flow not adjusted/does not apply
- Air flow adjusted/air flow not adjusted/does not apply
- Appropriate flame set-up (has two cones of flame)/flame too high or too low

Streak plate

Labeling

- Plate is labeled with name, lab section, date, culture ID
- Labeled on agar side/labeled on lid

Flaming the loop

- Loop is held fairly vertically in flame/loop is held horizontally/loop is held so vertically that the student gasps in pain
- Tip of loop is just above the interior bright blue cone of the flame/loop is too low/loop is too high
- Loop is heated just until red hot/loop is too cool/loop is too hot
- Loop is allowed to cool/culture or agar sizzles

Removing culture from tube

- Test tube is held in one hand, loop in the other/test tube is left in rack
- Lid is removed using little finger of hand containing loop/lid is removed with finger and thumb
- Remove barely visible (or invisible) amount of culture/use too much culture/did not pick up culture
- Lid is retained in little finger/lid is placed on countertop
- Flamed loop is inserted into culture/loop is not flamed
- Lid is immediately replaced on tube/replacement of lid is delayed

Opening Petri dish

- Lid is cracked open/lid is removed/lid is left on countertop

Streaking

- Loop is streaked across surface of agar by flexing fingers/looks as though student is “drawing” lines on plate
- Loop is flamed between sectors/forgets to flame loop between sectors
- Loop is allowed to cool after flaming/agar sizzles
- Loop is flamed before setting it down/contaminated loop is set down
- Other mistakes you see: such as pattern, amount, going back over old streak, etc.,

Turn in with plate agar side up/turn in agar side down

Clean-up

- Straighten work space/leave everything where it was last used it
- Disinfect lab bench/do not disinfect lab bench/leave spills uncared for

FIG. 3. Checklist used to assess the streak plate and work area preparation practical examination. Observers were to select the behavior they observed from the choices written. Each correct action scored one point; 28 points were possible. If students did something that was not listed, observers were to write the observation in the page margin for interpretation by the instructor.

the individual skill assessments were statistically significant (Table 4).

To increase sample size and decrease the likelihood that students who had used the Micro eGuide were training their partners, the Micro eGuide was assigned to Micro 140 students in the Fall 2003 semester but not in the Spring 2004 semester. Again, there was no statistically significant improvement in performance on the practical examination of general safety procedures, aseptic tube transfer (using a loop), and plate streaking (Table 3). During this analysis students who used the Micro eGuide received less in-class instruction on techniques that were taught in the Micro eGuide, and despite this decrease, the performance of students who used the Micro eGuide was not statistically different from students taught with traditional methods of lecturing and demonstrations. This was true for each of the individual skills tested. In the Fall 2003 semester, the Micro 140 instructor using the Micro eGuide spent 12 hours introducing laboratory exercises and teaching basic skills compared to 19 hours spent lecturing in the laboratory sessions for students who did not use the Micro eGuide. This decreased the lecture time per laboratory session from an average of 25 minutes to less than 16 minutes, leaving more time for experimentation and interaction. However, the lecture and demonstration time was decreased primarily in the first 6 weeks of the 15-week course, when students learn most of the basic methods covered in the Micro eGuide. Introductory lectures for the 18 laboratory sessions in the first through sixth weeks decreased from 30 minutes to an average of 13 minutes. Overall the instructor saved 7 hours, 5 of the 7 hours in the first 18 laboratory sessions.

Anecdotally, students express feelings of being overwhelmed with the prospect of choosing a project, designing an experiment, and analyzing results. In spite of this, during the Fall 2002 semester before the Micro eGuide was initiated, 55% of the students claimed the independent research project was their favorite class activity. None of the other laboratory activities was chosen by more than 15% of the students as a favorite activity. During the Fall 2003 semester, when 100% of the students used the Micro eGuide,

the project was the favorite activity of 85% of the students, suggesting an increase in student comfort with performing microbiological investigations. In these two semesters the only instructional change was the use of the Micro eGuide; the instructions provided and instructors involved were identical. Analysis of student project presentations did not show a difference in the scientific format, descriptions of materials and methods, background, and control of variables between student groups that did or did not use the Micro eGuide. Although the low sample size (ten posters each semester) precluded statistical evaluation of the results, groups that used the eGuide obtained higher scores on experimental design, data collection, and interpretation of data than those who did not, scoring an average of 4.5 versus 3.2 on a five-point scale. We also noted that students who used the Micro eGuide took on more original and complex projects. In the semester prior to the initiation of the Micro eGuide use, seven out of ten projects involved experiments similar to those done in class with only minor variations on technique. The semester the Micro eGuide was used, only three out of the ten projects involved minor variations of class laboratory experiments.

Student evaluation of the Micro eGuide. The semester we split the class alphabetically, some students assigned to use the Micro eGuide felt that their workload was excessive when compared to those who were not asked to use the Micro eGuide, while some of the students asked not to use the Micro eGuide felt that they were missing out on important instruction. Three of the 21 students in the control group confided to their instructor that they had used the Micro eGuide anyway. These types of complaints disappeared in the semester where all of the students were required to use the Micro eGuide.

Some students expressed unhappiness with the Micro eGuide because they thought that they had submitted Micro eGuide quizzes, but there was no computer record of the quiz submission. Often this was due to students forgetting to log onto the system. Though students who were not logged on could take the quizzes, log on was required for the quiz results to be reported to the instructor. Though the

TABLE 2. Impact of Micro eGuide on student performance on written and practical examinations in a nonmajor's introductory microbiology course (Micro 20)

	Fall 2003 (eGuide used)	Spring 2004 (eGuide not used)	<i>P</i> value ^a
Pretest mean score (n)	64.5 (108)	63.1 (105)	0.34
Posttest mean score (n)	77.1 (99)	72.5 (95)	0.00005
Gain	33%	23%	0.0023
Lab practical mean score (n)	91.2 (75)	82.3 (105)	0.00005

^a*P* value compares difference in students performance when eGuide was and was not used.

TABLE 3. Impact of eGuide on student performance on written and practical examinations in a biology majors introductory microbiology course (Micro140)

	eGuide used	eGuide not used	<i>P</i> value ^a
Spring 2003			
Pretest mean score (n)	62.4 (21)	64.1 (22)	0.2906
Posttest mean score (n)	79.6 (21)	74.7 (22)	0.0279
Gain	44%	23%	0.0104
Lab practical mean score (n)	84.2 (21)	79.4 (26)	0.2559
Fall 2003			
Lab practical mean score (n)	87.3 (43)		
Spring 2004			
Lab practical mean score (n)		83.6 (34)	0.09 ^b

^a*P* value compares students performance between when eGuide was and was not used.

^bThe *P* value of 0.09 compares student performance on the lab practical for the fall 2003 semester when the eGuide was used to performance in the spring of 2004 when the eGuide was not used.

completion of the Micro eGuide quizzes was only worth a small percentage of the total grade, students expressed frustration with this. To solve this problem we have added a feature that allows students to monitor their quiz records.

Students who were assigned to use the Micro eGuide were asked to respond to a short survey about how helpful they felt the Micro eGuide was. Most students felt the Micro eGuide was helpful, scoring 3.3 on a four-point scale (4 was very helpful). Students were ambivalent concerning whether or not the site was fun or easy to use; the average responses for these two topics were in the middle of the scale. Interestingly, about one-third of the students in the Micro 20 course took quizzes and investigated sections that they had not been assigned, suggesting some enjoyment in the process. Monitoring of Micro eGuide use suggests that students return to the site and retake quizzes after the due dates, suggesting they find the site useful for review of these basic techniques.

DISCUSSION

Ideally, students should acquire the ability to learn new skills and techniques as they are needed for their work. To increase the quality of instruction and to decrease laboratory time spent on laboratory safety, basic skills, and the use of

equipment, we developed the Micro eGuide website. Use of the Micro eGuide significantly increased student performance on written examinations in introductory microbiology courses for both biology majors and nonmajors. Use of the Micro eGuide in the sophomore-level course for nonbiology majors supported a statistically significant improvement in laboratory skills. The lack of a statistically significant impact of the Micro eGuide on skill performance assessment in the majors course may have been due to the smaller number of students tested, the more extensive laboratory experience of the junior and seniors in the class, or the fact that the major's course met for 90 hours over the semester and students had more time to learn and practice the techniques. The site was an effective primary source for learning the material tested and allowed the instructor to decrease the amount of time spent in class on material covered by the Micro eGuide. Analysis of group laboratory projects by students showed greater diversity in the selection of group project topics and an improvement in many of the student's enjoyment of the projects, these suggest that using the Micro eGuide increased the students' level of comfort with microbiology and an increased interest in exploring microbiology. We plan to increase the basic modules on the site to expand its usefulness in the future.

TABLE 4. Spring 2003 Micro 140 lab practical results broken into individual skills tested

Individual skill tested	Number of students using the eGuide	Average score for students who used Micro eGuide (%)	Average score for students who did not use Micro eGuide (%)	<i>P</i> value
Preparation	21	76.9	82.1	0.3728
Tube transfer	19	89.5	81.8	0.1279
Streak plate	19	81.3	73.9	0.1897
Aseptic pipetting	17	88.3	85.9	0.6008

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