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Virtual laboratories enhance traditional undergraduate biology laboratories

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1. Introduction

Much of the breathtaking progress in biology has been driven by powerful new methodologies that are not currently represented in many undergraduate biology laboratory courses. Molecular biology forms the core of modern biology and, as in the physical sciences, its successful application relies on quantitative reasoning. The drill and repetition of interpreting a diversity of data sets—required to master such skills—cannot be adequately provided during conventional laboratory periods. Virtual laboratory environments provide repetitive practice in techniques and data manipulation and interpretation that students cannot easily experience in the usual 3-h period of the traditional teaching laboratory.

2. Description of materials

Working with undergraduate students, skilled in producing animated web material, we have developed a series of biotechnology related "virtual laboratories" available on the web to our students and, beginning this August, available generally from McGraw-Hill. In our virtual laboratories, students are exposed to essential biomolecular technologies and, by using real-life case scenarios, learn how these technologies are used in the fields of medicine (for disease diagnosis), agriculture (for the generation of genetically engineered crops) and forensics (to generate genetic fingerprints). Web-based simulation software is used to make the virtual experiments visually engaging and interactive, requiring decisions and analytical input from the student.

Currently, iLaBS include several disease diagnosis labs (based on sickle cell anemia, cystic fibrosis, Huntington's disease and hemophilia), a DNA fingerprinting lab (based on the deposed Romanov family), and a restriction mapping lab. An animation detailing regulation of the lactose (*lac*) operon (with interactive tutorials that teach students how to interpret *lac* operon mutant genotypes), and comprehensive simulations of the processes of DNA replication and transcription will also be available. Future iLaBS (available January of 2002) include a mutations/protein modeling lab (to illustrate how changes at the DNA level affect amino acid sequence and ultimately the structure of proteins), an enzyme kinetics lab (illustrating Michaelis–Menten kinetics), and a genetic regulation lab (based on the regulation of bacterial operons), as well as animations illustrating modern approaches to sequencing and cloning.

3. Procedures

Our strategy is to implement a two-phase experience in many of our laboratories. First, we introduce students to demanding experimental procedures at the bench. Rather than repeating these costly "wet" labs to generate additional data sets, students then chose from a variety of case scenarios and use virtual simulations of the techniques that they learned at the bench—now in a virtual environment—to generate and interpret new data sets. As an added benefit, the on-line laboratory exercises allow us to expose students to time-consuming and/or hazardous techniques that they would otherwise not be able to experience in our "wet" laboratories.

This "virtual hands-on" approach forces students to think about the experimental setup and techniques. If the student tries to perform a step out of sequence, an error message appears indicating that an essential step in the procedure has been omitted. Similarly, if the student fails to set up the experiment correctly, incorrect data are obtained. Because one of the goals of the on-line laboratories is to teach students how to set up and conduct experiments, the student can repeat the virtual experiment as many times as necessary.

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For example, in the disease diagnosis labs, students are required to assemble the reaction components in virtual test tubes, load and run virtual electrophoretic gels, generate virtual Southern blots, and interpret the data they obtain using a variety of tools provided in the virtual lab environment (see Figs. 1 and 2). In the accompanying "wet" lab, students are taught how to set up reactions and run gels but do not carry out the time-consuming technique of Southern blotting.

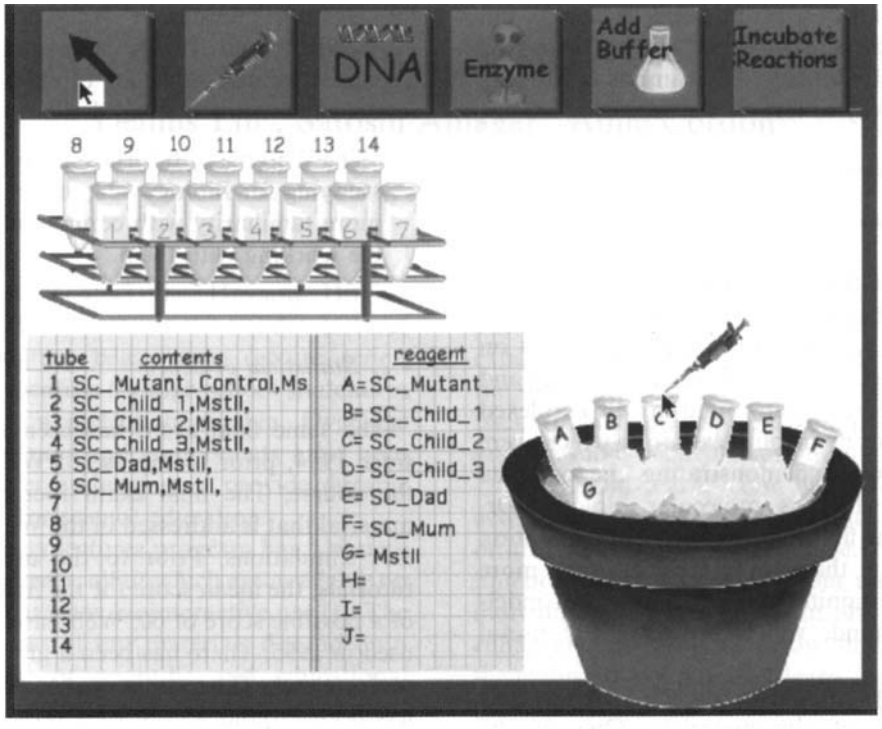

Fig. 1. A screen-capture of the template students use to set up restriction enzyme digests in a virtual disease diagnosis lab.

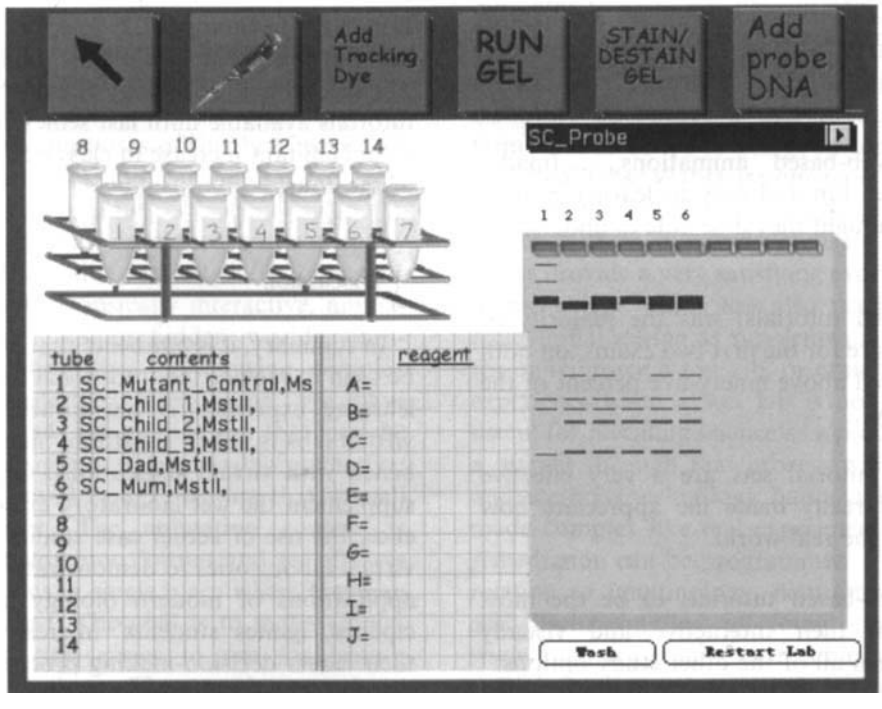

Fig. 2. A screen-capture of the template students use to run electrophoretic gels and generate Southern blots in a virtual disease diagnosis lab.

4. Outcomes

Formal evaluative analysis of the material is not yet available although there is both anecdotal and statistical evidence that the virtual simulations and laboratories are making a difference both to students' attitudes about learning as well as their ability to learn. None of this information would satisfy a professional evaluator but evaluating the "success" of these materials in the classroom is extremely difficult. The campus is working on a more rigorous way to test the usefulness of on-line materials.

4.1. Anecdotal evidence

Jay Lee, a student who took the course before the days of the virtual laboratories and subsequently helped develop some of the virtual labs, had this comment on how use of the early animations affected his learning and attitude, "As a student, I often found myself perplexed by the static illustrations in our textbooks which were hopelessly inadequate in demonstrating the complex dynamic processes which is molecular biology. Dr. Raineri's class was the first that used colorful animation sequences to illustrate these same concepts in a more memorable and entertaining fashion, leaving an indelible image in my mind, which proved really useful during exams."

Anonymous surveys are gathered each year to guide production and use of the materials. One of the questions asked was: "Did you find the virtual materials helpful? If so, briefly explain how they helped you. If you did not find them helpful, can you think of anything that could be done to make them more useful for you?" Typical of the replies are these selected randomly from a group of surveys.

> "...using the Web-based animations, ...(made) Molecular Genetics fun and easy to learn for those of us who never thought they'd be able to understand it."

> "It (the Web-based tutorials) was the majority of what I did to prepare for the first two exams, on both of which I answered above ninety-five percent of the questions correctly..."

> "The Web-based tutorial sets are a very effective learning tool and really made me appreciate how biology is used in the real world."

> "I found the Web-based tutorials to be the most useful because of their interactive and visually oriented nature than all of the other study options."

> "The animations were highly effective because they made it easier to visualize sub-cellular and molecular processes that we can't see."

> "...the tutorials are a useful supplement to classroom instruction, one that I would choose to use if it were made available to me in other courses."

> "Overall, I think the Web-based tutorials offer an excellent and highly accessible medium through which we can get a lot of supplemental instruction on our own time schedules."

> "The Web-based tutorials helped me directly with my studying for Biology 122, and it also helped me gain more familiarity with computers, and feel comfortable working with them."

4.2. Statistical evidence

The same final exam has been used for this course since 1994, prior to the use of Web-based materials in the course. The final exam focuses primarily on the material that is addressed in the Web-based laboratories and simulations. Prior to the use of the Web-based tutorials, the mean score for the final was around 42 out of a possible score of 60. Web-based materials were first used in 1995. There has been a gradual increase in class performance. The mean score for the past four semesters has been around 45 out of a possible score of 60 (n is 400–600 students/semester). However, much more interesting is the effect on the bottom part of the grading curve. Initially, a worrying number of students earned D's or F's in Biology 122. The number of students that fall into this category has now diminished significantly. The second half of Biology 122 did not have Web-based tutorials available until last semester. We have not seen a concomitant increase in class performance in this half of the course

5. Discussion

In summary, it is our belief that nothing can or should be used to replace the traditional hands-on approach to learning experimental techniques. The intent of the virtual labs is not to substitute hands-on training at the bench with virtual simulations. On the contrary, they supplement the wet laboratory exercises. In our experience, the use of actual case studies through web-based virtual laboratories to demonstrate practical, workplace applications of modern biology in a variety of disciplines, ignites students' interest and contributes to their career decision-making processes.