Genetics Education

Innovations in Teaching and Learning Genetics

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The Use of Scenario-Based-Learning Interactive Software to Create Custom Virtual Laboratory Scenarios for Teaching Genetics

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ABSTRACT

Mutagenesis screens and analysis of mutant phenotypes are one of the most powerful approaches for the study of genetics. Yet genetics students often have difficulty understanding the experimental procedures and breeding crosses required in mutagenesis screens and linking mutant phenotypes to molecular defects. Performing these experiments themselves often aids students in understanding the methodology. However, there are limitations to performing genetics experiments in a student laboratory. For example, the generation time of laboratory model organisms is considerable, and a laboratory exercise that involves many rounds of breeding or analysis of many mutants is not often feasible. Additionally, the cost of running a laboratory practical, along with safety considerations for particular reagents or protocols, often dictates the experiments that students can perform. To provide an alternative to a traditional laboratory module, we have used Scenario-Based-Learning Interactive (SBLi) software to develop a virtual laboratory to support a second year undergraduate course entitled "Genetic Analysis." This resource allows students to proceed through the steps of a genetics experiment, without the time, cost, or safety constraints of a traditional laboratory exercise.

IT is often difficult for undergraduate students to fully appreciate how genetic experiments, such as mutagenesis screens or mutant analysis, are performed. Additionally, students often have trouble understanding concepts such as epistasis and allelism. Students can gain a better understanding of these genetic principles by performing experiments themselves in a laboratory practical (MANNEY and MANNEY 1993). Laboratory exercises allow students to actively participate in learning and provide an alternative method of learning for those kinaesthetic students who do not learn well from lectures alone (FLEMING 2001). In addition, by performing laboratory experiments, students become familiar with the scientific method and standard laboratory procedures (IAZZETTI *et al.* 1998), providing a foundation for those students who wish to pursue further research for a higher degree or as a profession (HAFFIE *et al.* 2000).

Unfortunately, genetics laboratory teaching can be limited by several factors (MANNEY and MANNEY 1993; IAZZETTI *et al.* 1998; HORTON and TAIT 1999). First, the limited time available for a laboratory course often restricts the model organisms that can be used. Breeding experiments to determine the inheritance pattern of a particular phenotype are limited by the generation time of the organism, and thus only model systems with a relatively short life cycle can be used in a teaching laboratory to illustrate inheritance. Not all model organisms are amenable to the same types of genetic manipulation, and using organisms that are suited to the teaching laboratory can restrict the concepts that are taught. Additionally, the cost of the laboratory exercise is a consideration—an experiment that requires expensive supplies, equipment, or intense maintenance of the model organism between laboratory sessions is not suitable for courses that have large numbers of students or that lack specific funding. Finally, laboratory safety is a consideration, as students are not experienced with most laboratory techniques, and in most cases cannot safely handle reagents such as

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mutagens or hazardous chemicals that are often used in research laboratory experiments.

Therefore, to provide an undergraduate genetics laboratory exercise that teaches experimental concepts and allows active learning on the part of the students, we have devised an online genetics virtual laboratory. We used Scenario-Based-Learning Interactive (SBLi; http://www.sblinteractive.org) software to create custom laboratory scenarios that complemented the lecture content on a second year university course, "Genetic Analysis," which currently does not have a laboratory component. Approximately 30 students per year register for this course. This online problem-based learning (PBL) resource allows students to participate in virtual laboratory experiments that are designed to complement lecture material. The students do not have as many limitations on the types of experiments that are performed, because time, cost, and safety factors are eliminated when using an online laboratory simulation. By adding an online resource, there is minimal additional cost associated with the virtual laboratory, yet the students still gain the advantages of having a self-directed, active learning laboratory component to support lectures (FLEMING 2001; SMITH 2002).

DESCRIPTION OF THE RESOURCE

As an initial step, we decided which experiments would be best to design as part of our virtual laboratory exercises. We examined the course content and previous exams to identify important concepts that were amenable to virtual experiments. We concluded that experiments related to determining inheritance patterns, performing mutagenesis screens, physical mapping of mutations, and candidate gene analysis would be best for inclusion in virtual laboratory exercises. We identified experiments from the published literature and from our own research that we could adapt for inclusion in each scenario. We invented an organism for the students to study: the "chocolate monster." By using an imaginary model system we were able to combine the genetic techniques used in different model organisms all into one series of laboratory exercises. Additionally, the lectures in the Genetic Analysis course are focused on teaching certain genetic concepts using examples from model organisms. Therefore, if the online PBL were focused on real model organisms, students would associate a particular model with specific lectures. By using an imaginary organism, the students have to apply the concepts they learn in lectures and are not immediately able to guess the outcome of the laboratory experiment based on the model organism used.

For each virtual experiment we devised a story that was written out. From this template, the images to be incorporated into the scenario were identified and then created or obtained from a variety of sources, including hand-drawn images, photographs of the authors' laboratories and offices, data generated in the authors' laboratories, and images on the Internet (for which we obtained permission from the publishers). For the virtual laboratory to succeed images of experiments and data are essential, and much effort was devoted to identifying the images needed at each step of the scenario. We also then wrote quiz questions, answer choices, and feedback for each answer, and identified the place where each question should be incorporated into the scenario. Once a scenario was completely written, we then constructed the virtual exercise using SBL Interactive. Each scenario was tested by the course instructors and several Ph.D. students before it was open to the undergraduate students.

SBL Interactive software (http://www.sblinteractive.org) was used to design a custom laboratory scenario. This software allows the programming of an online interface with four windows (Figure 1). The top left window shows all locations or levels used in the PBL exercise. The bottom left window has tabs for actions and collections. The user can choose between different actions, or view items they have collected, such as lab notebooks or data sets, in this window. The top right window shows an image of the current location. Users can select items from this top window to add to their collections by dragging them into a box in the lower right-hand corner. Finally, the bottom right window displays the text and figures associated with each of the actions.

Scenarios consist of a series of locations, each of which may contain a number of actions, items, or quizzes. A simple system of prerequisites allows the designer to create a narrative flow by specifying under which circumstances an object should be available. For example, you may wish a location to become available only after the user has answered a quiz to a specified threshold or performed a specified action. A limited degree of branching is possible, so that users who perform less well in a quiz or choose an inappropriate action can be directed along an alternate route. Once created, scenarios can be distributed along with a player application on removable media or uploaded to a web server to be distributed via the Internet. Scenarios use an Internet browser to be rendered, so a variety of media can be embedded within the content window.

Images can be added to SBLi from a variety of file formats. We used a combination of images ranging from hand drawings that were scanned to create jpeg files, to images of actual laboratory data such as gel electrophoresis photos and DNA sequencing output files. Each laboratory scenario was planned to include a series of experiments linked by a common concept. Students were presented with several choices throughout the scenario that reflected the decisions they would be faced with when performing the experiment in an actual laboratory. Students then had to select the correct action to progress, since the selection of the correct
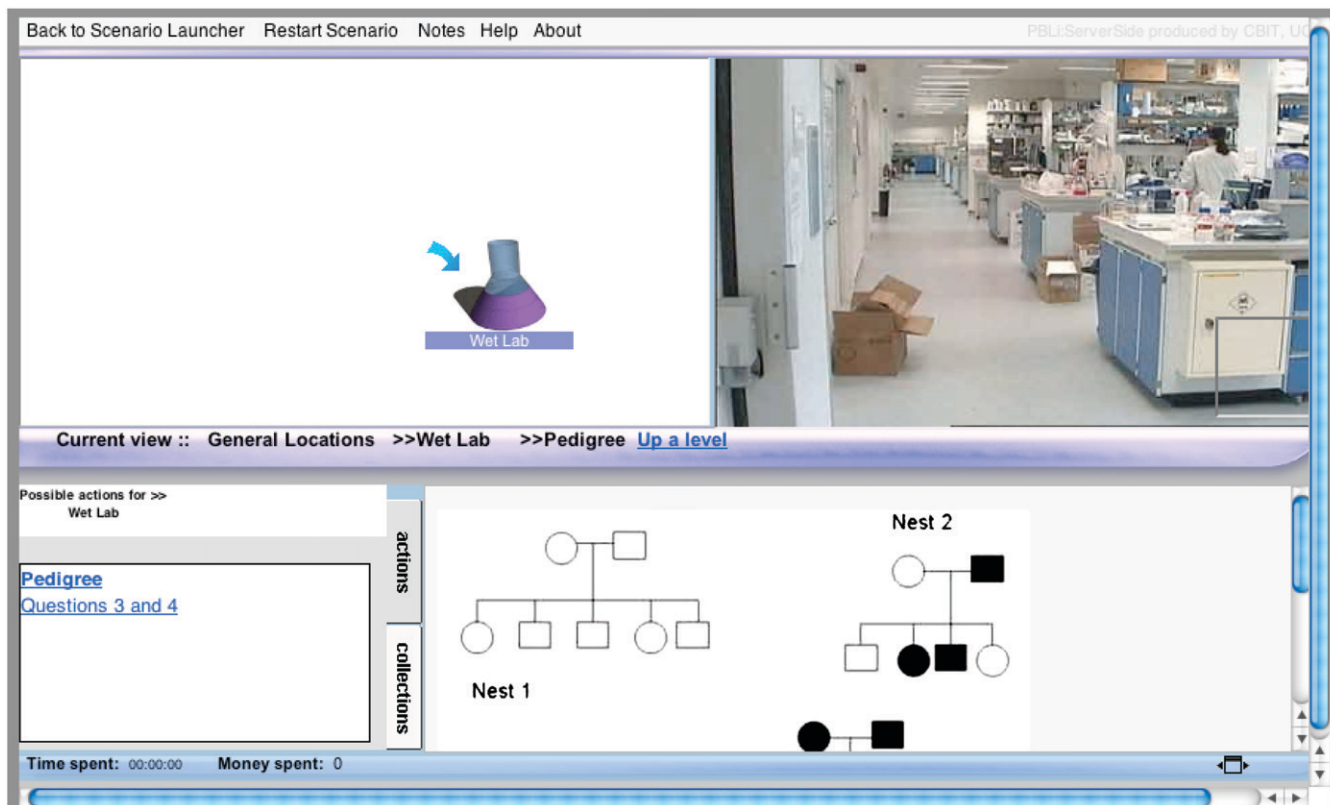
FIGURE 1.—The online SBLi interface. In the top left window the locations used in the scenario are shown. The top right window has a picture indicating the current location. The bottom left window has possible actions or collections. By selecting a choice from the bottom left window, such as "Pedigree", students can view a pedigree used in the scenario in the bottom right window. By choosing the action "Questions 3 and 4" the student can answer the quiz questions required to progress through the scenario.

action triggered an item, location, or another action to be released. In this scenario, actions were largely used to convey different pieces of information about an experimental breeding cross. The student would then have to consider everything they had found to answer quiz questions that appear within the scenario. Each question was presented in a multiple-choice format, and incorrect answer options had feedback to assist the student in arriving at the correct answer.

The SBLi software is fairly intuitive to learn and required no specialist training to use. In fact, as part of an undergraduate research project, we trained students to use the software and produce basic scenarios within 7–10 days. However, to build more complicated scenarios the designer must understand how to bypass limitations in the software. For example, implementing branching can be difficult since there is currently no process to release content on the basis of a choice between two variables. This necessitates the production of a complex structure of locations and location maps, linked by many prerequisites.

The software currently costs ∼$350 (Australian dollars) per copy. For those wishing to locally host scenarios, the server software costs $1500 (Australian dollars) per license and can be hosted on a server of fairly modest specifications. Hosting scenarios locally is

not absolutely necessary, although it is required for more sophisticated user tracking and management. We chose to host the scenarios locally because it allowed us to create a separate user account for each student so that we could track their activity and quiz performance in each scenario. Additionally the locally hosted version improved the user experience, as it allowed a faster response time within the scenario.

We estimated that each scenario would take students 1.5 hr to complete. Students must answer the scenario quiz questions correctly to progress through the scenario. In addition, students must make choices about the actions they perform as part of experiments. Choosing the wrong action, such as skipping an important step in an experimental protocol, will send the students back to the beginning of the scenario. Each scenario was available to students online for two weeks, during which time students had to work through the scenario and answer the quiz questions presented within the scenario. Students received marks for completing each scenario, but were not penalized for incorrect answers in the quizzes (aside from having to repeat that question within the scenario). Students were not given any credit or penalized for participation in the course bulletin board. With the SBLi software it is possible to track the actions a student performs in each

scenario (supplemental File 1). The decisions a student makes to navigate through the scenario are recorded, along with the time between each decision. With this activity log it is possible to determine if students are randomly clicking on choices rather than reading the scenario content and working out the answers to progress with the scenario.

Because students in the "Genetic Analysis" course often struggled with understanding experimental approaches, we designed one scenario to focus on mutagenesis screens and analysis of mutant phenotypes, which can be viewed at: http://sbli.ls.manchester.ac. uk/playerframe2.aspx. This scenario is best viewed using Mozilla Firefox as the web browser. Students were presented with chocolate monsters carrying potential mutations, and performed breeding experiments to isolate new mutant animals. As part of this scenario, students are given the choice of breeding different lines of chocolate monsters with potential mutations. When no phenotype is observed following one generation, students can choose whether to interbreed the offspring to create a second generation, or instead move on and breed other lines to produce first generation offspring from new crosses. This is similar to the decisions students would be faced with when performing a mutagenesis screen in an actual laboratory. Another concept students can find difficult is allelism. In the scenario students selected mutants to cross to each other to perform complementation tests and were presented with data to allow them to identify allelic mutations. Finally, to assist students in understanding the link between molecular defects and phenotype, they were presented with a candidate gene for the allelic mutation, which had several protein isoforms. Students were asked to compare the effect of each mutation on the protein structure and known mRNA expression pattern to the severity of the phenotype to determine which lines carried each mutation. We have designed other scenarios, ranging from a simple review of Mendelian genetics to a scenario covering the analysis, mapping, and positional cloning of a quantitative trait gene. Access to these scenarios can be provided upon request.

DISCUSSION

Teaching and learning in a genetics course can be enhanced by the addition of a laboratory component. However, for many courses, laboratory exercises are too expensive, time consuming, or lengthy to adequately allow students to reinforce concepts taught in lectures. For these reasons we decided to create a custom virtual laboratory exercise to support a second year course entitled "Genetic Analysis." The use of SBLi as the platform for building our virtual laboratory exercises meant that we could design specific experiments in a specific order to exactly complement our lecture course. This flexibility is not offered in other virtual laboratory exercises (IAZZETTI *et al.* 1998; HORTON and TAIT 1999). SBLi is ideal for the creation of custom laboratory scenarios, as the programming is straightforward and easy to learn. It is possible to link actions, allow students to gather collections, import images for locations or data analysis, and insert quiz questions to assess student progress. Activity logs for each student can be checked to identify those students who are simply making random clicks throughout the scenario rather than reading the information and making deliberate choices in each action menu. The use of SBLi allowed the design of several scenarios that incorporated many individual experiments and required students to make choices about protocols, similar to real laboratory research.

The SBLi software and the virtual laboratory exercises have some limitations. One particular shortcoming was the inability to easily create sophisticated branching within a scenario. This can be overcome, but requires the use of a complex number of interacting perquisites that can be hard to track. We would have liked to create exercises where students were required to make choices about each particular experiment to perform and which reagents to collect. It would have been ideal to be able to create a long branch of the scenario where an inappropriate or confusing result was obtained from performing an experiment without the correct reagents or choosing the wrong experiment altogether. However, within the software it is only possible to send students back to the beginning of the scenario, rather than to a point in the middle, after they reach a "dead end." This meant that we were hesitant to put in experimental choices with incorrect options late in a scenario, as students could only be sent back to the start rather than to the place where they had made the wrong decision. In addition, the question format to be used in the scenario was limited to multiple choice, and it was not possible to set up questions where students had to choose several correct answers from an answer list. Instead, each question had to have one correct answer. Additionally, providing students with more choices in terms of experiments requires more images and data to be created within the scenario for students to analyze, and it is difficult to anticipate all possible experimental combinations students may choose at each step of the scenario.

The virtual laboratories created in SBLi enhanced teaching and learning. Students were able to actively participate in a virtual laboratory exercise that required them to make decisions throughout each scenario. Students who made the correct decisions and answered questions correctly could progress through the scenario, while students who were incorrect were provided with feedback on their decision and automatically sent back to repeat that portion of the scenario. The ability to instantly see the result of an experiment is an advantage

over traditional laboratory practicals, which extend over several days, and can allow students to forget experimental details or lose interest in the results of a particular experiment. Because the laboratory was online, students could complete the PBL at any time, from any computer with Internet access, and receive instant feedback from the questions within the PBL. The instant feedback is a huge advantage of the virtual laboratory exercise over written problem sets, because it allows the students to immediately reexamine the data or experiment approach and correct their mistake. It is also an advantage for the instructor, in that feedback for each correct and incorrect answer can be written once and then viewed by each student within the scenario. Thus, students were able to assess their own learning, in a manner that is not possible with a lecture-only course. In addition, the performance of laboratory experiments, even in a virtual fashion, served to reinforce and explain the concepts taught in the lectures.

After the final scenario students were given a survey to complete on the usefulness of the online PBL exercises. Sixty percent of students (16 of 27) agreed or strongly agreed that the online PBL was a useful addition to the course. Seventy-eight percent of students (21 of 27) agreed or strongly agreed that the feedback on incorrect answers was useful. Students also enjoyed the interactive aspect of the PBL scenarios. One student commented, "I thoroughly enjoyed these PBLs simply because they were interactive and not just sitting down reading to answer the questions! I definitely recommend for the future!" On the basis of the positive student feedback to the online PBL experience, we are extending this genetics PBL exercise to cover epistasis, genetic modification, and statistical methods used in genetics. We are also currently generating new resources, based on the chocolate monster, to cover a second year course on "Principles of Developmental Biology," as well as an introductory course entitled "Genes, Evolution, and Development."

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