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Use of HTML-Based DNA Fingerprinting Simulations to Enhance Student Learning and Critical Thinking in Introductory Biology Courses

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The workshop introduced an html5/JavaScript version of our popular Java applets on DNA fingerprinting which now will run on almost all platforms and operating systems, including iPads. The two programs both generate RFLP banding patterns that require students to extend and apply what they have learned about biotechnology. The user the may request an unlimited number of new data sets as generated by an algorithm. These DNA fingerprinting simulations have many potential uses, including online components of a laboratory, active-learning exercises in the classroom, and web-based homework. Both simulations may be downloaded and used for any academic purpose.

Keywords: DNA-fingerprinting, simulation

Introduction

Our first use of web-based simulations of DNA fingerprinting utilized Java applets

(Niedzlek-Feaver, 2007). While these simulations proved quite useful in Introductory Biology courses, they have proved difficult for some students to access online due to security settings in newer computer operating systems. Thus, we have developed an html5/JavaScript version which will run on almost all platforms and operating systems, including Apple® iPads. The two simulations both generate RFLP banding patterns that require students to extend and apply what they have learned about biotechnology.

Our DNA fingerprinting simulations are based on the work of Sir Alec Jeffreys (1985). Jeffreys was studying areas of variable DNA, i.e., portions of the genome which varied, even among related individuals such as Jeffreys" technician and her parents. To detect such variation, his laboratory extracted DNA and fragmented it using enzymes found in bacteria that can cut foreign DNA. Each excision enzyme cuts the DNA in different places. (The benefit to bacteria is probably for use against their viral pathogens and other bacterial species). Jeffrey's group then separated the fragments according to size using gel electrophoresis and used "radioactive probes" to pick out fragments containing some of the variable regions. In this way they produced what is essentially a bar code of at least 30 different bands within the gels. Each band then represents a "dominate" allele (fragment of a specific length cut by an excision enzyme and binding to a certain probe). Another individual may produce a smaller or longer fragment, or have a mutation or recombination that changes the sequence so the probe does not bind to it, but the result is no comparable band in the gel of that individual. As mothers and fathers produce gametes, there is a 50% chance that a given band will be placed in the gamete passed to offspring, so children should share approximately 50% of their bands with their parents. Note that this does not tell you the number of bands that should be present nor the number donated by each parent. For example, with a particular enzyme and probe, Mom's DNA may produce 17 bands and Dad's DNA 13. Their children might then be expected to inherit 14-16 bands. Additionally, the recombination that occurs during meiosis, may give rise to a band or two not found in the parents. This is why the probabilities of relatedness or identity when Jeffrey's DNA fingerprints where used in court were based on a large number of fingerprints using several different enzymes and probes.

The first practical application of Jeffreys' work involved a case of immigration. A boy was detained by immigration officers who felt he was not the legitimate son of a woman, Christiana Sarbah. The boy had lived with his father in Ghana prior to immigrating to be with his mother in Eng-

land. At one point, authorities believed the boy was the son of the mother's sister. Sir Jeffreys compared DNA samples from the mother, boy, three undisputed children of the mother, and an unrelated individual. The fingerprints revealed that not only was Christiana the boy's mother, but all the children were siblings. Jeffreys also reconstructed a DNA fingerprint for the father using all bands not present in the mother but present in the boy or his siblings. Approximately half of the bands of the boy matched this fingerprint and those that did not matched bands found in Christiana. The possibility of this happening if the boy was not her son (given the polymorphisms at these sites existing in the human population) was one in a trillion (http://www.dnai.org/d/index.html).

The current version of our DNA fingerprinting simulations were created using Adobe Edge Animate® (Fig. 1). A Java script programmer (OneTime Software) used an algorithm, based on the work of Jeffreys, which generates bands within the simulated gels to represent restriction fragment length polymorphisms (RFLPs). In one simulation, DNA from a mother and two of her children are shown along with two potential fathers. Students must choose the father of each child or indicate that the real father is neither of these. The second simulation contains DNA bands from five individuals, and the student must decide which four are family members and which one is unrelated. Both programs indicate whether a student's answer is correct, with additional attempts allowed for incorrect answers. Students can request an unlimited number of new fingerprint questions.

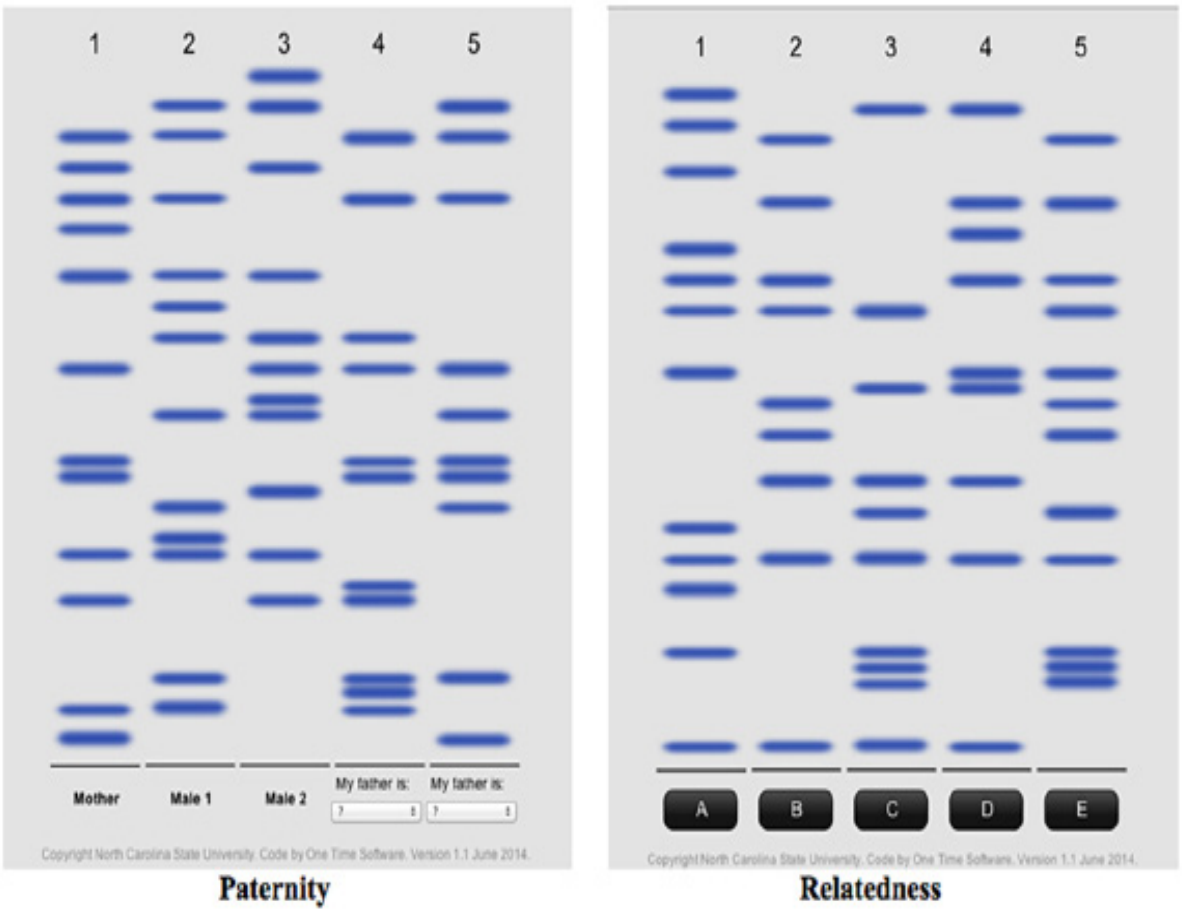

Figure 1. Examples of the two DNA fingerprint simulations.

Student Outline

A major use of the new simulations at NCSU is in the distance education section of Introductory Biology. As one of the online laboratories in this course, students learn the process of gel electrophoresis as well as the essentials of DNA fingerprinting by both the RFLP and PCR method. Our fingerprinting simulations provide the last activity of this laboratory, "Testing Your Understanding". Students are guided through the famous Jeffreys paternity case and given information on how to analyze stylized gels before they work with the simulations. Then they access each of the two simulations and follow these directions on their worksheet:

The next four questions are based on simulations of DNA fingerprints. You have multiple chances to pick the correct answer, but be sure that you understand the rationale for your answer. Try several different versions of each question to assure that you **understand how to solve the problem**. (There will be similar questions on your next exam, with only one chance to pick the correct answer.)

1. Image upload (2 points)
   Determining paternity: Examine the five lanes within the gel. Note that lane 1 is the DNA fingerprint of a mother, lanes 4 and 5 are her children, lanes 2 and 3 are potential fathers. Choose the correct father for each child or indicate that neither is the father (absent father).
   Capture an image of one of the DNA fingerprints in simulation 1 for which you have determined the correct answer. The pop-up window that says your answer is correct should be in the image. Submit your image of the gel and "correct" box to WebAssign.

2. Essay (2 points)
   Explain, in detail, how you analyzed the above DNA fingerprint (question 11) to obtain the correct answer.

3. Image upload (2 points)
   Determining relatedness among five individuals: Examine the five DNA fingerprints in this gel. Four of the individuals are related to one another, but one is not. Pick the unrelated individual by clicking the letter beneath the gel. HINT: two of the lanes represent parents and two lanes their children.
   Capture an image of one of the DNA fingerprints in simulation 2 for which you have determined the correct answer. The pop-up window that says your answer is correct should be in the image. Submit your image of the gel and "correct box" to WebAssign.

4. Essay (2 points)
   Explain, in detail, how you analyzed the above DNA fingerprint (question 13) to obtain the correct answer.

Notes for the Instructor

Prior to utilizing the simulations, students should be familiar with the process of electrophoresis and how it can be used to separate DNA fragments of various lengths. We use the banding patterns produced by RFLPs analyses of genomic DNA, as opposed to more modern fingerprinting methods, because this was the first DNA evidence used in the court system. It also makes use of techniques such as gel electrophoresis that are part of a typical laboratory experience in Introductory Biology.

Students in our course capture images of the gel they analyzed via any screen capture method available on their computer. They can also download free software that performs this function, such as Irfanview (http://www.irfanview.com/) or Skitch (http://evernote.com/skitch/). The images are uploaded to WebAssign (https://www.webassign.net), the quizzing and homework submission site used in this course. The entire online laboratory that utilizes the DNA fingerprinting simulations can be viewed on the course website at www.ncsu.edu/project/bio183de/Lab/dna_fingerprinting/biotechnology3.html. Note that these simulations can be used in a number of ways unrelated to distance educations, such as online components of a laboratory, active-learning exercises in the classroom, and web-based homework.

The simulation packages with instructions for use on your own computers or website can be downloaded from http://biology.onetimesoftware.com/ under the heading DNA Fingerprint quiz. There are two versions of the paternity simulation. In the "easy" verison both children might have the same father or have different fathers, whereas in the "harder" version (described above) the father of one or both children might be absent (neither male 1 or male 2). The Edge Animate files are also available upon request for those who wish to edit the simulations using the Adobe Edge Animate® application. Both the simulations and Edge Animate files may be freely used in academia under a Creative Commons license. Questions or comments are welcome and may be sent to either of the authors.

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Betty L Black received her Ph.D. from Washington University (St. Louis) and has pursued research on development of embryonic and post-natal intestine. She currently teaches a course in Developmental Anatomy of the Vertebrates, plus distance education courses in Introductory Biology, Histology, and Animal Diversity. She has received two University awards for *Innovative Excellence in Teaching and Learning with Technology* and has numerous publications on teaching technology topics.

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