

DNA as Evidence

Suggested Grade Levels: 9 and up

Possible Subject Area(s): Social Studies, History

Math Skills: use of percentages and proportions; understanding and applying the multiplication rule of probability

Overview: DNA evidence entered the courtroom for the first time in 1985, and is now commonly submitted as evidence to try to prove guilt or innocence. At least 100 people have been exonerated using DNA testing and 10 of those people have been freed from death row. Students will be presented with a basic introduction to DNA and how it can be used as evidence in forensic investigations or identity disputes. Students will answer questions to clarify their understanding and calculate the probability of a perfect DNA profile match for two datasets. Understanding the power of DNA evidence requires understanding the multiplication rule of probability. As more pieces of a person's DNA are analyzed, the probability that the resulting DNA profile will perfectly match another person becomes smaller and smaller.

Student Activities: DNA as Evidence

- A. The FBI claims that it can analyze your DNA and that the odds of another person matching your DNA profile are about one in a hundred billion. Unless you have an identical twin, you are statistically two thousand times more likely to win the Publisher's Clearinghouse sweepstakes (1 in 50,000,000 odds) than to have a DNA profile that matches anyone else. Do you believe the FBI? How can the odds be so unlikely? Why might the FBI want a sample of everyone's DNA?
- B. Read the following questions and answers to learn about DNA.

What is DNA? DNA, or deoxyribonucleic acid, is the chemical name for our genetic material. DNA is a component of virtually every cell in the human body and provides the instructions for our cells to function.

Why is DNA useful in identifying individuals? While the majority of DNA does not differ from human to human, because we all function in similar ways, some of our DNA is unique to us. DNA is therefore a powerful identification tool because each person's DNA is different from every other individual's, except for identical twins. Also, a person's DNA is the same in every cell, so the DNA in a man's blood is the same as the DNA in his skin cells or in his saliva, bones, teeth, muscle, etc.

How is analyzing DNA similar to traditional fingerprint analysis at a crime scene? When using either DNA or a fingerprint to identify a culprit, the evidence collected from a crime scene is compared with a sample from a suspect individual. If all of the analyzed features are the same and enough features were analyzed, the DNA or

fingerprint is determined to be a match. If however, even one feature is different, it is determined not to have come from that suspect.

How is DNA evidence different and more powerful than traditional fingerprint evidence? There are two major differences between DNA evidence (sometimes called DNA fingerprinting) and traditional fingerprint evidence. First, DNA evidence can be used to determine relatedness between individuals. You inherited half of your genetic material from your mother and half from your father; therefore your DNA profile is more similar to your parents than it is to an unrelated person. Traditional fingerprint patterns are unique to individuals, but do not show predictable similarities among family members. Second, we can calculate the probability (or likelihood) that a DNA pattern from one person is shared by another person, thereby giving us a way to estimate our confidence that a particular pattern came from a specific individual.

C. Answer the following questions to test your understanding.

1. Would it be legitimate for a lawyer to argue that the evidence against his client is questionable because the DNA sample from the crime scene came from a skin specimen (found under the victim's fingernails), while the client's blood (not his skin) was sampled to look for a DNA match? Why or why not?
2. As a member of a jury, would you feel more confident drawing conclusions based on a partial fingerprint that matched the suspect or a complete fingerprint that matched the suspect? Why? What about a partial fingerprint that was a perfect match vs. a complete fingerprint that was almost a perfect match (had just a small section that did not match)?
3. Why might a traditional fingerprint actually be more convincing evidence of a person being at the scene of a crime than DNA evidence collected at the scene?
4. Do you think it would generally be easier to exclude a suspect or convict a suspect based on DNA evidence? Why?

D. Now back to the FBI's claim...

When we analyze a person's DNA, we actually examine a number of different sites along their DNA. There may be many people who have the same type of DNA at one particular site, but as more sites are examined it becomes less likely that two people will share the same DNA type at all sites.

If half of all people have a particular DNA type at site #1, then that particular site by itself is not very useful for identifying an individual because the probability of having that type is one out of two, or 0.5 (1 divided by 2). A DNA type, or any trait that is common, is not very useful by itself in pinpointing an individual. For example, if your only clue is that the suspect has blonde hair, you will have a difficult time finding the culprit, because many people have blonde hair.

However, suppose you know the culprit has blonde hair and wears size 12 shoes. Two independent traits can narrow the suspect pool considerably. If 20% of all people are blonde and 5% wear size 12, then the multiplication rule says:

Probability of both = probability of being blonde * probability of size 12 shoes

Probability of both = $0.20 * 0.05 = 0.01$ (or 1 out of 100 people)

The same thing is done with DNA evidence, except that the FBI can look at more than 20 different DNA sites to calculate the probability of a perfect match. The following table describes a particular DNA profile from a sample collected at a crime scene and the proportion of people in the general population that has each piece of the profile. Use these data to calculate the probability that a person besides the culprit will have a perfect match. Check your answer before continuing with the exercise.

DNA site	1	2	3	4
Frequency of DNA type in general population	30% (3 out of 10, or 0.3)	20% (2 out of 10, or 0.2)	5% (5 out of 100, or 0.05)	2% (2 out of 100, or 0.02)

E. Now we will add more sites to our analysis to see how that affects the probability of a perfect match. Calculate the probability that a person besides the culprit will perfectly match the profile described below:

1	2	3	4	5	6	7	8	9	10	11	12
0.3	0.2	0.05	0.02	0.5	0.25	0.4	0.1	0.15	0.8	0.1	0.15

Remember, the FBI has over 20 different DNA sites that it can examine for each person. Their claim is true. The key to their analysis is to know the frequencies of particular DNA types in the general population at each site. While they have not sampled every person in the country (or the world), they have sampled enough people (i.e., hundreds of thousands) to have a good estimate of these frequencies.

F. Answer the following questions to test your understanding.

1. Which piece of DNA from the analysis in part E is the most common (i.e., found in the largest percentage of the general population)?
2. Which piece of DNA from analysis E is the most rare and why are rare traits (like an uncommon DNA type or a strange tattoo) more helpful in pinpointing a particular person than common traits?
3. Common traits can be used to pinpoint an individual, but it takes more of them to be confident in a positive identification. Calculate the number of different DNA sites you would need to examine if the frequency of each site was 0.5 (or 50%) and you wanted less than or equal to a one out of 1000 chance of a match. Then

compare that to the number of different DNA sites you would need to examine if the frequency of each site was 0.1 (or 10%) to achieve the same matching power.

4. What probability do you think would be low enough to count as “beyond a reasonable doubt” in a court case? Is a one out of 1,000 chance low enough to convict someone of a crime with very severe consequences? How about one out of 10,000 or one out of 100,000?

Information for the Teacher

Part A can be presented to the whole class to facilitate discussion about the relevance of DNA testing and DNA evidence.

Parts B-D can be done individually or by groups of students. Discuss the answer to parts C and D and clarify any questions before continuing on to the next section.

Parts E and F can be done individually or by groups of students. Part F can be used to facilitate closing discussion and clarification of overall content.

Answers to Problems and Questions

- A. Students will work through and probably eventually come to the conclusion that the FBI claim is true (which it is). The exercise is designed to help them understand the power of analyzing many different pieces of DNA and that the likelihood of a perfect profile match becomes smaller as the number of sites examined increases (as a consequence of the multiplication rule of probability). A database of DNA profiles is currently used by the FBI to try to match criminals to crime scene evidence. The British police have an online database of more than 360,000 profiles that they compare to crime scene samples and more than 500 positive matches come up each week. The more people who are part of the database, the more likely a match will be found. You may want to discuss ethical issues related to catching criminals in this way. Should all people be required to submit a DNA sample?
- B. Answers are already provided in this section.
- C. Answers:
 1. No, since a person’s DNA is the same in all of his cells, it does not matter that the tissue type at the crime scene is different than the type used as comparison.
 2. The more parts that match, the more confidence we would have in the match. Thus, I would feel stronger about my conclusions based on a full fingerprint match compared to a partial print match. However, if even one part does not match, the suspect should be dismissed even if many other parts matched. The match has to be perfect to conclusively point to a specific person.

3. DNA evidence can be planted at a crime scene (this, along with the possibility of laboratory contamination, was the defense argument in the O.J. Simpson trial). A person could take hair from someone's hairbrush and drop it at a crime scene. A traditional fingerprint is great corroborative evidence to show that the suspect was actually at the scene because it would be difficult to transfer a print to an immovable part of the scene without the person's fingers.
 4. It is generally easier to exclude than convict using DNA evidence, because it only takes one miss-match to show it was not the person, while it takes numerous matches to pinpoint the culprit. In fact, about 30% of the DNA profile comparisons done by the FBI result in excluding someone as a suspect.
- D. Probability of all 4 types matching = $0.3 * 0.2 * 0.05 * 0.02 = 0.00006$. About 0.006% of people would match, or about 6 people out of 100,000. This may not be specific enough, but what if you analyzed more DNA pieces.
- E. Probability of a match = $0.3 * 0.2 * 0.05 * 0.02 * 0.5 * 0.25 * 0.4 * 0.1 * 0.15 * 0.8 * 0.1 * 0.15 = 0.00000000054$. About 54 out of 100 billion, or one out of about 1.8 billion people would match.
- F. Answers:
1. The DNA piece from site 10 is the most common (in 80% of population).
 2. The DNA piece from site 4 is the most rare, as it occurs in 2% of the general population. Rare traits are more helpful in pinpointing a particular person because few people exhibit those traits. Remember, much of human DNA is similar across all people; it is the accumulation of small differences that allows DNA to be used as a unique marker specific to an individual (except in the case of identical twins who share the same set of genetic material).
 3. It would take 10 sites with 0.5 frequencies to get less than one out of 1000 match ($0.5 * 0.5 * 0.5 * 0.5 * 0.5 * 0.5 * 0.5 * 0.5 * 0.5 * 0.5 = 0.00097825$), while it would only take three sites with 0.1 frequencies to reach about the same power ($0.1 * 0.1 * 0.1 = 0.001$)
 4. This is an opinion question that will probably generate much discussion. Some people are naturally more conservative than others and will want a lower probability in order to reach a decision. Scientists generally have confidence in an effect if the likelihood of it happening by chance is less than 5% (0.05 or one chance out of 20). Some people may argue that there is still a chance of imprisoning the wrong person, even if the data suggest the chance is less than one in a hundred billion (as claimed by the FBI analyses). However, once the probability is less than one out of the total number of people on the planet (about 10 billion), we would probably need to say this is "beyond a reasonable doubt."

References and Resources

- What Every Law Enforcement Officer Should Know About DNA Evidence (1999) at <http://www.ojp.usdoj.gov/nij/pubs-sum/000614.htm>
- How DNA Evidence Works by Ann Meeker-O'Connell at <http://www.howstuffworks.com/dna-evidence.htm>
- More discussion about the use of DNA evidence can be found at the Human Genome Project Information website at <http://www.ornl.gov/hgmis/elsi/forensics.html>
- The following website is an up-to-date list of inmates who have been freed using the results of DNA analysis and the length of time each spent incarcerated.
- <http://www.pbs.org/whbh/nova/sheppard/cleared.html>