

Mathematical Journeys I

Lab 5

Blood Spatter Analysis



Introduction

Cautionary Note

This lab involves blood spatter analysis, which by its nature may be unsettling to some people. While all the graphics contained in the write up of the lab are simulated bloodstains, the suggested web sites and key search words may produce materials that contain images of real bloodstains which may be fairly graphic. In addition, to avoid the risk of injury and contamination inherent in handling human or animal blood samples, faculty and students must not use actual blood samples for the experiment in this lab.

Whether it was while you were watching your favorite TV crime show or the evening news, you have probably heard about some form of crime scene investigation involving analysis of blood. Blood can be a very powerful form of physical evidence. DNA evidence and blood typing have provided crucial pieces of information in many criminal cases. In addition to these two types of blood analyses, bloodstain patterns left at a crime scene can also be analyzed to give valuable information about the events that took place. This form of forensic science is known as blood spatter analysis.



Technology Problem

I have just come from the chief prosecutor's office and we have been assigned to perform the blood spatter analysis for Case #65. As my intern, you will assist me in investigating this case. The fingerprinting, blood typing and DNA analysis have already been conducted and have revealed that all the blood came from one source, the victim. Our task is to analyze the bloodstain patterns and advise the chief investigator on the possible weapon used and the victim's general location in the room. The body was missing and the following bloodstains were found on the ground at the crime scene. Using the knowledge gained from research and experimentation, you will analyze the bloodstain evidence. In your analysis, include a description of the probable position(s) of the victim and the possible wounding agent. Note that the bloodstains are actual size whereas the distances measured outside the bloodstains are scaled so that 1 cm is equivalent to 3.82 inches. Your analysis will be very important, for it may be used either to incriminate or to exonerate a suspect.



You will apply the scientific method to solve your problem. The scientific method has five steps – problem, question, hypothesis, test, and decision. The first two steps of the scientific method (problem, question) depend on exploring the situation and developing a better understanding of the problem. You may want to develop a timeline with specific objectives and deadlines. You will probably begin exploring your problem with some bibliotechnology research.



Bibliotechnology Research

How can blood spatter analysis be helpful to a criminal investigation? A starting point might be to find information on how blood spatter analysis has played a role in previous criminal cases. Check out the following web sites for information on actual criminal cases.

- The “Fatal Vision” Murders
<http://www.crimelibrary.com/forensics/serology/index.htm>
- The Mad Carpenter
<http://www.crimelibrary.com/forensics/serology/2.htm>
- Blood Trails, DNA, and O.J.
<http://www.crimelibrary.com/forensics/serology/5.htm>
- Analysis Gone Wrong
<http://www.crimelibrary.com/forensics/serology/6.htm>

What are the general ideas behind blood spatter analysis? A web search will help familiarize you with this field. Here are some key words to help you in your search.

Blood Spatter	Blood Spatter Analysis
Bloodstain	Blood Stain
Crime Scene	Forensic Science

In addition, the following web sites may be useful:

- Building a Case from a Drop of Blood
http://www.apbnews.com/crimesolvers/kobilinsky/2000/03/13/kobilinsky0313_01.html

- Blood Spatter-What is it?
http://www.suite101.com/article.cfm/crime_stories/34498
- Serology: It's in the Blood: Blood Pattern Analysis
<http://www.crimelibrary.com/forensics/serology/4.htm>

- 1) Based on your web search, what kinds of information can bloodstain patterns reveal about a crime scene?
- 2) For ease of communication, forensic experts use agreed-upon scientific terminology when discussing bloodstain patterns and their characteristics. To make sure that you are familiar with this terminology, provide technical definitions of the following terms as found in the Suggested Terminology List on the web site below.

- <http://brazoria-county.com/sheriff/id/blood/terminology.htm>
 - a) Blood Spatter
 - b) High/Medium/Low Velocity Impact Spatter
 - c) Directionality of a Bloodstain
 - d) Angle of Impact
 - e) Point of Origin
 - f) Target

- 3) From your research, you may have read that bloodstain pattern analysis is not an exact science. What are some of the issues that contribute to the inexactness of bloodstain pattern analysis?

By applying the problem and question steps of the scientific method, you have gained a basic understanding of bloodstain pattern analysis in general and have learned vocabulary specific to the field. Now you are ready to tackle the technology problem.



Mathematics Tools

In the investigation of this problem, you will need to select mathematics tools that best fit the problem, that help explain the problem, and that provide a solution to the problem. The physics of fluid motion will be important for analyzing blood spatter patterns. Trigonometry, geometry, and measurement are mathematics concepts that you may find helpful.



Model Portfolio

As a forensic scientist, you do not work in isolation. You may need to present evidence at a trial where the accuracy of testimony needs to be determined. It is important that you provide solid, factual information so that jurors can come to an informed decision. You will need to create a model portfolio documenting both your process of solving the problem as well as the product you create. The model portfolio should contain a thorough description of the technology problem and the identifying characteristics. You need to explain the mathematics, technology, and science you use to solve the problem. In addition, you need to include the mathematical and/or physical models you create. The portfolio needs to be accurate and specific to the point that another person could follow the steps exactly and obtain the same results.

The model portfolio will be built on the scientific method. The third step of the scientific method involves developing a hypothesis about the real world situation under consideration. In this context, you can think of the model(s) that you create as a hypothesis. In effect, your model describes and explains the technology problem. It will mirror and explain the technology problem as well as reflect its solution. The fourth step of the scientific method will be to test the hypothesis for its ability to accurately describe the technology problem. Based on these results, you will then decide to retain, reject, or modify your model.

Model Development

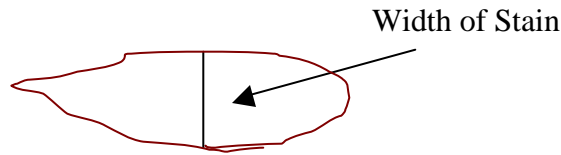
Your task now is to create a model that fits the geometry of the blood spatter pattern and gives the desired information – the possible weapon used and the victim’s general location in the room. You will need to consider the sizes of the blood spatter, the appearance at the edges of the blood spatter, and the shapes of the blood spatter.

Section I

What was the possible wounding agent?

To answer this question, you will need to determine the preponderant stain size. When carefully examining a bloodstain pattern that results from an impact force, more than one size of spatter may be found. To understand why this happens, it is important to recognize that the force of impact of the wounding agent is not necessarily a constant uniform force. It is more likely to be a force that varies over time. As an example, the force may increase, reach a peak, and then decrease. Therefore, spatter of various sizes may occur.

Forensic scientists generally categorize bloodstain patterns based on the preponderant stain size, which is the size of the spatter most prevalent in the bloodstain. The size of the spatter is determined by measuring the width of each stain, as shown in the diagram below.



- 4) Examine the bloodstain pattern below. Determine the number of each size of blood drop. Find the percent frequency for each droplet size and determine which size is preponderant.



Table 1

Stain Size (Width)	# of Stains	% Frequency

- 5) Upon examining blood spatter in many crime scenes, forensic experts noticed a relationship between the size of the blood spatter and the velocity of the wounding agent. This relationship led them to a vital clue in deciphering the type of weapon or wounding agent that caused the blood spatter in a crime scene. The impact velocity of the wounding agent was categorized as low impact, medium impact, or high impact velocity.

From your research, you will need to identify the velocity ranges that are generally considered low-impact velocity, medium-impact velocity, and high-impact velocity. For each type of impact velocity, identify the possible corresponding wounding agents.

The information on type of impact velocity and possible wounding agents can now be connected to preponderant stain size. Experts have determined that a low-impact velocity wounding agent generally produces spatter of at least 4 millimeters in size. A medium-impact velocity wounding agent produces spatter with size between 1 and 4 millimeters. A high-impact wounding agent produces spatter with size ranging from 0.1 to 1 millimeters.

Summarize your findings in the following table. Be sure to write the units when recording all measurements. Provide a logical explanation for any gaps that occur in the velocity ranges.

Table 2

Type of Impact Velocity	Velocity Range	Spatter Size	Possible Wounding Agents
Low			
Medium			
High			

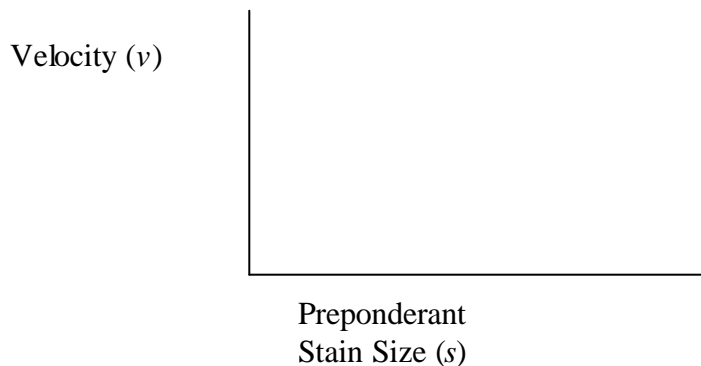
- 6) According to the data that you tabulated above, what is the relationship between the impact velocity of the wounding agent or weapon and the size of the blood spatter?
- 7) Does the relationship you discovered surprise you or did you anticipate it?

- 8) You completed Table 2 using either metric units or English units. Convert the information into the other system of measurement to complete Table 3 below.

Table 3

Type of Impact Velocity	Velocity Range	Spatter Size	Possible Wounding Agents
Low			
Medium			
High			

- 9) Does the change in the velocity measurement units alter the relationship you found earlier between the velocity and the size of the bloodstain? Explain.
- 10) Let s represent the preponderant size of the bloodstain pattern and v denote the impact velocity. Use the data you tabulated to draw a graph that depicts the relationship you found. Be sure to label the axes using the appropriate units. (More than one type of graph is possible).



- 11) Refer to the bloodstain pattern in Exercise 4. Based on what you have learned in this section, give a possible wounding agent that produced the pattern.

With the above information on preponderant stain size and possible wounding agent, you are ready to develop the first part of your model to solve the technology problem – how to identify the possible wounding agent.

Section II

What was the victim's general location in the room?

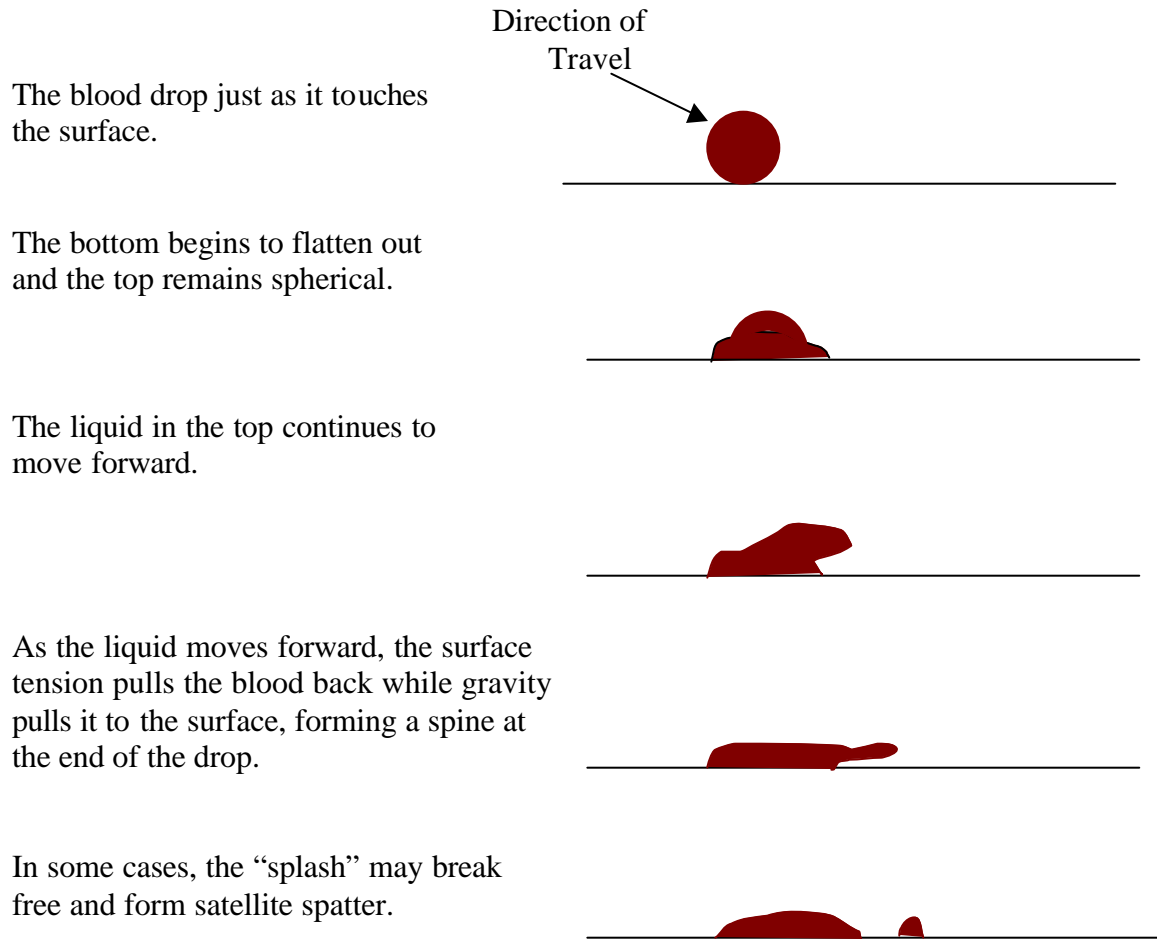
Now that you know how to determine the possible wounding agent based on the spatter size, you can consider the reconstruction of the sequence of events that resulted in the bloodstains. You must first figure out the point in the room where the blood originated. This is called the point of origin. Locating the point of origin involves four steps: Part A determine the directionality of a bloodstain; Part B locate the point of convergence of the paths of several blood stains on a two-dimensional plane; Part C calculate the angle of impact for each stain; and Part D locate the three-dimensional point of origin. Let's start with the directionality of the bloodstain.

Part A Directionality of a Bloodstain

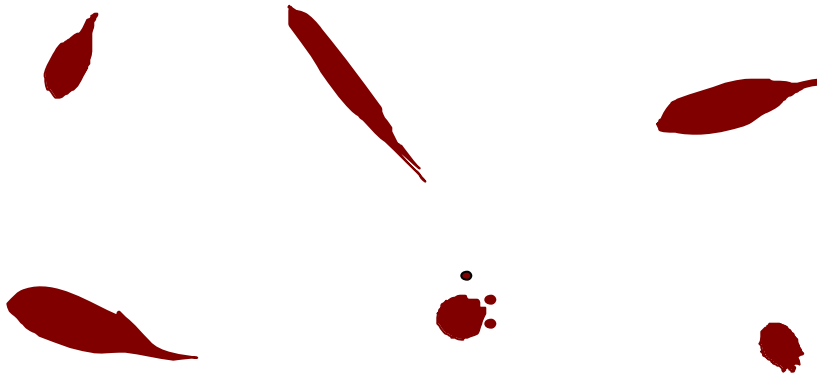
As a blood drop is flying through the air, it takes on a spherical shape. The force of surface tension causes the drop to maintain its shape until some other force, such as contact with a surface, acts upon it. When the blood drop hits a surface, a bloodstain results. The angle at which the drop strikes the surface determines the shape of the resulting bloodstain. Initially, only the bottom of the blood drop contacts the surface. The bottom flattens out, and the liquid that was contained in the bottom part of the drop moves to the outer edge. This slightly increases the area of the drop in contact with the surface. The top of the blood drop retains the spherical shape, and the liquid in that part of the drop continues moving forward. The surface tension acts to keep the drop together, thus decreasing the area of the blood in contact with the surface.

The inertia of the blood drop keeps it in motion until it is acted upon by another force. The opposing relationship between the forces of surface tension and inertia determine the shape of the bloodstain. If the blood hits a surface such as a floor or wall, it will splash against the surface and result in a shape with a ragged edge called a scallop or a spine. In some cases, the surface tension may not be able to overcome the inertia and keep the entire drop together. Consequently, the original drop, also called the parent drop, breaks and forms little droplets called satellite spatter. The edge of the blood drop closest to the blood source will be smooth, and the opposite edge will have the ragged features created by the splash. By studying the shape of the stain, you can determine the direction from which it came. This process is illustrated below.

Phases of a Blood Drop Impacting a Surface Side View



12) Study the six bloodstains below, and draw an arrow indicating the direction of motion from the blood source to the target. The head of the arrow should point away from the blood source.

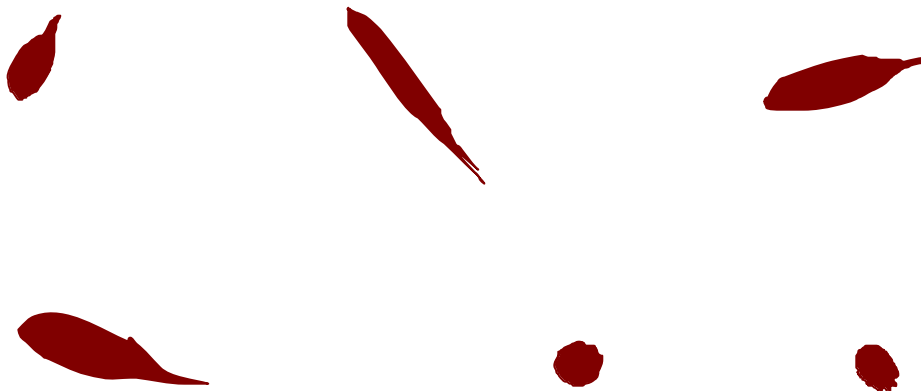


Another way to describe the directionality of a blood drop is to determine the directionality angle. This is the angle that is formed between the long axis of the bloodstain and a standard reference ray as described below.

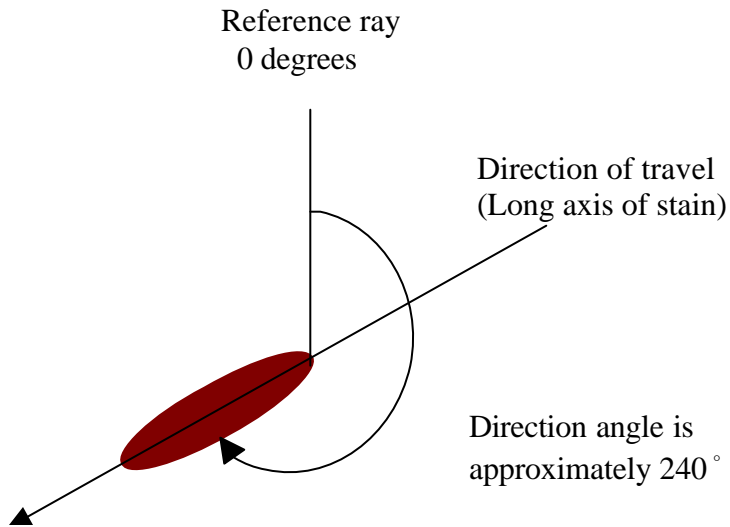
To find the directionality angle, you must first determine the long axis of the bloodstain. If you ignore the scallops and spines at the end of the bloodstain, the bloodstain has an elliptical shape. This is a good time to review what you know about ellipses from math class.

13) Sketch the graph of an ellipse. Label the identifying characteristics.

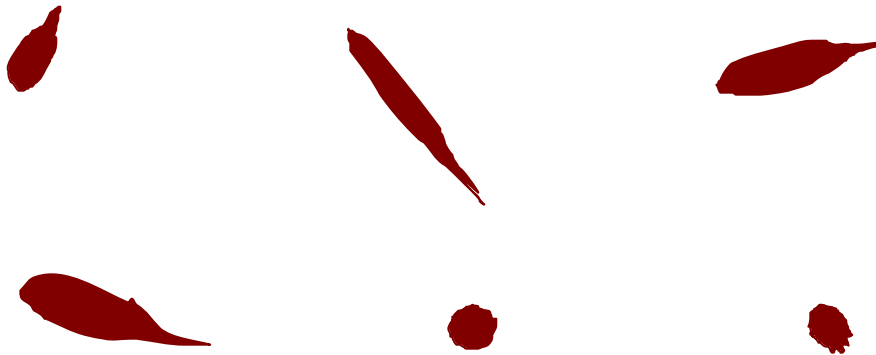
14) Fit an ellipse to each of the bloodstains below, and draw the major axis of each. The major axis of the ellipse corresponds to the long axis of the bloodstain.



15) Remember that the directional angle of the bloodstain is the angle formed by a standard reference ray and the long axis of the bloodstain, as shown below.



The bloodstains from Exercise 14 are repeated below. Draw each directional angle and estimate its measure.



Part B Two-Dimensional Point of Convergence

Now that you have learned how to determine the direction of motion of each blood drop, you can use this information to locate the point of convergence. You will need to retrace the path of each blood drop before it impacted the target. The point of convergence is a point located in the same plane as the bloodstains and serves as a starting point for finding the location of the blood source. The location of the blood source, also called the point of origin, can be traced to a spot related to this point. The process for obtaining the point of origin will be studied later in the lab.

The source of the blood was most likely located along these paths. When two or more paths intersect, this indicates a very likely location for the blood source. The intersection of the paths is called the point of convergence.

16) Consider the group of bloodstains given below. These bloodstains were found on the floor at the crime scene.



To start, limit yourself to considering two dimensions (the floor) from an overhead view. Fit an ellipse to each bloodstain as you did earlier in this lab and draw the major axis of each.

Using a ruler or a straight edge, extend the long axis of each bloodstain in the direction of the blood source. The intersections of two or more of these paths indicate the point or points of convergence.

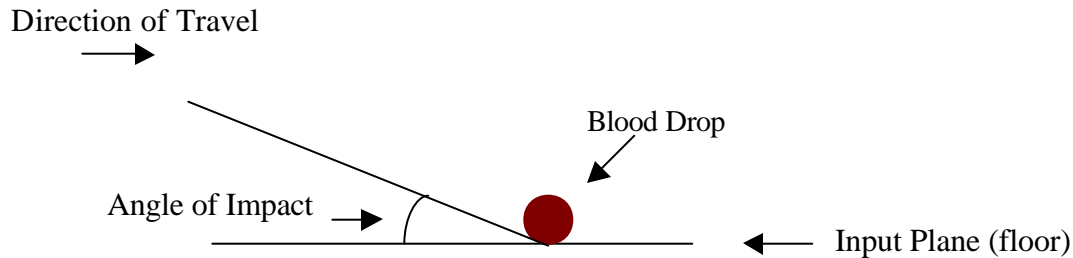
Interpret your work. How many points of convergence are there for this set of bloodstains? Explain your answer.

17) Find the point or points of convergence of the bloodstains below and interpret your results.



Part C Angle of Impact

The source of the blood will be a point above the target plane measured in three-dimensional space. In the previous exercises, you found the point of convergence for a group of bloodstains. You will also need to find the angle at which each blood drop impacted the surface. This is called the angle of impact, or impact angle. Using the angle of impact, you can elevate the point of convergence into a third dimension and thus locate the point of origin of the blood. A diagram illustrating the angle of impact, just as the blood drop strikes the surface, is given below.



18) The angle of impact directly affects the size and shape of the stain. You can see this relationship by conducting a very simple experiment using milk, which has fluid properties similar to human blood.

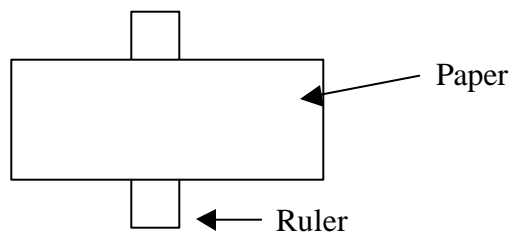
To conduct this experiment you need the following items:

- | | |
|--------------------------------------|---------------|
| ¼ Cup of Milk | Scotch Tape |
| Food Coloring (optional) | A Ruler |
| A Medicine Dropper | A Protractor |
| 4 Sheets of White Construction Paper | A Paperweight |

Mix a few drops of the food coloring into the milk if desired.

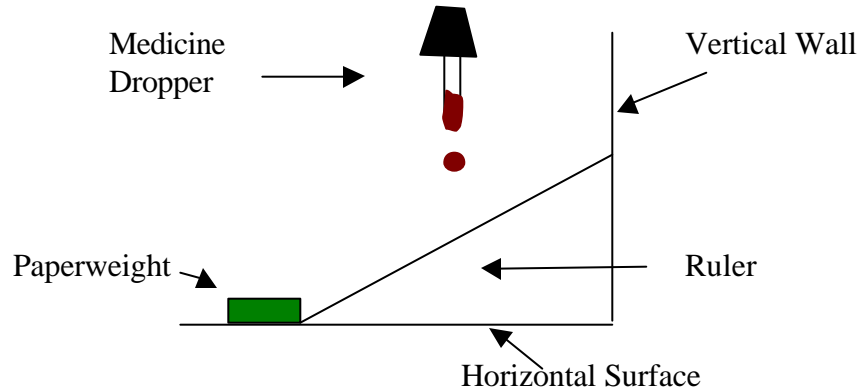
To simulate an impact angle of 90° , place one of the sheets of paper on a horizontal surface. With the medicine dropper perpendicular to the horizontal surface, squeeze one drop of the milk onto the paper. Take note of the characteristics of the resulting stain.

To simulate impact angles of 60° , 45° and 30° , tape a sheet of paper onto the ruler as shown below.



Next, lean the ruler with paper attached against a vertical surface, and identify the impact angle. Use a protractor to position the ruler so that the desired impact angle is obtained.

Once the ruler is in position, place your paperweight at the base of the ruler to keep it in place as shown below. With the medicine dropper in a vertical position, squeeze a drop onto the paper that is taped to the ruler. Produce drops with impact angles of 60° , 45° and 30° . Note the characteristics of the resulting stains.



Explain the relationship between the measure of the impact angle and the shape of the stain.

- 19) From the above experiment, what are the maximum and minimum possible values for the impact angle? Explain.
- 20) From the previous experiment, you observed that the angle of impact affects the shape of the stain. You are now ready to explore the mathematical relationship between the shape of the stain and the angle of impact. Begin by studying the bloodstains and impact angles on the next page. (Note: The size of the bloodstains has been magnified to make measuring easier.)

Bloodstains with Given Impact Angles

90°



80°



70°



60°



50°



40°



30°



20°



10°



Fit an ellipse to each bloodstain on the previous page. The width of the bloodstain is given by the minor axis of the ellipse, while the length is given by the major axis. Because of the small distances being measured, it is best to measure in millimeters. Fill in the table below.

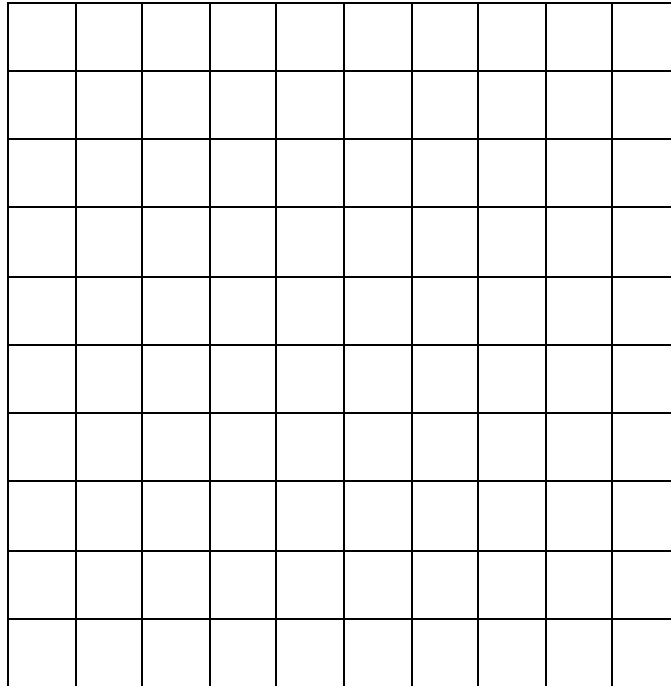
Table 4

Angle of Impact	Width (Length of Minor Axis) mm	Length (Length of Major Axis) mm	Width/Length Ratio
10°			
20°			
30°			
40°			
50°			
60°			
70°			
80°			
90°			

21) Can the width/length ratio of a bloodstain ever exceed a value of 1? Explain.

22) On your graphing calculator, produce a scatter plot with the impact angle on the horizontal axis and the width/length ratio on the vertical axis. Give the viewing rectangle used, and sketch the graph on the grid below. Be sure to label the axes.

Xmin: _____ Ymin: _____
Xmax: _____ Ymax: _____



23) Recall that the values on the horizontal axis are angle measures, and consider the pattern of the scatter plot. What trigonometric function could be used to model this data? Define the variables that you use.

24) Using the regression capabilities of your calculator, find the curve that best fits the data you obtained in Exercise 20. Write the equation you found, and define the variables you used. How did you determine that this curve is the best?

25) Compare the trigonometric function you predicted earlier with the regression equation you derived in the previous exercise. In analyzing bloodstains, which function would you prefer to use to find the impact angle and why?

26) The dimensions of three bloodstains are given below. Use the information given and the equation you chose in Exercise 25 to determine each angle of impact.

a) Width 1.30 mm
Length 3.00 mm

b) Width 3.40 mm
Length 4.30 mm

c) Width 2.10 mm
Length 2.15 mm

27) Based on your research on bloodstain pattern analysis, use the function you chose in Exercise 25 and calculate three sets of reasonable values for the width and length of the bloodstains formed at impact angles given below. Give a set of answers for each type of impact velocity. Fill in the appropriate units next to the title of each column. (Refer to Table 2 or Table 3, depending on the units you use.)

a) 15°

Table 5

Type of Impact Velocity	Width of Stain	Length of Stain
Low		
Medium		
High		

b) 72°

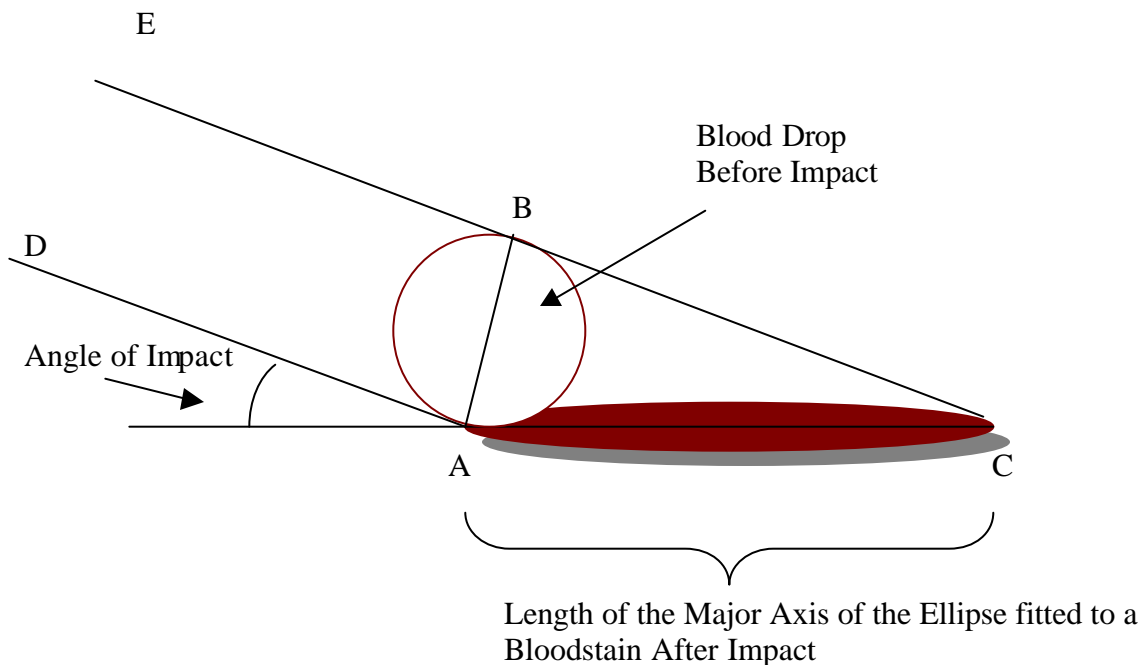
Table 6

Type of Impact Velocity	Width of Stain	Length of Stain
Low		
Medium		
High		

Determining the Angle of Impact Geometrically

In the Part A Directionality of a Bloodstain, you explored the process of bloodstain formation when a blood drop impacts a target plane. (Reread if necessary.) Due to the behavior of the spherical blood drop upon impact, the width of the resulting bloodstain is approximately equal to the diameter of the blood drop before impact. The length changes, however, based upon the angle of impact.

The relationship between the blood drop before impact and the resulting bloodstain is illustrated in the diagram below.



Lines CE and AD are both tangent to the circle at the endpoints of diameter, AB.

28) What is the measure of the angle ΔABC ?

29) What is the relationship between line CE and line AD? Explain.

30) Which angle in triangle ABC is equal to the impact angle shown in the diagram? Explain.

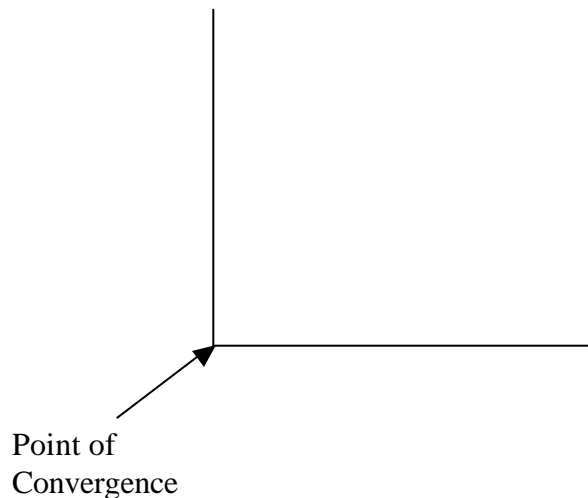
31) What measurement on the bloodstain approximates the length of AB? Explain.

32) Use the picture of the blood drop just as it impacts the surface to find an equation involving the impact angle. Compare this equation to the one you derived previously.

Part D Determining the Point of Origin

At this point, you have explored the directionality of bloodstains, the point of convergence, and the angle of impact. The point of convergence of a group of bloodstains provides some information regarding the source of the blood, but it does not give the height of the blood source above the target surface. To get the height, you will also need to consider the angle of impact. For this process, you must change your view of the scene from the overhead or “bird’s-eye” view to a side view.

- 33) When looking at a scene from a side view, we see two dimensions that can be represented on a coordinate system. Suppose we orient the coordinate system so that the point of convergence is at the origin, and the horizontal axis represents the distance along the target surface from the point of convergence. What does the vertical axis represent? Label each axis in the coordinate system given below.



- 34) Suppose that at a crime scene one of the many bloodstains with a common point of convergence was found to be 15 inches from the point of convergence with an impact angle of 37.5° . Represent this bloodstain on the coordinate axes below. Extend the side of the impact angle until it intersects the vertical axis. Be sure to label your axes.



35) Study your picture above, and calculate the height of blood source.

36) The following set of bloodstains was located on the floor at a crime scene. Locate the point of origin. Note that the three blood stains are actual size whereas the distances measured outside the bloodstains are scaled such that 1 cm is equivalent to 10 inches.



37) Suppose that only the above bloodstains were found at the scene. (The body is missing.) Based on the results of the previous question, give a plausible explanation of what occurred at the crime scene. In your explanation, include a description of the probable position of the victim and the possible type of wounding agent.

With the above information on point of convergence and angle of impact, you are ready to develop the second part of your model to solve the technology problem – how to identify the location of the victim. The model you develop constitutes your hypothesis, which is the third step of the scientific method. The development of the model now leads to the fourth and fifth steps of the scientific method – testing the hypothesis and making a decision about the hypothesis.

Test the Model

Now that you have developed your model, you can test the model by analyzing the bloodstain patterns from Case #65 (repeated below from The Technology Problem). Recall that the fingerprinting, blood typing, and DNA analysis indicate all the blood came from one source, the victim. The bloodstains are actual size whereas the distances measured outside the bloodstains are scaled with 1 cm equal to 3.82 inches. Results of your analysis will provide information regarding the location of the victim and possible wounding agents. This information will be forwarded to the chief prosecutor's office, so the accuracy of the model is very important to the criminal investigation.



Decide to Retain, Reject, or Modify the Model

Your decision regarding the action you take depends on how well the model actually predicts the wounding agent and the location of the victim. If the model does not accurately predict this information, you will want to revise it to improve its predictive abilities.



Thesis Defense

You will be asked to give an oral presentation of your model portfolio. This is called the thesis defense. It might help to imagine that you are presenting the results of your research to a courtroom audience. Be sure to include in your defense a discussion of the development of your model as well as the results from applying the model to the bloodstain patterns from Case #65.

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- Suggested Terminology List
<http://brazoria-county.com/sheriff/id/blood/terminology.htm>
- Iowa State Medical Examiner Newsletter: September- October 1997
<http://www.state.Ia.us/government/dps/sme/septnews.htm>
- Blood Spatter Analysis
<http://www.law.depaul.edu/criminalseience/blood/bloodspatter.html>
- JFK Case: What does the Blood Tell Us
<http://www.jfklancer.com/BloodEvidence.html>
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<http://www.crime-scene-investigator.net/computersvstrings.html>
- Blood Spatter is Key in Trial
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<http://www.forensicdna.com/Timeline.htm>
- Blood Spatter Analysis with Computers
<http://www.physics.carleton.ca/~carter/>