ARTICLE

Making Tracks: The Forensic Analysis of Footprints and Footwear Impressions

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Analysis of footwear characteristics, impressions, and track ways can provide important evidence in a crime scene investigation. In this article, we present examples of how students can be involved in hands-on laboratory-based activities as a means of introducing the forensic sciences. The teaching methodology employs active learning strategies that allow students to discover scientific principles for themselves, develop techniques of critical thinking and problem solving, and gain appreciation for how knowledge arises. By including forensic sciences in the science curriculum, students develop an appreciation for the interrelatedness of all the sciences. From this series of activities, i.e., examining analyses of footprint and footwear impressions, students working as teams will gather information, analyze data, and draw conclusions. Moreover, students will be able to assess the significance of the quality and variability in the data collection process as well as learn the value of controls and experimental design through comparison of results with other groups. ***Anat Rec (Part B: New Anat) 279B:9–15, 2004.*** **© 2004 Wiley-Liss, Inc.**

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INTRODUCTION

Modern forensic scientists perform comprehensive chemical and physical analyses of evidence submitted by law enforcement agencies. Their work is often instrumental in apprehending and convicting criminals. However, although most forensic scientists focus on criminal cases, others (such as those experts performing handwriting comparisons to determine the validity of a signature on a will) (Dillon, 1999) work in the civil justice system. The increasing sophistication of crime investigations has resulted in greater use of physical evidence. The application of new technology to criminal and civil investigations has the effect of extending the limits of physical evidence. From this evolution of criminal investigation procedures has come a greater need for well-trained forensic scientists as well as initiatives for developing innovative approaches to educating students in science.

Forensic science provides evidence to resolve legal issues through the application of scientific principles. Because forensic science is a broad field that integrates many science disciplines, it is important that students pursuing such a career be able to draw on a wide spectrum of scientific knowledge from biology, chemistry, physics, and mathematics. Although formal training in forensic science generally begins at the college or university level, many secondary schools include forensics as part of the curriculum. This allows students to gain experience in applying problem-solving skills to a broad field using the natural and physical sciences. Furthermore, including forensics in the science classroom is an excellent way for students to develop an appreciation for the interrelatedness of all sciences. As a result, science becomes a process rather than a body of knowledge. When this process is applied to problem solving where students learn by doing, the science classroom is perceived as exciting and challenging (Heppner, 1996).

We have developed hands-on laboratory-based activities as a way of introducing forensic sciences to students. Recently, we published an article on forensic entomology (Miller and Naples, 2002) that described ways investigators utilize insects in gathering information from a crime scene that later could serve as evidence in a legal proceeding. This approach allowed students to gain a better understanding of insect biology as well as an appreciation for how understanding biology could be applied to a real-life situation. In this article, we describe activities that engage students in hands-on experiments in which they perform their own investigations, collect data, and draw conclusions. Our goal is to provide science teachers with instructional materials directed toward an inquiry-based approach. Although there is value in lecture and pencil and paper activities, our experience demonstrates that students re-

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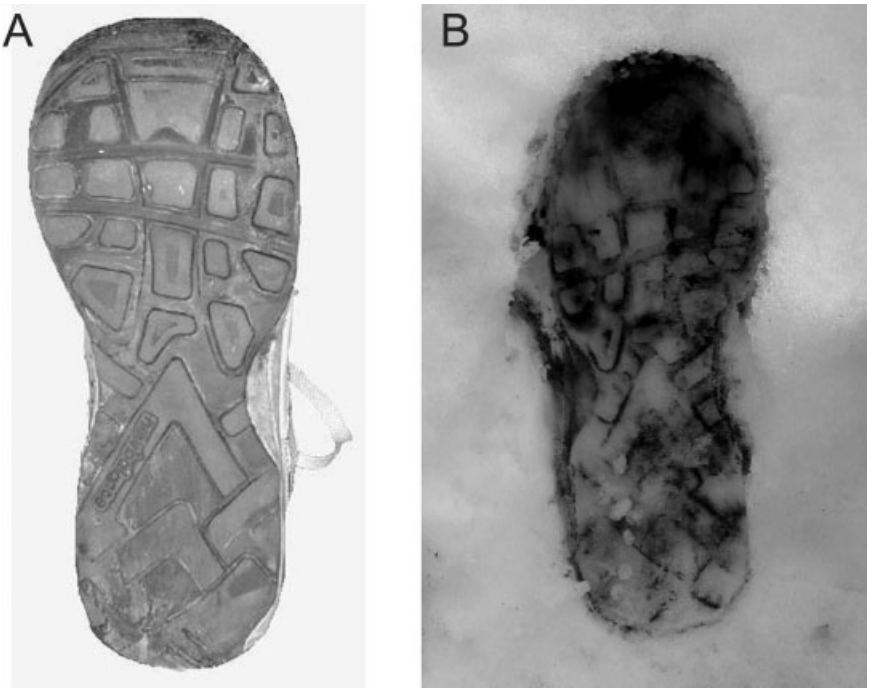

Figure 1. Sole of footwear (**A**) that made the print in snow shown in **B**.

tain more information when learning by doing. Moreover, our approach gives students more opportunities to discover scientific principles for themselves. Active learning methods, on the other hand, allow students to develop techniques of critical thinking and problem solving and gain appreciation for how knowledge arises (Lumpe and Oliver, 1991; Lawson, 1999). The learning-by-doing model gives students ownership of their learning and creates opportunities for them to take knowledge, apply it, and comprehend its application in an environment that is both meaningful and fun (Heppner, 1996).

BACKGROUND

Forensic evidence consists of all the physical objects that can be observed by the five human senses and analyzed regarding their relevance to the events that occurred at a crime scene. Any physical item can be a source of information that assists the investigator in reconstructing the sequence of occurrences.

A line of evidence that can establish a time frame for the presence of an individual is the interpretation of footwear impression evidence (Hamm, 1989; Bodziak, 1995; DiMaggio, 1995; Eckert, 1997). Furthermore, footwear impression analysis is easily done with a class of students at many different levels, from elementary to university. Understanding and interpreting footwear patterns can teach students the basic ethos of forensic analysis as well as incorporate principles necessary to engage in any form of scientific research. The materials required to perform the activities described herein range from inexpensive to moderate cost, allowing this discipline of study to be readily incorporated into any science program.

The gait of each individual is different and the unique features of each person's gait sculpt their footwear in individual and repeatable patterns. As a result, items of footwear identical at the time of purchase will rapidly take on the characteristics of the anatomy and movement patterns of the feet that wear them, as well as reflect the effects of the physical environments into which they step. Thus, within perhaps as short a time as a few hours, each shoe, boot, slipper, or other kind of footwear can become a unique reflection of the wearer (Figure 1) (Rowe, 1981). In cases where identifying those present at a crime scene becomes the focus of interest, the impressions left by the wearer prove not only his or her presence or absence, but can often demonstrate a clear association of the wearer with the crime scene at the time of the crime, before it, or after it.

Footwear impressions reflect the real activities of individuals and can reveal patterns of activity in the order in which they occurred despite lack of other documentation of the crime scene. Impression evidence can be of two kinds, as can many other types of forensic evidence. The first is class, which refers to the general type of a footwear impression. Class characters include such information as the type of tread on the bottom of a piece of footwear. This is usually specific to a brand of manufacturer, and often to a single line or model of footgear. Other kinds of information that would fall into the category of class include the movement pattern of a person at a walk, trot, or run. Sizing of footwear also provides class information. These attributes have features in common with items from one or more groups, but do not necessarily characterize the activities of a specific individual or item.

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The second kind of information is more specific and is often possible to discern in addition to class characteristics. Examples of specific identifiers for footgear would include unique wear patterns, cuts or defects in sole impressions, and the contents of scrapings from treads or other parts. When an individual item of footwear shows characteristics that are unique, it can be associated with the crime scene to the exclusion of all others of the same class, and this constitutes making a positive identification. In other words, this object and this one only was responsible for the marks at the crime scene, proving beyond the shadow of a doubt that it was present,

TABLE 1. Relationship of foot length, shoe size range, height, and percentage of adult males with feet and shoe sizes in each percentile*

Foot length range		Shoe size	Shoe size/length	Height range	
mm	Inches	range	range (mm)	(feet and inches)	% of adults
251	$9^{7/8}$	$4^{1/2}$–6	6/267–273.5	5′2″–5′6″	1%
254–257	10–$10^{1/8}$	5–$6^{1/2}$	$6^{1/2}$/267.6–277.8	5′3″–5′8″	1%
260	$10^{1/2}$	$5^{1/2}$–7	7/275–282.2	5′4″–5′8″	3%
263	$10^{3/8}$	6–$7^{1/2}$	$7^{1/2}$/283–286	5′5″–5′9″	3%
266–269	$10^{1/2}$–$10^{5/8}$	$6^{1/2}$–8	8/283–290	5′6″–5′10″	11%
272	$10^{3/4}$	7–$8^{1/2}$	$8^{1/2}$/285.4–294.7	5′6″–5′10″	11%
276–279	$10^{7/8}$–11	$7^{1/2}$–9	9/288.3–298.6	5′7″–5′11″	15%
282	$11^{1/8}$	8–$9^{1/2}$	$9^{1/2}$/295–302.1	5′8″–6′0″	15%
285	$11^{1/4}$	$8^{1/2}$–10	10/294.8–306.1	5′9″–6′1″	14%
288–291	$11^{3/8}$–$11^{1/2}$	9–$10^{1/2}$	$10^{1/2}$/300.9–310.2	5′10″–6′2″	11%
294–298	$11^{5/8}$–$11^{3/4}$	$9^{1/2}$–11	11/302.5–315	5′10″–6′2″	9%
301	$11^{7/8}$	10–$11^{1/2}$	$11^{1/2}$/313–320	5′11″–6′2″	2%
304	12	$10^{1/2}$–12	12/311.7–322.8	6′0″–6′4″	2%
307–310	$12^{1/8}$–$12^{1/4}$	11–$12^{1/2}$		6′1″–6′5″	1%
311–317	$12^{3/8}$–$12^{1/4}$	$11^{1/2}$–$13^{1/2}$		6′1″–6′5″	1%

*These data are for running shoes or other similar flat-soled casual shoes.

as was the person wearing it at the time. This specific piece of evidence might become a key in determining what happened. In proceeding from analyzing the general to the specific, students learn the skills of deductive reasoning, and how to organize information into hierarchical patterns.

The number of individuals present at a crime scene is often difficult to determine, unless separate footwear impressions allow their number to be counted. The direction in which an individual was moving, the speed at which they were moving, and whether they were carrying anything heavy can be learned from analyzing footwear patterns. The order in which the impressions were made is discernible, as well as the extent, and perhaps the kinds of interaction among individuals who left mingled footwear impressions. Footwear can make additional marks as well as prints. Evidence of scuffs or dragging of feet can tell an alert investigator about the activities of individuals at the crime scene, even unique habitual or temporary patterns of the gait at that time.

Analysis of footwear impressions can reveal much about the timing of activities of an individual at a crime scene, as well as the individual's level of involvement. For example, if one set of footwear impressions is always overlain by those of others that can be demonstrated to be associated with the crime, it is reasonable to assume that the maker of the trodden-over impressions was present prior to the occurrence of the crime. It may not be possible to determine the length of time prior to the event that this individual was present, but this conclusion would support a determination of innocence or noninvolvement in the crime. If, on the other hand, the set of impressions in question always overlies those unquestionably in association with the crime, it suggests that they were made by someone happening onto the scene subsequent to the crime. The most important kind of impressions for analysis of the events at the crime scene illustrates interaction among the participants in the events. As tracks show a step-by-step sequence through time, the patterns in which they intertwine, affect other elements, and/or are affected by other elements at the scene can reveal who did what, and in what order, at the crime scene in a real-time manner.

In proceeding from analyzing the general to the specific, students learn the skills of deductive reasoning, and how to organize information into hierarchical patterns.

The length of footwear impressions can assist in the determination of the height of the track maker. Humans have similar body proportions, and there is a predictable relationship between the length of the foot leaving the impression and the height of the individual. These relationships do not change once a person reaches full growth, but may vary with age and gender. Women have generally achieved full stature by age 18, while men may continue to gain height until age 21. Body proportions of children also change dramatically from first age at walking through childhood. Table 1 serves as a reference for estimating the height of an individual based on an average of at least three left and right footprints. Although humans show a marked degree of bilateral symmetry (the left and right side of the body approximate mirror images), most people differ slightly in size between the left and right hands and feet. Although this difference is rarely marked enough to yield a significantly different estimate of height, it is useful for students to observe and note on themselves as well as others. The rate of change in height in children of dif-

ferent ages has not been published in sufficient detail to provide useful information here. It is a possible additional experiment for the students to do to collect such data from children of different ages in their school and to produce their own age/height plots, and to determine if the foot length/height ratio remains constant between boys and girls to adulthood.

MATERIALS

This list includes material needed for all the class activities.

(1) Measuring tapes, yardsticks, and rulers, preferably for each group of no more than four or five students.
(2) Data sheets for recording footwear impression measurements and other characteristics (Box 1).
(3) Pails, or other water containers, or a hose and faucet.
(4) An area of smooth concrete, such as a sidewalk, an area of soft soil, such as loam, and a soil area that can be wetted to form mud. Ideally, each region should be at least 10 meters long and 3 meters wide (40 feet long and 10 feet wide). A separate region should be available for each group of students. Prior to the start of the experiments, the areas should be dry and clear of debris. If these experiments are to be performed out of doors during the winter, 10 meter long areas of undisturbed snow can be used instead of areas of sidewalk and soil. Ideally, these areas should not be in heavy traffic areas, so that students can make their footwear impressions and observe them for several hours or days to see how they change over time.
(5) Colored chalk for marking the locations of prints on concrete.
(6) Several rakes and shovels and small trowels for moving soil (or snow) into or out of footwear impression areas.
(7) Three easily distinguished colors of nontoxic washable or nonwashable paint, depending on the preferences of the instructors.
(8) Mixing trays large enough to accommodate the sole of the experimental footwear and stirring sticks for each color of paint.
(9) A roll of brown wrapping paper or other absorptive paper on which students will make footwear impressions. Butcher's paper is not recommended because it tends to be too slick to accept paint.
(10) A variety of other items of surfaced textures that vary in their ability to absorb paint for students to make footwear impressions on. These may be suggested by students in the class.
(11) Photographic equipment and film for color prints. If students do not have their own cameras, instructors can take the pictures for them, or instant disposable cameras can be used, one for each group of students. Digital cameras may also be utilized at the instructor's discretion.
(12) A watch with a second hand, a stopwatch, or a timer that measures to the second or tenth of a second for each group.

BOX I. Data sheet for recording footwear impression information

Experiment title:_____ Date: _____ Time: _____

Observer'snames:_____

Weather conditions: _____

Temperature: _____ Wind strength and direction: _____

Relative humidity: _____ Most recent precipitation: _____

Substrate: _____ Number of tracks identified: _____

Impression measurements: Length _____ Width (widest, generally ball of foot) _____

Position in track series _____ Direction of track way: _____

Class characters: _____

_____

_____

Individual characters: _____

_____

_____

Observations of track interactions at scene: _____

_____

_____

Conclusions: _____

_____

_____

_____

CLASSROOM ACTIVITIES

Activity 1

The purpose of this activity is to allow students to determine how the appearance of footwear impressions can differ when tracks are made onto different substrates, and by using different media, such as paint of different viscosities or plain water. Students work in groups of three or four and

each member of the group should be assigned a specific task or job to perform. For example, the subject is the person making the footprints (print maker). Other jobs include observer, data recorder, clean-up engineer, and photographer.

Procedure

(1) Representatives (subjects) from each group step into plain water and make an impression on the brown wrapping paper and any other substrate they intend to test in this activity. Record the number of prints in a copy of the data sheet (Box 1).
(2) Students mix paint in the trays, starting with a mixture viscous enough to coat the soles of the footwear being tested. Subjects then step into the pans of paint and make prints repeatedly on the same substrate until no visible impression results. Record the number of prints in a copy of the data sheet (Box 1).
(3) Subjects make prints on substrates of different textures with the paint from the first mixture. Students then compare these impressions with those made on the brown wrapping paper.
(4) Subjects make footwear impressions starting with at least one additional dilution of the initial paint mixture and again determine how many prints they can make prior to them becoming invisible (Figure 2). Record the number of prints in a copy of the data sheet (Box 1).
(5) Students then perform a detailed analysis of the footwear impressions. By measuring the footwear impressions, students will be able to determine if there is variation among the prints even though they were made by the same person wearing the same item of footgear. Record the measurements in a copy of the data sheet (Box 1).

Results

There will be a great degree of variability in the results of these measurements, depending on how carefully each person placed his or her foot for each print. There also may be differences in the measurable length of the print, depending on foot placement and the level of visibility of the print as the paint is worn away by repeated contact with the substrate. As the paint thins, dries, or wears off the sole of the footgear, the print appearance can differ considerably and may make association of all prints in a single series difficult. Students need to describe the features of the series without comparing them to the original and, once this is completed, compare their descriptions to the original sole. For both the prints and the original sole, students should note any unique identifying characteristics. They are likely to discover that some features that are distinctive on the prints are not easy to see on the exemplar, although the reverse may also be true.

Students are then asked to exchange prints with those of other members of their group to increase the novelty of the print they are studying and to reduce their knowledge of the details of how they made their own prints. Each student should fill out a data sheet for each series of prints (Box 1). The same data sheet used for recording observations in this set of experiments can be used for the subsequent sets as well. If time permits, students should measure and make observations on more than one different set of prints and compare

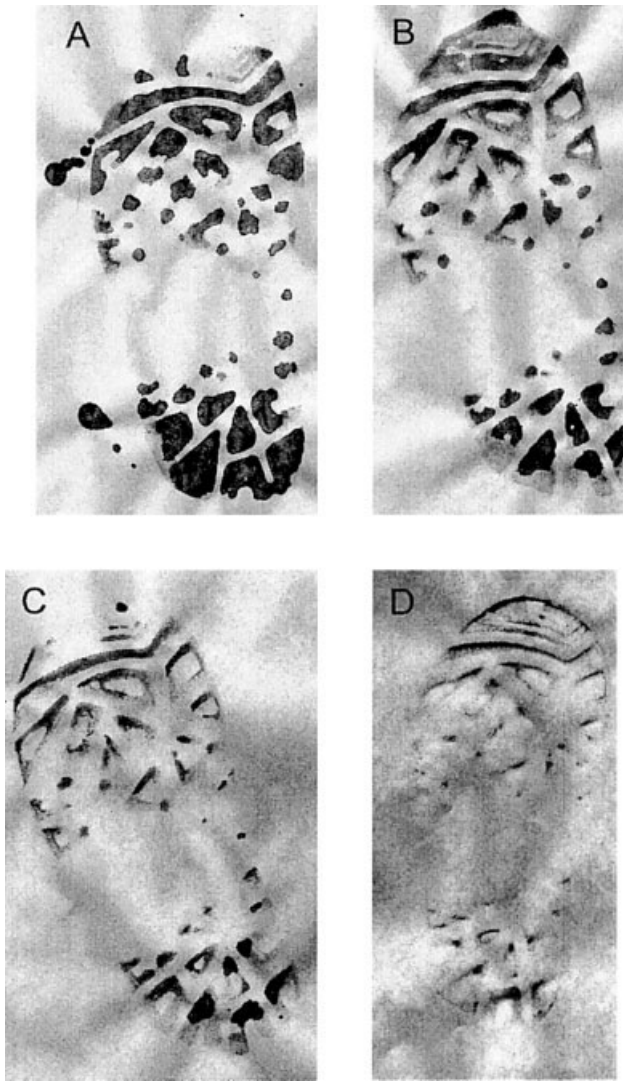

Figure 2. A series of prints made by a left running shoe dipped into a moderately viscous paint mixture. The first print (**A**) is the upper left, the second (**B**) the upper right, the third (**C**) the lower left, and the last (**D**) that shows sufficient definition to be identifiable as a part of the series is on the right. Both class and individual characters are visible; the former include the tread pattern of small squares and the latter the extensively worn outer side of the heel.

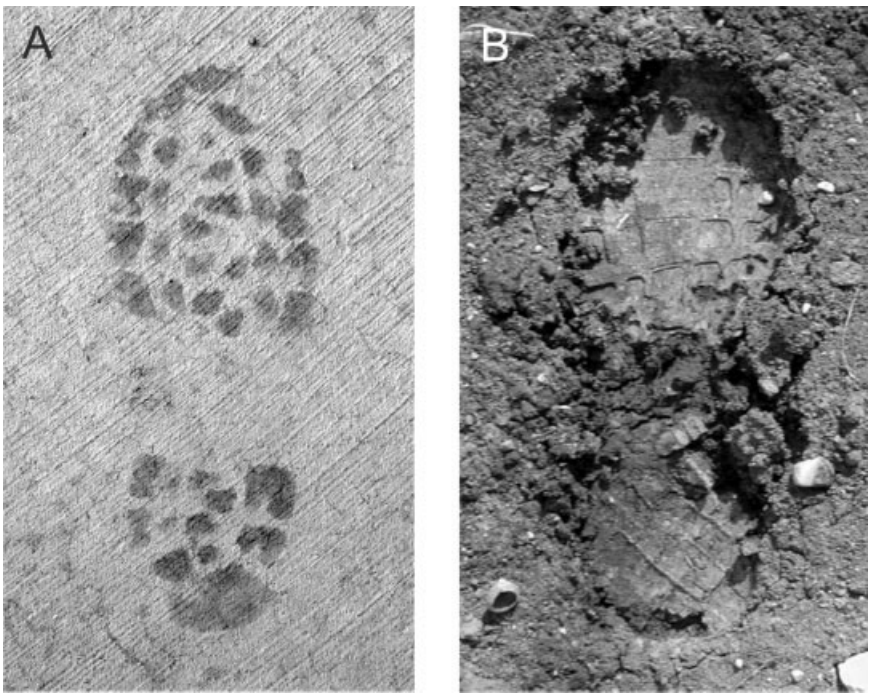

Figure 3. A: A track way made by a hiking type of boot with the sole wetted on a dry concrete sidewalk. **B:** Impression of footwear from Figure 1A left in soft soil.

results among their group. In this manner, they will be able to assess the significance of interobserver differences in data collection.

Activity 2

Once students have finished the first activity, they are ready to investigate the differences in prints made on different outdoor substrates and at different rates of speed. The purpose of this activity is to demonstrate that forensic evidence may be fragile and subject to rapid change or deterioration. Students should work in groups as previously described.

Procedure

(1) Subjects take turns first walking, then running at a slow and rapid pace on an expanse of concrete. To enable observers to see the prints on the concrete, subjects should wet their feet using plain water (Figure 3A). Another member of the group then marks the prints with chalk. Members of the group can now make their measurements and record the information in the data table.
(2) After completing the exercise on the concrete, subjects should repeat their walk, slow run, and rapid run across the soft soil and muddy substrates (Figure 3B). Alternately, if students are working in snow, they can follow the same procedures as for soft soil or mud. If no stretch of outdoor concrete is available, they may work indoors, using a hallway or other long enough space in a classroom. If these experiments are done indoors, only washable paint should be used, and students are expected to clean the "crime scene" after completion of the experiments. Most importantly, the instructor needs to remind students of safety. A wet floor can be very slippery. Subjects need to exercise caution when walking or slow-pace running on a wet floor.
(3) When measuring prints on different substrates, students should take notice of any marks made in addition to the actual print. Some people tend to drag one or both feet and may leave scuff marks with the toe, heel, or both on some or all steps. These patterns reflect the habitual walking pattern of the individual and can contribute to the ability to distinguish a set of prints belonging to one person from those of others. As the print maker accelerates from walking to a slow run to a more rapid run, students need to measure the distances between the prints. The distance between steps increases with increasing speed. If students time the print maker across the course, they can calculate the rate of progress. Such a calculation might be important in the analysis of a crime scene because it could establish the basis for creating a time line of the presence or absence of a suspect, witness, or victim or to show how long a particular series of events might have had to occur.

Variations for activity 2

A variation of this activity on these substrates can demonstrate if and how the walking, slow-run, and rapid-run prints differ when the person is carrying a heavy weight. Students often wear backpacks containing many books and can be asked to wear one during this exercise. This will also work well in snow. The tracks should be made in a different location from the initial set, so as to preserve all the variables of track ways for later observation.

Another set of variables can be introduced by asking students to make observations on their sets of prints over the next several hours or days if possible. Particularly in cases where wind or precipitation can affect the prints, students can determine how these factors might affect analysis of this kind of evidence from a crime scene.

Additional variables can be introduced by having several students make track ways in the substrates, walking and/or running along the same path. The task will be to determine how many sets are present, which prints belong to each set, the order in which they were made, and the pace of each print maker.

Results

Depending on the weather conditions, the prints may remain visible for a long or short period of time. Once they have recorded the prints in this exercise, students should discuss the importance of rapid evidence collection and determine how to balance

the need for speed with the need for accuracy. The importance of photo documentation of evidence should be emphasized as well.

Activity 3

The purpose of this activity is to test students' ability to estimate the height of the individual making the tracks.

Procedure

(1) Students measure the prints on the different substrates as they did those made in paint.
(2) Students analyze the prints made at slower and faster paces.
(3) Students compare analysis of prints made at different speeds as well as different substrates.
(4) Students compare results with other groups and discuss reasons for differences and similarities.

Results

Students will observe an increased range of length variation in prints and should therefore average the impression from three right and three left prints. The average print length measurement may differ between prints made at different speeds and thus could affect the calculation of the height of the individual. As people do not alter their height by walking, running slowly, or running quickly, students can determine the level of confidence with which they can predict the height of an individual who made prints under different conditions.

OUTCOMES

Instructors should anticipate that students will learn to appreciate the difficulty of collecting data and the pitfalls of making a series of measurements, which can vary from one observer to another. They will also have the opportunity to learn about the problems encountered as they make measurements, particularly of the prints made in soft soil, mud, or snow, because investigators themselves make prints and can be responsible for contaminating the area under investigation, thus making analysis of footprint and other track mark evidence impossible.

CONCLUSIONS

Forensic science activities integrated into a laboratory-based science classroom can help capture students' interest in learning science. Coupled with the advent of television shows featuring the forensic sciences, the sensational media coverage of high-profile cases such as the O.J. Simpson trial, and the development of new technologies for gathering and analyzing information, it is not surprising that many students would take an interest in pursuing a career as a forensic scientist.

This set of activities demonstrates simple ways to introduce forensics into the science classroom. Moreover, it provides a learning environment in which students can generate and analyze data that will reveal both the value and some of the pitfalls in a forensic investigation. Depending on the preferences of the instructor, students can use a variety of observational and data collection skills as well as make analyses rooted in the principles of mathematics and science. These student-centered activities place emphasis on developing students' abilities to think scientifically and thus encourage them to learn how to deal with ambiguity, to use and evaluate the reliability of information, and to ask further questions.

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