Module 1D

Scientific Methods

Forensic Science Teacher Professional Development

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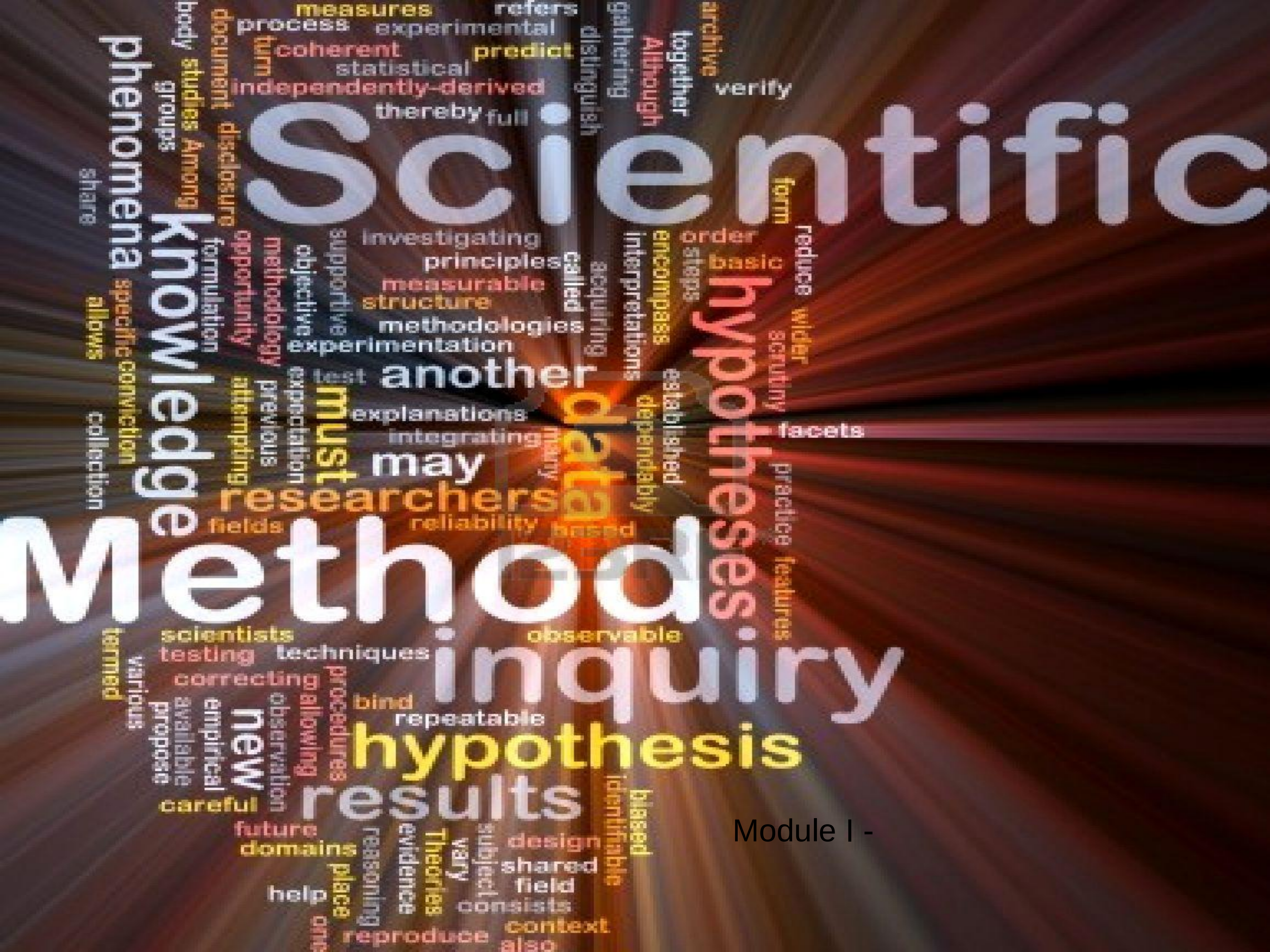
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Module I -

Scientific Methods

Scientific Methods are ways to systematically examine the world around us.

Scientific methods are used in both criminal investigation and forensic analysis.

The procedures used within scientific methods follow an orderly systematic approach that investigators or scientists use in the research process.

While there are minor variations of the scientific model, all include the same scientific concepts.

Unit 15: Scientific Method

The two pillars of science are

1) logic or rationality and
2) observation.

The three major aspects of the overall scientific enterprise are listed below:

1) Theory - Theory relates to the logical aspect of science.
2) Data collection - Data collection is the observational aspect of science.
3) Data analysis - Data analysis is the process of examining patterns in what is observed by the scientist.

Unit 15: Scientific Methods

- Scientific research may begin with a hypothesis or an observation. Researchers look for regularities and patterns in whatever phenomenon they are researching. In order to examine these regularities and patterns, researchers focus on variables and aggregates.
- A variable consists of attributes which are characteristics or qualities that describe an object. Variables are logical groupings of attributes.
- Hypotheses are formulated to describe the relationship that might be expected among variables. The independent variable is the variable which determines or causes the dependent variable. The dependent variable is the outcome variable.

Purpose of Research

- Exploration: Much research is conducted to explore the nature or frequency of a problem or, in some cases, a natural phenomenon.
- Description: A major purpose of many scientific studies is to describe the scope of problems or physical properties.
- Explanation: Why some physical properties account for certain outcomes or examinations result in certain findings would be another type of research.
- Application: Applied research stems from a need for specific facts and findings with scientific methods or laboratory procedures.

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In order to achieve these purposes, a systematic approach is needed. Scientific investigations may include these components.

1) **Theory construction:** This is often based on some existing theory that has a variety of concepts relevant to what you wish to study.
2) **Derivation of theoretical hypotheses:** We could derive hypotheses about the various concepts that make up the theory.
3) **Operationalization of concepts:** We must now specify indicators that represent the theoretical concepts. What we are doing is converting the theoretical hypotheses into an empirical one.
4) **Research design construction:** Most scientific investigation experiments are designed to test the hypothesis.

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Steps of scientific method model, continued:

5) **Collection of empirical data:** Data is collected relating to empirical indicators.
6) **Empirical analysis of the data**: Statistical testing of the data collected is now conducted to analyze the hypothesis.
7) **Writing up experiment conclusions**: Results are formally written up in a report.
8) **Communicating results:** Results are disseminated to interested stakeholders.

Theory Construction

- In order to formulate theory, deductive or inductive logic is employed.
- Deductive logic goes from the general to the particular. “All people are mortal; Socrates is man; therefore, Socrates is mortal.”
- Inductive logic goes from observations to generalizations to explain the relationships between the objects observed.
- Certain terminology is important in understanding research methods.
- These terms are listed on the slides that follow.

Terms used in Theory Construction

- **Objectivity and Subjectivity** - A subjective matter would be like asking whether Texas or New York is the better state. The notion that you are sitting in a desk right now is objective; it is independent of the mind and your experience of it.
- **Observation** - Observations involve information gathering through seeing, hearing, touching, etc.
- **Fact** - Facts are generally used in the context of social scientific research to mean some phenomenon that has been observed (e.g., the St. Louis Cardinals won the World Series in 2011).
- **Law** - Laws are universal generalizations about classes of facts.

Terms used in Theory Construction

- **Theory** - A theory is a systematic explanation for the observed facts and laws that relate to a particular aspect of life such as juvenile delinquency.
- **Concepts** – These are the “basic building blocks of theory.” They are abstract elements that represent classes of phenomena within the field of study.
- **Variables** - A variable is a concept’s empirical counterpart. They can be observed and can take different values; they vary.

Terms used in Theory Construction

- **Statements** - A theory has several types of statements such as principles and laws, the axiom, and propositions.
- **Hypotheses** - A hypothesis is a specified expectation about empirical reality, derived from propositions.
- **Paradigm** - This is a fundamental model or scheme that organizes our view of something. Some paradigms are thrown out in favor of new ones.

Hypotheses

- Hypotheses are testable and refutable, have a limited number of assumptions, are simple, are based on a rich body of data, and are predictive and reproductive.

Data Collection

- Keep a lab notebook with all the details of the experiment including data and measurements.
- Tables are good a way to organize data.
- Make sure everything is labeled clearly, including tables.
- If there is a mistake, write it down.
- Do not leave anything out.

Empirical Testing

A. Developing and performing an experiment:

- To test the hypothesis, make sure to have one variable; the rest are controls.
- Controls are values that do not change.
- The outcome of the experiment has only two options: it supports the hypotheses or does not support the hypothesis.
- Retest the experiment multiple times.
- Also, document all the steps taken to perform the experiment. These steps should be clear so the experiment can be repeated anytime.

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Empirical Testing

B. Analyzing the data:

- Look at the data collected. Compare and contrast the information. Use graphs, tables, and charts to visually review the data.

C. Writing the conclusion:

- Describe what conclusions can be drawn from the results. Tell whether the results support or do not support the hypothesis.

Empirical Testing

D. Communicating the results:

- Communicate the results by PowerPoint presentation, poster presentation, written paper, or other similar platforms. Be conscious of the type of audience who will be reviewing the scientific research.

Examples of Application of Scientific Method in Basic Science

Hypothesis-driven experiments: Null and alternative hypotheses

In the experimental design to test a hypothesis, your experiment should have at least one control or independent variable, and at least one response or dependent variable. The independent variable is the one that will change during the course of experimental measurements. The dependent variable is the one that you will measure, although you may not be sure if it will change. Therefore, the point of the experiment may be to determine if it does or does not change.

Examples of Application of Scientific Method in Basic Science

Hypothesis-driven experiments: Null and alternative hypotheses, continued

It is common to call the independent variable a control variable because you decide upon its value and control it. For example, in an experiment concerning the effect of fertilizer doses on size of tomatoes, you control the concentration of fertilizer given to each plant. In observational research, the independent variable may be something you cannot control. For example, you might conduct a study of tomatoes grown outside and investigate whether they grow faster on hot days than on cool days. In this case, nature will bring you the hot and cold days; you cannot control when they will happen, but you can still study their effects.

Examples of Application of Scientific Method in Basic Science

Hypothesis-driven experiments: Null and alternative hypotheses, continued

Experiments are usually better when the investigator controls the independent variable, but this is not always possible. Another way to think about the relationship between the independent variable and the dependent variable is in terms of cause and effect. The independent variable is something you believe may cause a change in the dependent variable. Finding causes is important because it lets one make predictions and gives a guide for action.

Examples of Application of Scientific Method in Basic Science

Hypothesis-driven experiments: Null and alternative hypotheses, continued

Once you have settled on an independent variable, you can state a null hypothesis. The null hypothesis is usually that changes in your independent variable will not lead to any significant changes in your dependent variable. The hypothesis that changing the first variable does change the second is called the alternative hypothesis.

The problems of error, time, and money

A number of problems must be solved in every experiment. One of them is that all measurements have error. A second is that time and resources always limit the number of measurements that can actually be performed. These two problems are in direct conflict with each other. The effects of random error can be eliminated by taking a vast number of measurements, but that takes a vast amount of time and money. Time and cost can be driven down by taking a minimal number of measurements, but the results can be plagued with error. Two examples may help illustrate how these problems arise in practice.

1) The Ball on a Ramp

An experimenter lets a ball roll down a metal channel 50 cm in length and measures the time needed to go from top to bottom. The time is measured by having the ball pass through a first optical gate at the top of the channel, which starts a clock, and through a second optical gate at the bottom, which stops it. After 10 measurements are taken, the channel is then sprayed with a thin layer of lubricant, and the time needed to roll the ball down the channel is measured 10 times again. The null hypothesis is that the lubricant has no effect on the time it takes to roll down the channel. The alternative hypothesis is that the time will become measurably greater or smaller. The effect could go either way because the lubricant might speed up the ball by lubricating it or, on the other hand, might slow it down by being a little sticky. Data from this experiment are shown in Table 1.

1) The Ball on a Ramp, continued

Table 1 measurements of time for a ball to descend a channel with and without lubricant.

Descent time in unlubricated channel (seconds)		Descent time in lubricated channel (seconds)	
0.303	0.291	0.352	0.317
0.301	0.314	0.331	0.332
0.292	0.308	0.327	0.340
0.296	0.298	0.315	0.324
0.291	0.336	0.313	0.285

The data are scattered. If the lubricant had an effect, it was comparable to the difference from one trial to the next in rolling a ball down the channel in supposedly exactly the same way. Did the lubricant affect the time the ball needs to roll or not?

1) The Ball on a Ramp, continued

Error analysis

The time it takes a ball to roll down a channel is conceptually very well defined. The problem in measuring it comes mainly from variations in how the ball is released, unevenness in the surface of the ball and of the channel where it rolls, and limitations in the reliability of the electronic circuit that responds to the ball reaching the end point of the experiment. These errors should be expected to vary in sign and magnitude from one trial of the experiment to another and can plausibly be eliminated by averaging.

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1) The Ball on a Ramp, continued

1. The average time needed for the ball to roll down in the unlubricated channel is given by the Equation 1: $x = x_1 + x_2 + x_3 \ldots\ldots x_N / N$ as

$t_{\text{un-lub}}$ = (0.303 + 0.301 + 0.292 + 0.296 + 0.304 0.291 + 0.314 + 0.308 + 0.298 + 0.336)/10 = 0.304

while for the lubricated channel one has

t_{lub} = (0.352 + 0.331 + 0.327 + 0.315 + 0.313 0.317 + 0.332 + 0.340 + 0.324 + 0.285)/10 = 0.324

1) The Ball on a Ramp, continued

2. Next, compute the sample standard deviations for each set of measurements. The formula is given by Equation 2: $s = \sqrt{\Sigma(x_i - x\square)^2/(N - 1)}$ and is in this case

$s_{\text{un-lub}} = \sqrt{[(0.303 - 0.304)^2 + (0.301 - 0.304)^2 + (0.292 - 0.304)^2 + (0.296 - 0.304)^2 + (0.304 - 0.304)^2 + (0.291 - 0.304)^2 + (0.314 - 0.304)^2 + (0.308 - 0.304)^2 + (0.298 - 0.304)^2 + (0.336 - 0.304)^2] / (10 - 1)} = 0.013$

$s_{\text{lub}} = \sqrt{[(0.352 - 0.324)^2 + (0.327 - 0.324)^2 + (0.313 - 0.324)^2 + (0.332 - 0.324)^2 + (0.324 - 0.324)^2 + (0.331 - 0.324)^2 + (0.315 - 0.324)^2 + (0.317 - 0.324)^2 + (0.340 - 0.324)^2 + (0.285 - 0.324)^2] / (10 - 1)} = 0.018$

This means that for the first set of measurements, the typical amount by which individual values differ from the average is 0.013, while for the second set of measurements the typical difference between individual measurements and the average is 0.018.

1) The Ball on a Ramp, continued

3. Next, compute the standard errors:

$s_{\text{unlubricated}} / \sqrt{N} = 0.013 / \sqrt{10} \approx 0.004$

$s_{\text{lubricated}} / \sqrt{N} = 0.018 / \sqrt{10} \approx 0.006$

The uncertainty in the mean time for the ball to roll down the unlubricated channel is 0.004 sec, and the uncertainty in the mean time for the ball to roll down the lubricated channel is 0.006. One combines the sample mean and standard error to write the estimates

$t_{\text{unlubricated}} = 0.304 \pm 0.004$ sec

$t_{\text{lubricated}} = 0.324 \pm 0.006$ sec

1) The Ball on a Ramp, continued

4. Graphically, the results can be presented as in Figure 1. Think of the error bars as showing the range where the true mean is most likely to fall.

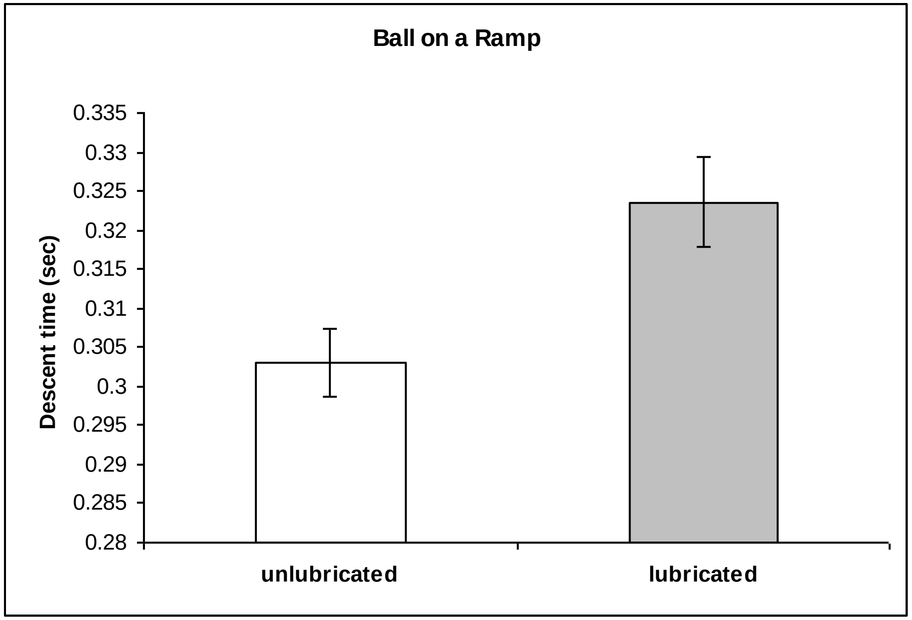

Figure 1. The experimental data in Table 1 are summarized by bars of two averages and associated standard errors as computed in Equations 1 and 2.

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1) The Ball on a Ramp, continued

5. The top of the error bar for the ball in the unlubricated channel is well below the bottom of the error bar for the lubricated channel. Therefore, it appears the lubricating the channel does indeed change the time needed for the ball to roll down and makes the time longer. The data allow one to reject the null hypothesis and conclude that lubricating the channel has a significant effect on the time needed for the ball to roll.

1) The Ball on a Ramp, continued

6. To make this conclusion more precise, compare the data for lubricated and unlubricated channels with a *t*-test using Equation 3: $t = (\mathbf{x} - \mu) /(s - \sqrt{N}) = (\mathbf{x} - \mu) / \Delta \mathbf{x}$

Using a two-sided test assuming equal variances, the probability of chance alone producing values as different as those appearing in Figure 1 is $p = 0.014$. This value of p is much less than the conventional value of $p = 0.05$ below which one can conventionally reject the null hypothesis. So the *t*-test confirms that the experiment has arrived at a significant result. The experiment has provided meaningful results despite the relatively large fluctuations in the individual measurements.

2) Flipping a coin

Someone hands a researcher a coin and says, “I flipped this coin and I don’t think it’s fair. Heads and tails don’t come up equally often.” The researcher decides to check. She flips it 100 times and gets the results in Table 2. There are 54 tails and 46 heads, not exactly 50–50. Is the coin fair?

Table 3. Results of flipping a coin 100 times. 1 represents heads and 0 represents tails.

0 0 1 1 0 0 0 1 1 0 0 0 0 1 0 0 0 0 1 0 1 0 1 1 1 0 0 1 0 0 0 1 1 0 1 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 1 0 0 0 1 0 1 1 0 1 1 1 1 1 1 0 1 0 0 0 1 1 1 0 1 1 1 1 0 1 0 0 0 1 0 1 1 1 1 1 0 1 0 0 1 1 0

2) Flipping a coin, continued

Error analysis

The property of the coin one wants to investigate is its “fairness.” The definition of fairness is that if flipped infinitely often, the coin comes up heads exactly half the time. More precisely as the number of flips approaches infinity, the fraction of heads converges to 0.5. In this case, the issue to settle is whether one can tell if a coin is fair after 100 flips, and whether having 46 heads instead of 50 indicates that it is not.

2) Flipping a coin, continued

1. In Table 2 there are 46 1s and 54 0s, so the average is 0.46.
2. The sample standard deviation is $s = 0.501$. It should come out to be very close to 0.5 because each number in the table is either 1 or 0, and the average is very close to 0.5; therefore, each individual value deviates by approximately a magnitude of 0.5 from the average. This is the definition of the standard deviation.
3. The standard error is $\Delta x = s/\sqrt{100} = 0.05$.

2) Flipping a coin, continued

4. A graph of the result appears in Figure 2.

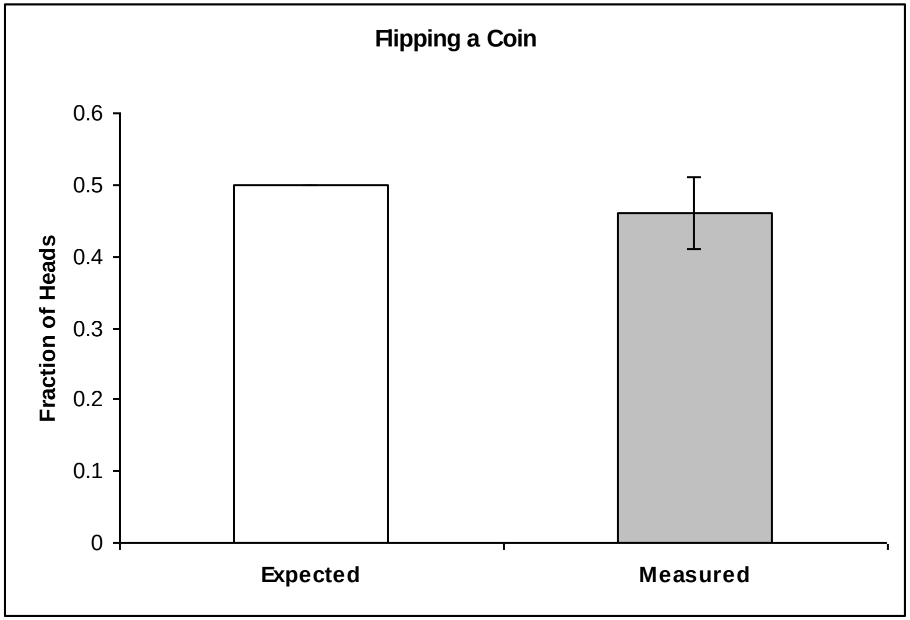

Figure 2. The experimental data in Table 2 are summarized by comparing the expected value of 0.5 for fraction of heads with the measured average value of 0.46.

2) Flipping a coin, continued

5. The error bar overlaps the expected value of 0.5. Therefore one has no grounds to reject the null hypothesis, and so far as one can tell the coin is fair. Finding 54 tails and 46 heads in 100 flips is quite consistent with the random nature of flipping a fair coin.

6. A statistical test that compares a set of measurements with an expected value is the *z*-test. Running this test gives a value of p 0.42, which is larger than 0.05, and which means that chance alone could easily be expected to produce an average value that differs this much from the expected value of 0.5. The bottom line is that so far as one can tell from 100 flips, the coin is fair. The coin might still be somewhat unfair and this experiment would not show it. If in the limit of an infinite number of flips, the coin comes up heads only 49% of the time, it is possible to detect, but many more flips are needed.

Scientific Methods Applied to Crime Scene Analysis

One of the scientific methods used at a crime scene follows a six-step process to collect and evaluate information related to a subject (Figure 3). These steps need to be performed with an applied methodology to provide objectivity to the crime scene reconstruction.

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Scientific Methods Applied to Crime Scene Analysis

The six-step process consists of the following:

1. Defining the problem or question to be solved
2. Collecting data to resolve the problem
3. Developing a hypothesis
4. Classifying and organizing the data
5. Testing the predictions of the hypothesis
6. Defining a conclusion

Scientific Methods Applied to Crime Scene Analysis

The six-step process, continued

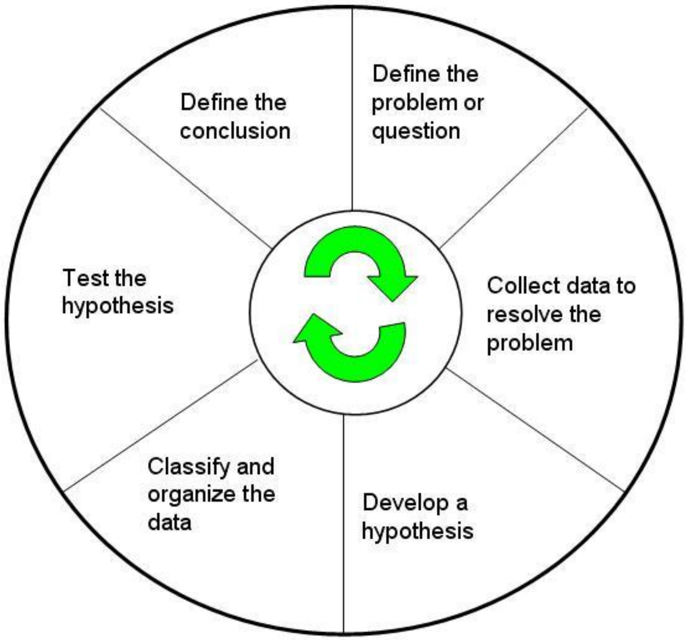

Figure 3. Scientific method is the foundation of crime scene analysis. A circular six-step process is often followed that starts with a question, the answer to which usually begs another question and ends with a conclusion.

Scientific Methods Applied to Crime Scene Analysis

- The scientific method helps us to find answers to complex questions by providing form and direction to the search. It defines the best explanation given the data, but it is not absolute.
- Criminal investigators routinely define investigative questions, seek and weigh data, develop hypotheses, and make conclusions (Figure 4).
- The scientific method is a circular process, creating an ever-expanding, self-correcting body of knowledge.
- When this body of knowledge develops, the scientific method is the best option to eliminate possibilities rather than to identify a unique answer.
- Therefore, if an analyst needs to solve an issue, he will have to evaluate all the viable hypotheses, test the predictions, and eliminate those that are improbable.

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Scientific Methods Applied to Crime Scene Analysis

Each question answered in this six-step process usually requires another question leading to more answers.

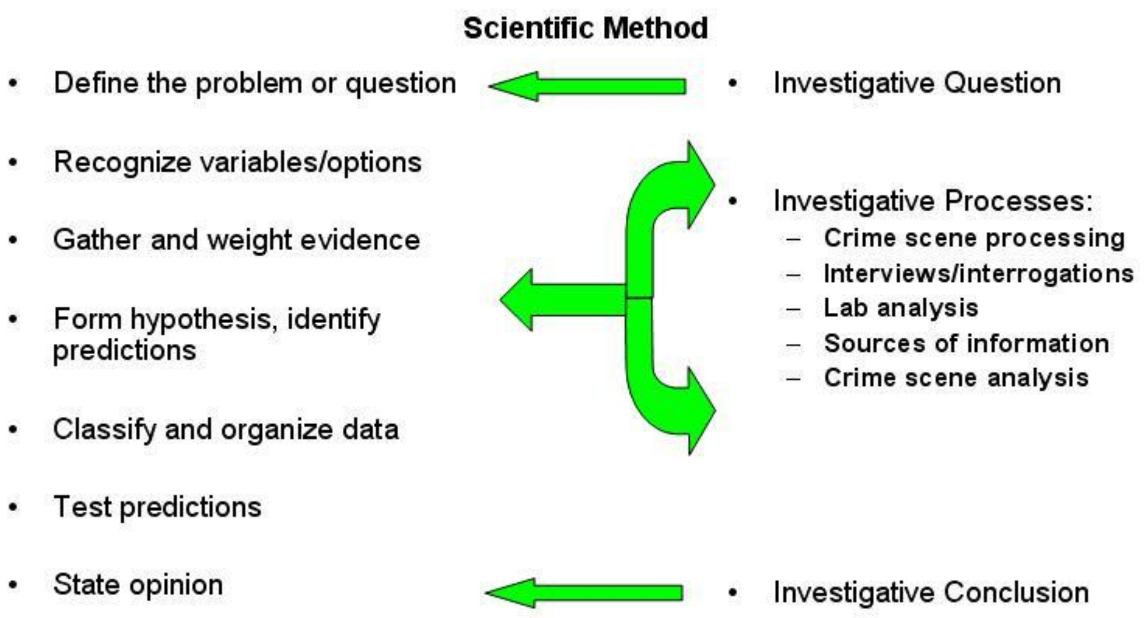

Figure 4. The methods employed by criminal investigators are an integral part of the scientific method.

Scientific Methods Applied to Crime Scene Analysis

- Scientific methodology is the foundation of crime scene analysis.
- It is used in conjunction with a six-step methodology (event analysis) to establish what happened and in what order it happened.
- In effect, a repeating series of questions is asked regarding what the context of each piece of evidence establishes.
- Event analysis only concentrates on physical evidence, not on testimonial/subjective evidence.
- However, the final result of the event analysis will be compared with testimonial evidence and investigative theories to corroborate or discard them.

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Scientific Methods Applied to Crime Scene Analysis

- In criminal investigations the *incident* is the overall situation being investigated. Each incident is made of macro-components referred to as events. Events define gross aspects of the incident.
- Each event is composed of micro-components or event segments. Event segments are snapshots of specific moments in time where specific actions occurred.
- The presence of items of physical evidence and their interrelationship will create a specific event segment.
- Event analysis is always reverse-engineered, starting with crime scene data and working backward to a conclusion.
- It is performed once all the forensic reports are concluded and all the available data have been gathered.

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Scientific Methods Applied to Crime Scene Analysis

The steps of the event analysis are as follows:

- Collect data and establish likely events (e.g., macro components of the crime or the analogy of chapters in a book). Events serve to break the reconstruction down into manageable parts to which specific details can be associated and then processed.
- Using the detailed evidence, establish event segments (e.g., micro components of the crime or the analogy of snapshots). As every aspect of the scene and physical evidence is examined, any number of event segments may be found and documented.

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Scientific Methods Applied to Crime Scene Analysis

The steps of the event analysis are as follows:

- Define associated event segments and events. As the event segments are developed, the analysis must look for associations between event segments and events, breaking the mass of data into manageable pieces of information.
- Order and sequence the associated event segments. Reconstruction considers specific actions that occurred during a crime and the order in which they occurred. This chronology of sequencing between every event segment can be identified. The chronology of event segments can be defined as absolute (timing aspects) or relative (sequencing of event segments in relation to one another).
- Audit the information to resolve conflicts. Auditing is the process of looking beyond the obvious with the purpose of validating or refuting previous conclusions.

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Scientific Methods Applied to Crime Scene Analysis

The steps of the event analysis are as follows:

- Determine a final order of the events and event segments. The information provided by the event segment analysis will give the basis for reordering the events.
- Flow chart the incident. The final product of event analysis is a defined outline of what can objectively be concluded as having occurred during the incident.

Event analysis provides a backdrop that the investigative team can use to test investigative theories and evaluate testimonial evidence. It is very important to note that the scientific method is best for excluding things rather than identifying the unique right answer.

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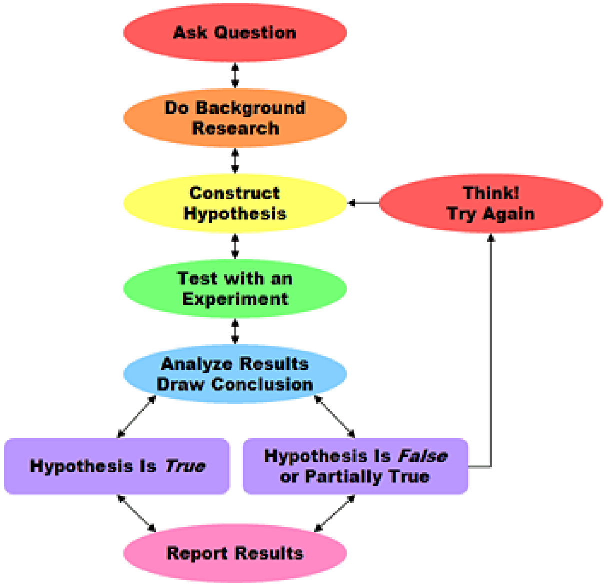
Scientific Method Overview

Scientific methods provide a guide for scientific research. They give steps on how to develop your research. There are different models of the scientific method, but they all include the same concepts and help focus scientific research. A typical model can range from six to eight components.

- Asking or defining a question
- Researching the question
- Forming a hypothesis
- Developing and performing the experiment
- Collecting the data
- Analyzing the data
- Writing the conclusion
- Communicating the results



http://www.sciencebuddies.org/science-fair-projects/project_scientific_method.shtml

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Asking or defining a question

Choose a question that can be tested. The question should be specific. It can be based on observations, and you may have to gather information before you decide on your final question.

Researching the question

Use books, journal articles, manuals, magazines, newspapers, etc. See who may have already studied your hypothesis or research.

Forming a hypothesis

Using an educated guess, state what is expected to happen. An experiment must be used to test the hypothesis. For a basic hypothesis for younger students, the experiment should have only one variable. A variable is defined as a value that changes.

Developing and performing the experiment

Test the hypothesis, with one variable and the rest as controls (values that do not change). The experiment either supports or disproves the hypothesis. Retest the experiment and document all the steps taken.

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Collecting the data

Keep a lab notebook with all the details of the experiment including data and measurements. Tables are a good way to organize data. Make sure everything is labeled clearly, including tables. If there is a mistake, write it down. Do not leave anything out.

Analyzing the data

Look at the data collected. Compare and contrast the information. Use graphs, tables, and charts to visually review the data.

Writing the conclusion

Describe what conclusions can be drawn from the results. State if the results support or disprove the hypothesis.

Communicating the results

Communicate the results by PowerPoint, poster, or written paper. Be conscious of the type of audience who will be reviewing the scientific research.

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Then take a look at the website below.
http://www.quia.com/cb/37429.html

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http://piperpages.wikispaces.com/file/view/Scientific_Method_Flipbook.pdf/163487913/Scientific_Method_Flipbook.pdf

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End of Module 1

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