The Scientific Method

Objectives

1. To understand the central role of hypothesis testing in the modern scientific process.

2. To design and conduct an experiment using the scientific method.

3. To learn how to summarize and draw conclusions from data.

Introduction

Science is often described as a way of knowing about the natural world (the word science has its origins in the Latin verb for knowing) and most dictionaries define science as a body of knowledge dealing with facts and/or truths about the natural world. The emphasis is on the body of knowledge and on facts, with the implication that absolute truth is involved. This is often how science is taught in schools, and how science is conveyed to the general public. Ask a scientist if these definitions are reasonable, however, and most would not agree with them. For scientists, science is a process. It involves gathering information that increases the collective knowledge and understanding of the facts, relationships and laws, of nature. At the same time, they recognize that this understanding is tentative, not absolute, and subject to change as new discoveries are made.

Three principles form the basis for modern scientific practice:

1. The principle of unification – the simplest explanation of complex events is considered the best; also known as the law of parsimony.

2. Causality is universal – irrespective of where an experiment is repeated, the results are always the same.

3. Uniformity of nature – the future resembles the past so what we learned yesterday will apply tomorrow.

The process of science is an extension of the problem solving process most people use every day. We try to identify cause and effect relationships and presume that what happened in the past has a high probability of occurring in the future. We ask ourselves questions about our daily experiences, often proposing tentative explanations of the phenomena we observe, which we try to confirm by further observation. We interpret newly gathered information in the light of previous experience and are always making decisions about whether our explanations are right or wrong. We are building experience from the past and applying it to the future.

The origin of the modern scientific process lies in the logical methods of Aristotle. Aristotle proposed three principles that should be applied to the study of natural phenomena:

1. Collect observations about natural phenomena.

2. Compare and contrast the observations.

3. Develop a summary of the observations.

Scientists may not strictly follow Aristotle's principles but all start where Aristotle started, with observations of nature or by reading reports of others who have made observations of nature. After gathering information a scientist then asks questions based on this information. The quality of the questions depends on the quality of the gathered information; good questions only come from good information.

The next step is one of the least understood steps in the process – the development of a hypothesis. Simply put, a hypothesis is a tentative answer to one or more of the questions identified in the previous step.

Forming a hypothesis involves studying events until the scientist feels safe in predicting that future events will follow a certain pattern resulting in an identifiable outcome. In forming a hypothesis, assumptions are stated and a tentative explanation proposed that links cause and effect.

A key part of any hypothesis is that it must be falsifiable, that is, it must be possible, by experimentation, to demonstrate the hypothesis is either true or false. Experiments test how useful a hypothesis is at predicting cause and effect relationships. If experiments demonstrate that a hypothesis is not useful for predicting outcomes, the hypothesis would be declared false and discarded. However, if a hypothesis cannot be proven false by experimentation, it is considered tentatively true and useful, but it is not considered absolute truth. This is because scientists recognize that another experiment in the future may show the hypothesis to be false, even though they cannot think of one at the moment. It is important to recognize that science does not deal with absolute truths but with a sequence of probabilistic explanations that when added together give a tentative explanation of natural phenomena. Scientific knowledge advances as false ideas, expressed as hypotheses, are rejected through testing by experimentation. Hypotheses that are not falsified over many years, and are useful in predicting outcomes, are elevated to the level of theories or principles. Examples of theories include Newton’s gravitational theory, the theory of atomic structure, Einstein’s theory of relativity, and Darwin’s theory of evolution. Each of these theories has proved useful in predicting outcomes over time and, thus far, has not been proven false by experimentation.

Hypotheses are formed in mutually exclusive pairs called the null hypothesis and the alternative hypothesis. The null hypothesis is stated as a negative and the alternative hypothesis is stated as a positive. For instance, in studying the movement of planets around the sun, a null hypothesis might be that Newton’s theory of gravity is not useful in predicting the locations of the planets in their orbits. The alternative hypothesis would be that Newton’s theory of gravity is useful in predicting the locations of the planets in their orbits. These two hypotheses are mutually exclusive; they cannot both be true.

The purpose of making a hypothesis is to make a statement that can be proven false if data were available. Experiments provide the data and are, therefore, the means for testing a hypothesis. In designing an experiment to test a hypothesis, predictions are made on the basis of the correctness of the hypothesis, that is, if the hypothesis is true, then predictions based on the hypothesis should also be true. Converting a hypothesis to a prediction involves using a deductive reasoning approach in the form of an if-then statement: if a hypothesis is true, then this will happen when an experimental variable is changed. (The scientific method is often referred to as the hypothetico-deductive reasoning method as a consequence.) When the experiment is performed, and the experimental variable is changed, the response is observed. If the response corresponds to the prediction, the hypothesis is supported and accepted; if not, then the hypothesis is falsified and rejected.

Experimental design is probably the most time consuming phase of the scientific process. A great deal of thought must be given to the design of the experiment to be certain that the variable to be tested can be tested and that no other variable could influence the outcome. The independent variable is the variable which is altered during the experiment; it is the cause. The dependent variable is the effect; it should change as a result of changing the independent variable. Control variables are also identified and kept constant during the experiment. The effect of these variables on the dependent variable is generally not known, but it is reasoned that keeping them constant stops them from altering the dependent variable and interfering with the interpretation of the results of the experiment.

To determine that the changes in the dependent variable are indeed due to changing the independent variable, scientists include a control group in the experiment as well as the experimental group. The control group undergoes all of the changes the experimental undergoes *except* the change in the independent variable. It can be reasoned, then, that any change seen in the experimental group that is not seen in the control group must be due to changing the independent variable.

After defining the variables to be measured it is important to decide how to measure the variables. Measurements can be quantitative (numerical and absolute) or qualitative (categorical and subjective); both require a standard of measure. The metric system has been adopted as the international standard for science. It is important to decide over what range the independent variable should be varied. For example, most of life exists in a temperature from 4^oC to 40^oC. It would be unproductive to do an experiment that varies the temperature outside this range as most organisms will die if exposed to these temperatures for prolonged periods of time. Finally, the number of repetitions of the experiment that need to be done to firmly establish cause and effect needs to be decided. It is generally accepted that 3-4 repetitions are adequate, but in dealing with biological systems, where an inherent amount of variation is expected, the more repetitions performed, the greater the confidence in the outcome.

Once the data have been collected they are analyzed to determine if they falsify or support the null hypothesis. Conclusions based on this analysis state whether the null hypothesis is acceptable or not and discuss the implications of that decision.

If the experimental data are consistent with the predictions based on the null hypothesis, the hypothesis is supported, but it is not considered to be proven absolutely true. It is only considered to be provisionally true. If the hypothesis is in a popular area of research, other scientists may independently carry out experiments to test the same hypothesis. A hypothesis that cannot be falsified, despite repeated attempts to do so, will be accepted by others, over time, as probably true. On the other hand, if the data are not consistent with the predictions based on the null hypothesis, the hypothesis is rejected and the alternative hypothesis is supported.

Modern science is a collaborative activity with people interacting in numerous ways. Whenever a scientist reviews the work of others in journals or works with others as part of a team, they help each other with the design of experiments and interpretation of data gathered by experimentation. Once a hypothesis has been tested and the results are judged to be significant, the results of the study are shared with others. This is accomplished by writing an article for a scientific journal or by making a presentation at a scientific meeting. In either case, the author shares the preliminary observations that led to the forming of the hypothesis, the data gathered from experiments that tested the hypothesis, and the conclusions drawn from the interpretation of the data. This information becomes public knowledge and is carefully reviewed by other scientists to determine if there is a flaw in the logic or if it represents a valuable contribution to the field of study. This open discussion makes science self-correcting; the only hypotheses that survive this carefully examination and become part of the common knowledge of science are those that are robust and well supported by experimental data.

Reaction Time

A reaction is a voluntary response to the reception of a stimulus. The word voluntary implies that your conscious mind initiates the reaction. Catching or hitting a ball requires that a message travel from the cerebral cortex to the motor neurons. The time required for this transmission to result in the action of the muscle is called the neuromuscular reaction time.

Several factors affect reaction time. Among them are the time it takes for the message to travel to the receptor, the time it takes for the receptor to process the message, the time it takes for the brain to process the information and make a decision, and the time it takes for the message to travel toward the brain and back to the effector. Last, there is the time it takes the effector to respond.

In today’s lab you will create a hypothesis, design an experiment to test it, conduct the experiment, summarize the data, and come to a conclusion about the acceptability of the hypothesis. Working in groups of four, you are to develop a hypothesis relating to the topic of neuromuscular reaction time. This is easily measured in the lab by determining how quickly a person can catch a falling meter stick. The distance the meter stick drops before being caught can be converted to time and is a measure of the person’s reaction time.

Procedure

1. Have one member of your group (the subject) sit with both feet on the floor. This individual holds the thumb and forefinger of one hand apart, as if to grasp something.

2. A second member of the group (the experimenter) then holds the meter at the top end so that the bottom is just above the subject’s thumb and forefinger. The bottom is the end with the low numbers.

3. The experimenter announces that the meter stick will be dropped within the next ten (10) seconds. The meter stick is dropped without any further warning.

4. The subject watches the meter stick and attempts to catch it between thumb and finger when it is dropped.

5. Measure the distance from the bottom of the meter stick to the subject's thumb and finger, in centimeters, and record this.

6. After a few practice drops, record the distance for ten (10) drops of the meter stick in table 1.

7. Calculate the average distance for the ten drops and convert this distance to a time in seconds using table 2.

8. Repeat this procedure for all four members of your group.

Some trials may result in times greatly different from the others. Should these be included in computing the average distance (and time)? Is one set of ten (10) measurements enough to determine a person's reaction time?

Table 1.

	Subject 1 Name:	Subject 2 Name:	Subject 3 Name:	Subject 4 Name:
Drop 1				
Drop 2				
Drop 3				
Drop 4				
Drop 5				
Drop 6				
Drop 7				
Drop 8				
Drop 9				
Drop 10				
Average Distance (cm)				
Reaction Time (sec)				

Table 2. Fall in centimeters versus time.

Fall Distance (cm)	Fall Time (sec)
0	0.000
5	0.100
10	0.142
15	0.174
20	0.201
25	0.225
30	0.246
35	0.266
40	0.284
45	0.301
50	0.318
55	0.333
60	0.348
65	0.362
70	0.376
75	0.389
80	0.402
85	0.414
90	0.426
95	0.438
100	0.449

Using the Scientific Method

Your assignment now is to create a scientifically answerable question regarding reaction times in individuals with different characteristics and to express this as a testable hypothesis. You will then design an experiment to test your hypothesis, collect the data, analyze, and come to a conclusion about whether to accept or reject your hypothesis. **(NOTE: Your instructor may choose to do this part as a class exercise, with each group contributing to the class results.)**

As you completed the previous exercise, you may have thought about the things that affect reaction time. Start your discussion of this assignment by summarizing your group's collective knowledge about neuromuscular reaction time. Are reaction times the same for all people or could they vary by athletic history, gender body size, age, level of distraction, manual dexterity, left versus right hand, or other factors?

Group Knowledge:

Summarize the group knowledge and observations about factors that influence reaction time.

Group Summary:

Write down 3 or 4 scientifically answerable questions that your group has about reaction times in people with different characteristics.
Group Questions:

Select the best question from the list above and restate it as a prediction (**HINT: If …... then …….**)
Group Prediction:

Use this prediction as a basis for forming a testable pair of hypotheses – a null hypothesis and an alternative hypothesis – and write them below.
Null hypothesis:

Alternative hypothesis:

Now devise an experiment to test your null hypothesis that involves dropping and catching the meter stick. This should be a controlled experiment that will collect evidence that would prove the null hypothesis false. To expedite the process, you may consider the data you collected above (see table 1) as the control data for your experiment. Design your experiment to collect data with respect to the reaction time variable you chose above. Which variable is to be your independent variable (the variable that invokes the response)?

Which variable(s) is(are) your dependent variable(s), the one(s) that are the effects?

What variables will be controlled and how will they be controlled?

How many measurements, of what type and over what time frame, will you need to make?

Write out a set of instructions for carrying out the experiment and perform the experiment on all four members of your group. Record the results in table 3 below. In the space below the table write a brief description of each subject with respect to age, gender, athlete, and left- or right-handed.

Table 3. Experimental results

	Subject 1 Name:	Subject 2 Name:	Subject 3 Name:	Subject 4 Name:
Drop 1				
Drop 2				
Drop 3				
Drop 4				
Drop 5				
Drop 6				
Drop 7				
Drop 8				
Drop 9				
Drop 10				
Average Distance (cm)				
Reaction Time (sec)				

Description of Subjects:

You should now collect together the data that needs to be analyzed. Fill in table 4 below by transferring the relevant information from tables 1 and 3.

Table 4.

	Subject 1 Name:	Subject 2 Name:	Subject 3 Name:	Subject 4 Name:
Control Reaction Time (table 1)				
Experimental Reaction Time (table 2)				

The data you have collected can be analyzed a number of different ways. Subjects can be grouped according to any one of the characteristics you have included in your descriptions to see how the independent variable you chose affects individuals showing that characteristic. Write a few sentences that summarize the trends you see in the data and the differences between the different groups.

Now return to the hypotheses that you made at the beginning of the experiment. Compare them to the experimental results. Must you accept or reject the null hypothesis? What data most influenced your decision? If you demonstrated that there is a difference in reaction time between two groups, how can you decide if it is a significant difference?