University of Phoenix Material

The Scientific Method

The Scientific Method is an approach to acquiring knowledge in science.

STEPS OF THE SCIENTIFIC METHOD

1. Recognize a question or a problem.
2. Develop a hypothesis.
3. Design and perform an experiment to test the hypothesis.
4. Analyze the data and reach conclusions about your hypothesis.
5. Share knowledge with the scientific community (your class).

EXAMPLES

1. Recognize a question or a problem.

   A good scientist is observant and notices things in the world around him or herself. He or she sees, hears, or in some other way notices what is going on in the world and becomes curious about what is happening. This can include reading and studying what others have done because scientific knowledge is cumulative. In physics, when Newton came up with his Theory of Motion, he based his hypothesis on the work of Copernicus, Kepler, and Galileo as well as his own, newer observations. Darwin not only observed and took notes during his voyage, but he also studied the practice of artificial selection and read the works of other naturalists to form his Theory of Evolution.

   For centuries, people based their beliefs on their interpretations of what they saw going on in the world around them without testing their ideas to determine the validity of these theories — in other words, they did not use the scientific method to arrive at answers to their questions. Rather their conclusions were based on untested observations.

   Among these ideas, since at least the time of Aristotle (4th Century BC), people (including scientists) believed that simple living organisms could come into being by spontaneous generation. This was the idea that non-living objects can give rise to living organisms. It was common “knowledge” that simple organisms like worms, beetles, frogs, and salamanders could come from dust, mud, etc., and food left out quickly “swarmed” with life.

   Observations: It was known that soup that was exposed to the air spoiled — bacteria grew in it. Some people claimed that there was a “life force” present in the molecules of all inorganic matter, including air and the oxygen in it that could cause spontaneous generation to occur, thus accounting for the presence of bacteria in spoiled soups. Even when briefly-boiled soup was poured into “clean” flasks with cork lids, microorganisms still grew there. Containers of soup that had been boiled for one hour were sealed remained sterile. Boiling for only a few minutes was not enough to sterilize the soup.

   The scientist then raises a question about what he or she sees. The question raised must have a “simple,” concrete answer that can be obtained by performing an experiment. For example, “How many students came to school today?” could be answered by counting the students present on campus, but “Why did you come to school today?” could not truly be answered by doing an experiment.

2. Develop a hypothesis.

   Hypothesis:

   This is a tentative answer to the question, a testable explanation for what was observed. The scientist tries to explain what caused what was observed.

   Question: Is there indeed a “life force” present in air (or oxygen) that can cause bacteria to develop by spontaneous generation? Is there a means of allowing air to enter a container, thus any life force, if such does exist, but not the bacteria that are present in that air?

   Hypothesis: There is no such life force in air, and a container of sterilized broth will remain sterile, even if exposed to the air, as long as bacteria cannot enter the flask.

   In a cause and effect relationship, what you observe is the effect, and hypotheses are possible causes. A generalization based on inductive reasoning is not a hypothesis. An hypothesis is not an observation, rather, a tentative explanation for the observation. For example is that I might observe the effect that my throat is sore. Then I might form hypotheses as to the cause of that sore throat, including a bacterial infection, a viral infection, or screaming too much at a ball game.

   Hypotheses reflect experience with similar questions (“educated propositions” about cause) and the work of others. Hypotheses are based on previous knowledge, facts, and general principles. Your answer to the question of what caused the observed effect will be based on your previous knowledge of what causes similar effects in similar situations. For example, I know that colds are contagious, I do not know anyone with a cold, I was at the ball game yesterday, and I was doing a great deal of yelling while I was there, so I think that caused my sore throat.

   Multiple hypotheses should be proposed whenever possible. One should think of alternative causes that could explain the observation (the correct one may not even be one that was thought of!) For example, maybe somebody sitting near me at the ball game had a sore throat and passed it on to me.

   Hypotheses should be testable by experimentation and deductive reasoning. For example, throat culture and other tests yielded no signs of a bacterial or viral infection, I have no fever or other signs or symptoms, and the doctor says my vocal cords are “swollen” in a way that would indicate overuse.

   Hypotheses can be proven wrong or incorrect but can never be proven or confirmed with absolute certainty. It is impossible to test all given conditions, and someone with more knowledge, sometime in the future, may find a condition under which the hypothesis does not hold true.

3. Design and perform an experiment to test the hypothesis.

   Next, the experimenter uses deductive reasoning to test the hypothesis.

   Inductive reasoning goes from a set of specific observations to general conclusions: I observed cells in x, y, and z organisms; therefore, all animals have cells.

   Deductive reasoning flows from general to specific. From general premises, a scientist would extrapolate to specific results: if all organisms have cells and humans are organisms, then humans should have cells. This is a prediction about a specific case based on the general premises.

   Generally, in the scientific method, if a particular hypothesis/premise is true and “X” experiment is done, then one should expect (predict) a certain result. This involves the use of “if-then” logic. For example, if my hypothesis that my throat is sore because I did too much screaming at the ball game is true and if a doctor examines my vocal cords, then he or she should be able to observe that they are inflamed, and as the inflammation heals, the sore throat should go away.

A prediction is the expected results if the hypothesis and other underlying assumptions and principles are true and an experiment is done to test that hypothesis. For example, in physics if Newton's Theory of Motion is true and certain "unexplained" measurements and calculations pointing to the possibility of another planet are correct, then if I point my telescope to the specific position that I can calculate mathematically, I should be able to discover or observe that new planet. Indeed, that is the way in which Neptune was discovered in 1846.

Prediction: If there is no life force and *broth in swan-neck flasks should remain sterile even if exposed to air because any bacteria in the air will settle on the walls of the initial portion of the neck. Broth in flasks plugged with cotton should remain sterile because the cotton can filter bacteria out of the air.*

4. Analyze the data and reach conclusions about your hypothesis.

Then, the scientist performs the experiment to see if the predicted results are obtained. If the expected results are obtained, that supports (but does not prove) the hypothesis.

In science when testing, when doing the experiment, it must be a controlled experiment. The scientist must contrast an "experimental group" with a "control group." The two groups are treated exactly alike except for the one variable being tested. Sometimes several experimental groups may be used. For example, in an experiment to test the effects of day length on plant flowering, one could compare normal, natural day length (the control group) to several variations (the experimental groups).

When doing an experiment, replication is important. Everything should be tried several times on several subjects. For example, in the experiment just mentioned, a student scientist would have at least three plants in the control group and each of the experimental groups, while a "real" researcher would probably have several dozen. If a scientist had only one plant in each group, and one of the plants died, there probably would be no way of determining if the cause of death were related to the experiment being conducted.

The experimenter gathers actual, quantitative data from the subjects. For example, it is not enough to say, "I'm going to see how the dog reacts in this situation." Rather, in that experiment, the scientist might have a list of certain behaviors and record how often each of the dogs tested exhibits each of those pre-defined behavior patterns. Data for each of the groups are then averaged and compared statistically. It is not enough to say that the average for group "X" was one thing and the average for group "Y" was another, so they were different or not. The scientist must also calculate the standard deviation or some other statistical analysis to document that any difference is statistically significant.

Testing: Broth was boiled in various-shaped flasks to sterilize it. As the broth and air in the containers cooled, fresh room air was drawn into the containers. None of the flasks were sealed — all were exposed to the outside air in one way or another.

Control group — Some flasks opened straight up, so not only air but any bacteria present in that air could get into them.

Experimental group(s) — some flasks had long, S-shaped necks (swan-neck flasks), and others were "closed" with cotton plugs. This allowed air to enter these flasks, but the long, swan neck or the cotton balls filtered out any bacteria present in that air. The long necks were subsequently broken off some of the swan-neck flasks.

Replication — several flasks were used in each of the groups.

Data: Broth in flasks with necks opening straight up spoiled (as evidenced by a bad odor, cloudiness in previously clear broth, and microscopic examination of the broth confirming the presence of bacteria), while broth in swan-neck flasks did not, even though fresh air could get *it. Broth in flasks with cotton plugs did not spoil, even though air could get through the cotton. If the neck of a swan-neck flask was broken off short, allowing bacteria to enter, then the broth became contaminated.*

5. Share knowledge with the scientific community (your class).

   Conclusion(s): There is no such life force in air, and organisms do not arise by spontaneous generation in this manner. To quote Louis Pasteur, “Life is a germ, and a germ is Life. Never will the doctrine of spontaneous generation recover from the mortal blow of this simple experiment.”

Scientific Method Case Study

Scientific Method Case Study and Exercise

To give you an idea of how the scientific method works, you are going to go through the steps that we outlined above. You are given the scenario below, and you are to design and conduct an experiment.

Use the scenario below, and solve the problem using Scientific Method.

You notice that the grass around your house is brown, short, and dead. The grass around your neighbor’s house is green, tall, and alive. Use your understanding of the Scientific Method to explain what you have observed.

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