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The Scientific Method

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Preface

Some students have been given the impression by their teacher that wild guessing is a part of science. I have observed middle school students at the science center in response to a question give a series of wild guesses. They would look at my eyes in an effort to detect which guess is correct. Apparently, they had been conditioned to respond to a stimulus. Because, when they saw something that indicated to them that they had guessed correctly, they would then look for an expected reward. Well, the scientific method is not about wild guessing and I really doubt if a scientist can be created using operant conditioning

Sir Isaac Newton said, "I saw further than others because I raised myself onto the shoulders of giants such as Galileo Galilei and Johannes Kepler." Your students should understand that people such as Newton and Einstein studied and understood the intellectual giants of their day and then built upon what they had learned and corrected what was discovered wrong.

If you want your students to become a scientist, they should understand what it means to 'stand on the shoulder's of giants', to build upon what the current scientific leaders have discovered, correct their errors, to understand what it means to expand knowledge using the scientific method and publish. (This certainly does not apply to young students. They would first need to have prerequisite knowledge to understand and that, in most cases, would not happen until high school.)

The Scientific Method

The scientific method is simply a self-correcting process for finding answers to questions. Also, the inductive form of the scientific method can be thought of as focused child's play. It takes two forms: deductive and inductive.

Deductive method: The deductive form arrives at a conclusion by reasoning (the application of principles may substitute for testing) where the conclusion follows necessarily from a premise. It is the mental process of thought experiments and mathematical reasoning.

Rene Descartes, French mathematician and philosopher, 1596-1650, reduced his method of determining the truth into four steps. He was careful to preface by stating that this was his personal method and he was not suggesting at anyone should follow his lead. His caution was likely from a concerned that he may offend those in power and thus suffer the consequences.

First, never accept anything as true that I did not know evidently to be so; that is, carefully to avoid precipitous judgment and prejudice; and to include nothing more in my

judgments than what presented itself to my mind with such clarity and distinctness that I would have no occasion to doubt it.

Second, to divide each of the difficulties I was examining into as many parts as possible and as is required to resolve them best.

Third, to conduct my thoughts in an orderly fashion, starting with the simplest and easiest to know object, to rise gradually, as by degrees, to the knowledge of the most composite things, and even supposing an order among those things that do not naturally precede one another.

Fourth, everywhere to make enumerations so complete and reviews so general that I would be sure of have omitted nothing.

Source: Discourse on Method and Meditations on First Philosophy, Rene Descartes, 1637

Inductive method: The inductive method begins with observations. From these observations a hypothesis is created that is then tested. A conclusion is then drawn from the testing that is next taken though a confirmation process. The conclusion may then be subjected to additional observations and thus another cycle of the inductive method begins until all questions are resolved.

Sir Francis Bacon, 1561-1626, was an English philosopher, scientist and author. Bacon is recognized as the first person to clearly explain induction.

The following is Sir Francis Bacon's comment regarding the alchemist's method. "If a man were to look closely into the works of the alchemists or magicians, he would be in doubt whether he should laugh over them or weep, for the alchemist nurses eternal hope. And when the experiment fails, he lays the blame on some error of his own, feeling that he has insufficiently failed to understand the words of his art or his authors or in his manipulations, he has made some slip of a scruple in weight or a moment in time where upon he repeats his trials to infinity."

Bacon went on to state that from time to time the alchemist would stumble upon some discovery. This is only through pure chance and pure chance is no way to undertake science intelligently. It is from the stumbling of the alchemist that Bacon was motivated to clarify a method that is known now as the inductive method.

Sir Francis Bacon said, "Their are and can be only two ways (inductive and deductive methods) of searching into and discovering truth. The one (deductive) flies from the senses and the particulars to the most general axioms and from these (principles); the truth it takes as fore settled and immovable proceeds to judgment and to the discovery of middle axioms and this way is now in fashion. The other (inductive) derives axioms from the senses and particulars rising by a gradual and unbroken assent, that it arrives at the most general axiom last of all. This is the true way."

Bacon went on to explain that the inductive method begins with observation. From these observations, one draws a tentative conclusion, but then instead of trying to make everything else fit the conclusions; the conclusions become the source of further experiments to test their validity and range of application of each conclusion. This leads to further tentative conclusions that are likewise tested and thus the process of scientific induction proceeds indefinitely.

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Reading what is reported at LessonPlans.com is not science; however, it does become a part of science when you test what has been reported, draw a conclusion and publish.

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1. Whimsy:

a. Whimsy has no prior purpose. If whimsy has purpose, it is only as an after thought.
b. The whimsical process is chaotic. Consequently, it is not repeatable by others and may not even be repeatable by the originator.
c. The whimsical process is capricious. i.e. The capricious process is apt to change suddenly and be unpredictable.
d. Whimsy is not science nor is it whimsical.

2. Scientists using the inductive form of the scientific method have already created a verified knowledge base that answers the fundamental questions. It is this knowledge that can be taught to students and students can be thus expected to learn it.

3. Students can be caused to use the scientific method to discover what scientist has determined to be true for the purpose of practicing the scientific method. (It would be like rediscovering the wheel, where the intent is not the discovery of the wheel but rather practicing the process of discovery.)

These five steps are called the scientific method:

1. Question: What gets hotter in the sun: water in a black cup or water in a white cup?

2. Gather information about the question.

3. Hypothesis: I think that the water in the black cup will get hotter.

4. Testing the hypothesis: Create a test. e.g. Get a black cup and white cup of equal size and fill the cups with an equal amount of water of the same temperature. Place them in the sun for one hour and then measure the water with a thermometer.

5. Draw a conclusion based on test results and report.

A Scientific Method Example: growing seeds in a magnetic field

Scientists hope that an experiment slated for launch on the space shuttle this summer will reveal how plants know up from down.

Part one of the scientific method: forming the question (**hypothesis**).

When gardeners poke a seed into the ground, they never worry in which direction it lays. Give it enough water and food and care, and sure enough, its root will grow downward and its stem will sprout upward -- every time! Lay the seed upside-down, and the root and stem would still find their proper positions.

How do plants do it? We humans know up from down [even with our eyes Closed] because we have a complex organ in our inner ear that senses gravity's pull and then signals the brain. But plants have no such organ. It's a puzzle.

Everyone knows that plants grow toward light, but there must be more to it than that. Trees in northern forests, for example, grow straight up even though the Sun is never directly overhead, and the first stem emerging from a buried seed grows upward through dark soil.

It's clear that gravity must play some role, too. Indeed, scientists know that the direction of gravity's pull is behind many plant behaviors, such as corn crops righting themselves after being flattened by a storm. What's unclear is exactly how plants "feel" gravity and respond to it. What part of a plant senses the direction of gravity's pull? And how is that pull translated into a chemical response that alters the plant's growth?

Part two of the scientific method: **presenting the hypothesis** (There are two in this case)

But, scientists do know enough to suggest two possibilities. First, when the fluid contents of plant cells (called the "protoplasm") are pulled downward by gravity, the pressure exerted on the cell walls might serve as a signal that helps plants distinguish up from down. Second, plant cells contain starch grains, which like protoplasm, drift down when gravity is present. Scientists suspect this might act as a cue, too.

But which is it? A novel experiment slated to fly aboard the space shuttle in July 2002 (STS-107) might reveal the answer.

Part three of the scientific method: **the testing phase**

Karl Hasenstein, principal investigator for the BioTube/Magnetic Field Apparatus experiment, explains: The shuttle will carry a payload of flax seeds to orbit. Once there, a computer-controlled dose of water will start them growing. Unlike flax sprouts growing

on Earth, these won't feel the usual pull of gravity. The protoplasm and the starch grains within their cells will float rather than sink.

Plants have been grown in space before. But this experiment will be the first to subject plants to an "artificial gravity" created by magnets.

The experiment will have a high-gradient magnetic field in the plant growth chamber. Within the cells of the plants, the protoplasm will be essentially unaffected by the magnet, but the starch grains will feel the magnetic force. They will sink to the bottom of the cell as if drawn there by gravity.

Starch grains are not magnetic in the usual sense -- if you held one against your refrigerator it wouldn't stick. But the grains are "diamagnetic," which means they develop a weak magnetic field when other magnets are nearby. The diamagnet's field will naturally oppose that of the nearby magnet -- hence the prefix "dia" -- so the starch grains will be repelled. Although the effect is weak, this diamagnetic response allows researchers to use magnets to move the starch grains.

"By changing only the internal displacement of the starch grains, we can put one of these two arguments to rest," explains Hasenstein, a professor at the University of Louisiana at Lafayette. "If the starch grains are the gravity-sensing trigger, we should see the flaxseed roots curve along the magnetic gradient. And if the pressure on the cell walls triggers the curvature, we should see no response."

Infrared cameras will automatically photograph the germinating roots. Regular cameras can't be used because the chamber will be kept completely dark. The darkness allows scientists to know that the seeds are responding to the magnetic fields, not just growing toward a light source.

Don't bother trying this experiment at home with ordinary refrigerator magnets. Only special "high-gradient" magnetic fields will do. Hasenstein's experiment uses magnets about 50 times more powerful than a typical refrigerator magnet. The magnets have ferromagnetic wedges attached to them, which focus a strong magnetic field into a small area. Around that area, the strength of the field tapers off quickly, creating the "gradient" of field strength that moves the starch grains. High-gradient magnetic fields will be used in two chambers of the experiment, while a third chamber will use a homogeneous magnetic field as a "control."

The lessons learned won't only apply to flax seeds (which were chosen for their small size and their quick, reliable germination). All normal plants have these starch grains, so the results of this experiment will add to our basic understanding of plants in general.

Starch grains or protoplasm? No matter which proves correct, researchers will have lingering questions. For example: "how does the mechanical trigger starch grains to drift downward produce a biochemical response?" BioTube/MFA won't provide all

answers right away, but it is an important first step -- one that will teach us something fundamental about the leafy-green life all around us.

Part four of the scientific method: **results**

(The result has not been published at the time this report was written.)

Part five of the scientific method: **conclusion and reporting**

Here too, this phase of the experiment cannot be completed until the results are known. We will just have to wait until after this phase is completed until we will know the conclusion of the experiment.

Withholding judgment until the results are known is an important part of the scientific method.

Glossary

Terms sometimes interfere with or even block understanding, especially when communicating a concept to students that don't have the terms in their vocabulary. There is also a problem when terms that belong to another method are used to explain the subject method. Consequently, the educator should understand the terms that are unique to the subject and then substitute language that the student understands, being always careful not to interject terms that do not belong.

If you understand that the inductive form of the scientific method is focused child's play. Then you will know that you do not need to explain the inductive form. You only need to stage it and then monitor the process.

You can avoid confusing your students by not mixing terms unique to the deductive method with the inductive method.

attention *noun* : the act or state of attending, especially
through applying the mind to an object of sense or thought : syn. FOCUS

awareness *noun*: having or showing realization, perception or knowledge : syn. COGNIZANT, CONSCIOUS, AWAKE

cause and effect : the relationship between events when the first
causes the second : syn. CAUSAL

conclusion *noun* 1: a final summing up 2 : the act or instance of concluding : syn. RESULT or OUTCOME

constant *noun* something that does not change or is prevented from changing

control *noun*: a part of an experiment that is held as a constant and used to compare with the variable.

control experiment *noun* : an experiment to check the results of other experiments

control group *noun* : the part of an experiment that contains the constant

doubt *adjective* 1: the condition of being objectively uncertain 2 : uncertainty of opinion

experimental group *noun* : the part of an experiment that contains the variable

focus *verb* : the center of activity, attraction or attention : syn. CONCENTRATE

hypothesis *noun* : a tentative assumption that is then tested to determine if it is true or false.

mathematics *noun*: the language of science

observe *verb* 1: to inspect or take note of 2: to make a scientific observation on or of

question *noun* : an interrogative expression used to challenge

prejudge *verb transitive* : to draw a conclusion before full and sufficient testing

principle *noun*: a comprehensive and fundamental law, doctrine or assumption

proposition *noun* : something proposed or offered for consideration or acceptance : syn. PROPOSAL

question *noun* 1: the beginning point for scientific discovery 2: an interrogative question : syn. INQUIRY

reasoning *noun* : the process of drawing an inference or conclusion through the use of reason

repeatable *adjective* : able to go though or experience again

result *noun* 1: something that is a consequence or conclusion 2: something this is obtained by calculation or investigation

tenacious *adjective* : holding fast to a behavioral path : syn. PERSISTENT

test *verb* : a critical examination observation or evaluation

theory *noun* 1: the analysis of a set of facts in their relation to one another 2: the general or abstract principles of a body of fact or science 3: a plausible or scientifically acceptable general principle or body of principles offered to explain phenomena.

variable noun : a known change within an experiment that the scientist is testing.

verify *verb* 1: a process for determining if the experiment is reliable 2: a process to determining if the results are true 3: checking the process for reliability

whimsy *noun* 1: a sudden turn or start of the mind 2: a disposition to change one's mind impulsively 3 : a fanciful or fantastic device, object, or creation

Glossary of Terms Unique to the Deductive Method

axiom *noun* : a general truth widely accepted on its merit : syn. PRINCIPLE

conclusion *noun* 1: to reach and end to reasoning; especially : the inferred proposition of a syllogism 2: the act or instance of concluding

posit *verb transitive* : to dispose or set firmly : syn. POSTULATE

postulate *noun* : a hypothesis advanced as an essential presupposition or premise of a train of reasoning : syn. AXIOM, HYPOTHESIS

premise *noun* : a proposition antecedently supposed or proved as a basis of argument or inference; *specif* : either of the first two proposition of a syllogism from which the conclusion is drawn reductio ad absurdum *noun* : disproof of a theory or an explanatory conclusion by showing an absurdity to which it leads when carried to its logical conclusion

syllogism *noun* 1:a deductive scheme of a formal argument consisting of a major and a minor premise and a conclusion (as in "every virtue is laudable; kindness is a virtue; therefore kindness is laudable") 2 : deductive reasoning

Source: Webster's New Collegiate Dictionary, A Merriam-Webster