A naturalist’s life would be a happy one if he had only to observe and never to write.
What is research?
(from the Middle French recherché meaning “to go about seeking”)

"creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications” (OECD, 2002)

The Scientific Method is used to conduct research in a scientific way.

What is science?
(from the Latin scientia, meaning “knowledge”)

Science refers to a system of acquiring knowledge based on the scientific method, as well as to the organized body of knowledge gained through such research.
“Science is a particular way of knowing about the world. In science,
- explanations are limited to those based on observations and experiments that can be substantiated by other scientists.
- Explanations that cannot be based on empirical evidence are not part of science.”

National Academy of Sciences (1999)
What science cannot do
(after University of California Museum of Palaeontology)

• Deal with supernatural explanations
  *Super is beyond nature*

Characteristics of scientists

The Merton-Ziman norms (Ziman, 2000)
Shared by members of the scientific community.

Communalism
Universalism
Disinterestedness
Originality
Organized Skepticism
CUDOOS (Ziman, 2000)

Communalism
knowledge is public; results published; freedom of exchange of information; responsibility for trustworthiness of works.

Universalism
science is independent of race, color or creed; essentially international.

Disinterestedness
Not subject to personal profit; ideology; expediency; *i.e.* honest and objective.

Originality
Requires research to be novel.

Organized Skepticism
No acceptance on word of authority; free questioning; truth rests on comparison with observed fact.
Universal Intellectual Standards
(Elder & Paul, 1996)

- Clarity
- Accuracy
- Precision
- Relevance
- Depth
- Breadth
- Logic

Critical Thinking
(Scriven & Paul, 1996)

The intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action.
Critical thinking can be seen as having two components:

- a set of skills to process and generate information and beliefs.
- the habit, based on intellectual commitment, of using those skills to guide behavior.

Critical thinking is thus to be contrasted with:

- the mere acquisition and retention of information alone.
- the mere possession of a set of skills.
- the mere use of those skills.
The Scientific Method

“… is a body of techniques for investigating phenomena, acquiring new knowledge, or correcting and integrating previous knowledge”
(Goldhaber and Nieto, 2010)

“A method of research in which a problem is identified, relevant data are gathered, a hypothesis is formulated from these data, and the hypothesis is empirically tested.”
(Random House dictionary, 2014)

Observation, hypothesis, and experimentation

• Observations are fundamental to the Scientific Method.
• Formulation of hypotheses is fundamental to making sense of observations.
Observation

- Science begins and ends with observation.
- Experimentation may follow upon observation, and it results in further observations *i.e.* the results of experimentation.
- Research can be said to consist of systematic observation.

**Commonly-held belief vs. established fact**

Consider . . .
Jean Louis Théodore Géricault (1821) “The Epsom Derby”

J. Cameron (1890) “Great Horses in a Great race”
Palo Alto, 1872

Much debated question of the time:

*Is a galloping horse ever completely aloft?*

- Stanford, a race-horse owner took a position on “unsupported transit” in horses.
- Wanted it proven scientifically and hired the photographer Eadweard Muybridge to provide evidence.
Eadweard Muybridge (1878) “The Horse in motion”

Observation >>> hypothesis 1
A prick in the arm

1979
The WHO declared smallpox an eradicated disease.

Edward Jenner
(1749-1823)

Pioneer of vaccination
“Father of immunology”
Common observation:
Milkmaids do not get smallpox. “Smooth as a milkmaid’s skin”

Jenner hypothesized:
Immunity is conferred by cowpox.

1796
Jenner inoculated a young boy with cowpox material.
The boy did not develop smallpox when later challenged with smallpox material.

Observation >>> hypothesis 2

Something in the water

John Snow
(1813-1858)
The Father of Epidemiology*

*The science that deals with the incidence, distribution, and control of disease in a population
Hypothesis: Incidence of cholera is correlated with contaminated drinking water.
When the Broad St. pump was disabled, deaths dropped dramatically.

Snow’s observations and hypothesis was a major achievement because . . .
the causative microorganism (Vibrio cholerae) was not discovered until 29 years later by Robert Koch.
The John Snow pub, Broadwick St.
Observation >>> hypothesis 3

A pain in the gut
Perth, Western Australia

In the late 70s J. Robin Warren observed through biopsy, bacteria colonizing the stomach in about 50% of patients.

*Helicobacter pylori* associated with gastric mucosa
Warren’s critical observation:

. . . these bacteria were always associated with inflammation close to where the bacteria were seen.

Barry Marshall joined Warren and eventually a previously unknown bacterium *Helicobacter pylori* was discovered in 1982.
Marshall & Warren found:

*H. pylori* present in almost all patients with gastric inflammation, duodenal ulcer or gastric ulcer.

Based on these results, they proposed that *H. pylori* is involved in the aetiology of these diseases...

... in the face of the then idea that stress and lifestyle were the major causes of peptic ulcer disease.

For their work, Marshall & Warren were awarded the 2005

**Nobel Prize in Physiology or Medicine**
“In the fields of observation, chance only favors the prepared mind” — Louis Pasteur

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**Hypotheses and scientific enquiry**

* hypo = under; thesis = an arranging

Critical to the development of science. They bridge
- the known and unknown,
- and past and future expected observations.

- Hypotheses are tentative, explanatory, interpretative generalizations about natural phenomena.
- They arise out of past or present observations, experimentation, and scientific thinking.
- They are subject to **confirmation** or **verification**, which is done by testing.
Hypotheses

Hypotheses are generally derived by inductive and deductive reasoning.

Deduction

- Inference by reasoning from general to the particular (Oxford dictionary).
- Application of a proven and accepted law to a specific situation (Lindsay, 1995).

Induction

- Inferring a general law or principle from the observation of particular instances (Oxford dictionary).
- Logical process of assembling facts until a conclusion, usually a generalization, is reached (Lindsay, 1995).
Deductive or inductive reasoning?

“When I kick a ball in the air, it always returns to the ground. So whenever someone kicks a ball in the air, it will return to the ground.”

“The rate at which a ball falls back to the ground depends on the force of gravity. On a planet with twice the gravitational force of earth, all things being equal, there will be less time to catch a ball before it hits the ground.”

The null hypothesis
Predicts no difference between comparison groups or association among tested variables.

The alternative hypothesis
Predicts either a simple difference (two-tailed hypothesis) or a difference in a particular direction (one-tailed hypothesis)
Examples

Null hypothesis
There is no association between smoking and lung cancer.

Alternative hypotheses

Two-tailed
There is an association between smoking and lung cancer.

One-tailed
There is a positive association between smoking and lung cancer.

The nature of hypotheses

- Hypotheses set up expectations for subsequent observations.
- They join given conditions to predicted consequences and are inherently conditional and predictive.
- Therefore, when accurately stated, they are predictive if-then statements.
Metapyride has been extracted from the roots of the Sasquach tree.

Animals have been known to eat roots of the Sasquach tree.

Saquach-root eating animals seldom fall sick.

The leaves of the Sasquach tree are edible.

The leaves of the Sasquach tree are edible.

Sick animals have been known to recover after eating leaves of the Sasquach tree.

Metapyride can be extracted from the Sasquach tree.

If animals are not given metapyride, they could get sick.
Metapyride is extractable from the Sasquach tree.
Sick animals are deficient in metapyride.
Normal animals have never been seen to eat leaves of the Sasquach tree.
If animals having normal levels of metapyride in their bodies eat leaves of the Sasquach tree then they will fall sick.

The leaves of the Sasquach tree are edible.
Sick animals have been known to recover after being administered a drug called metapyride.
Metapyride has been extracted from the Sasquach tree.
If sick animals are fed leaves of the Sasquach tree, they may recover.

Hypotheses and experiments

- Experimental findings do not prove hypotheses. Hypotheses are confirmed, supported, substantiated, or verified.
- Confirmation can be accepted only as long as the hypothesis continues to be confirmed. Therefore, hypotheses are forever open to disconfirmation.
- Therefore science is constitutionally provisional and uncertain. No generalization, conclusion or finding is immutable.
The testability of hypotheses

Consider the statement “All swans are white”. If, from observation a bird-watcher:
• sees a white swan.
• and another, and another, and so on
• the bird-watcher may conclude that “All swans are white.”

But it would not be possible to observe all the swans in the world.
So what do we make of the statement? The statement is still testable because ...

... in continued observation, if a single counterexample (a black swan) were seen ...

it can be concluded that the statement is not true i.e. NOT ALL swans are white.
The statement is falsifiable.
Karl Popper and Falsifiability

The less possible it is to disprove a proposition the more it is capable of being believed.

A scientific theory or hypothesis has the important characteristic that it is capable of being subject to experimentation that could show it to be untrue i.e. it is falsifiable.

Falsifiability

is the logical possibility that an assertion can be shown false by an observation or a physical experiment.

That something is "falsifiable" does not mean it is false; rather, that *if* it is false, then this can be shown by observation or experiment.
Consider . . .

“There are little green men on the moon, but when as soon as they are observed, they turn invisible.”

Is this proposition falsifiable?

Are hypotheses always required?

*Not all experiments test hypotheses e.g. surveys; observations.*

*However,*

- there is a reason for, and expectation from the work.
- a hypothesis lies within that reason and expectation.
Consider:
A survey of the birds in a particular bush environment.

- Would a reader find a paper reporting this work interesting or easy to assess?
- What possible reasons were there for the study?
  - The possibility of finding new species?
  - Finding out if the crop you want to introduce in that area will be pollinated by the local bird population.
  - A census to record variety prior to clear felling of the native trees in the area.
- A purpose and direction for the work becomes clearer when a hypothesis is derived from the above.

Flow in the Scientific Method

- **Observe some aspect of nature**
  (a tentative description consistent with the observations)
- **Use hypothesis to make predictions**
- **Test predictions (experimentation)**
- **Return repeatedly to testing until there are no discrepancies between theory and experiment**
- **Accept**
- **Reject**
- **New hypotheses**
- **Other observations**
Characteristics of the Method

- Unprejudiced.
- Repeatability.
- Conclusions are not subject to influence by state of mind, religious belief, and/or subject of the investigation.

The Method and How Science Works

- The Method lies at the core of a much larger process that is iterative and integrative.
- The following is a view of “How Science Works” (University of California Museum of Paleontology, 2011) that shows more complexity than is usually depicted in explanations of the Scientific Method.
Sources


