Scientific Methods

There are many ways to work on scientific problems. They all require common sense. Beyond that, they all display two features that are characteristic of science:

- Skepticism. Good scientists use highly-critical standards in the judging of evidence (data, claims, and theories).
- Tolerance of uncertainty. Scientists often work for years - sometimes for an entire career - trying to understand one scientific problem. This often involves finding facts that, for a time, fail to fit into any coherent pattern and that even may support mutually contradictory explanations.

Although scientific methods are as varied as science itself, there is a pattern to the way that scientists go about their work. Scientific advances begin with observations.

- A census of the members of a species in some habitat is an observation.
- The readings on the display of a laboratory instrument are observations.

But science is more than a catalog of facts. The goal of science is to find **an explanation for why the facts are as they are**. Such an explanation is a **hypothesis**.

Testing Hypotheses

A good hypothesis meets several standards.

- It should provide an adequate explanation of the observed facts.
- If two or more hypotheses meet this standard, the simpler one is preferred.
- It should be able to **predict** new facts.

So if a generalization is valid, then certain specific consequences can be **deduced** from it.

The null hypothesis

Experimental science often involves setting up an experimental treatment and - at the same time - a **control**. Then one compares the results of the experimental treatment with the results in the controls. If there is a difference, what is the probability that it is due to chance alone; that is, the experimental treatment really had no effect?

The hypothesis that the experimental treatment had no effect is called the **null hypothesis**. Most workers feel that if the probability (designated p) of the observed difference is less than 1 in 20 ($p < 0.05$), **then** the null hypothesis is disproved and the observed difference is **significant**.

But significance is not proof. In fact, hypotheses can never be proven to be absolutely "true" in the sense that a theorem in geometry can. The most we can say is that there is a high probability that the hypothesis provides a valid explanation of the phenomenon being studied. Hypotheses that are supported by many observations come to be called **theories**.

Reporting Scientific Work

Science is a communal activity. Only as new facts and hypotheses are taken up by the entire community of interested scientists do these facts and hypotheses become part of science.

Therefore, one of the major responsibilities of scientists is to see that their work is reported to all those who might be interested. Often this is done by word of mouth when scientists of similar interests gather together at meetings. But to be assured of a permanent place in the scientific edifice, the work is reported in a scientific report submitted to a scientific journal.

In most cases, the scientific report (colloquially called **paper**) will not be accepted for publication until it has been approved by several knowledgeable scientists from other laboratories who serve as **referees**. Often they will suggest editorial changes or even **additional experiments that should be done before the paper is accepted for publication**. The scientific report usually follows a standard plan; it is divided into several sections as follows.

1. **Introduction.**

This section describes **<u>the scientific question or problem that was the subject of the investigation</u>**. Introductions usually have four common **moves** (elements):

    1. Topic (establishing the field). It indicates the specific subject of the report, the nature of the problem and its significance, and gives some theory and key definitions.
    2. Background on the topic (summarizing previous research). Here the authors say what has been done, where, when (historical background), and who did it (references).
    3. Background on the situation (preparing for present research). It gives information about the current status of the subject and the situation that brought about the need for the report. For example, if there were a gap, some problem, or conflicting data about some new technology, which brought about the need for the research.
    4. Purpose and situation (introducing present research). Here, the report indicates why it was written, for whom, and for what purpose (the main and secondary objectives).

2. **Materials and Methods.**

Here are precisely described the materials used (e.g., strains of organism, source of the reagents) and all the methods followed. The goal of this section is to give **<u>all the details necessary for workers in other laboratories to be able to repeat the experiments exactly</u>**. When many complex procedures are involved, it is acceptable to refer to earlier scientific reports describing these methods in greater detail.

3. **Results.**

Here the authors report what happened in their experiments. This report is usually supplemented with graphs, tables, and photographs.

4. **Discussion.**

Here the authors point out what they think is the significance of their findings. This is the place to show that the results are compatible with certain hypotheses and less compatible, or even incompatible, with others. If the results contradict the results of similar experiments in other laboratories, the discrepancies are noted here, and an attempt may be made to reconcile the differences.

5. **Acknowledgments.**

In this brief but important section, the authors give credit to those who have assisted them in the work. These usually include technicians (who may have actually performed most of the experiments!) and **<u>other scientists who donated materials for the experiments and/or gave advice about them</u>**.

6. **References.**

This section gives a careful listing of **<u>all earlier scientific work referred to in the main body of the scientific report</u>**. Most of the references are to other scientific reports. Each reference should provide enough information so that another person can locate the document. This means that each reference should include the name(s) of the author(s), the journal or book in which the report appears, and the year of publication. In the case of scientific journals, the volume number in which the scientific report appears and the page number on which the scientific report begins should be included. Sometimes the full title is given as well, although scientific reports often have such long titles that this is omitted from the reference.

7. **Summary or abstract.**

This section includes only the essence of the other sections. It should be as brief as possible, telling the reader what the goal of the experiment was, what was found, and the significance of the findings. The abstract is often placed at the beginning of the paper rather than at its end.

Source: edited and modified (***moves in introductions***) from two articles originally published in **Kimball's Biology 2001.**