# The Scientific Method

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The purpose of science is to find out about the world and understand how it works. Science has been very successful in discovering interesting and useful things, but knowledge is only valuable if it is reliable and trustworthy. To ensure that it has these qualities, scientists use an agreed set of procedures, assumptions and standards when they are making their investigations. This is called the *Scientific Method*.

The *Scientific Method* is a manifestation of human curiosity and is the way science works. It applies to all subjects from quantum physics and cosmology, through chemistry and biology, to psychology and sociology. Because it is so successful, many people believe it to be one of the greatest intellectual achievements of mankind.

*The aim of science*

A scientific investigation should yield new information which increases human understanding. The information must be new, otherwise there is little point in trying to obtain it. It must increase understanding of the world, and not be just a set of descriptive statements. Consider the following definitions:

Knowledge = a collection of facts (information)

Understanding = the interpretation of knowledge

It is not enough simply to know things – understanding comes from putting facts together, interpreting them and looking at things from a new perspective.

A further property of scientific information is that it is applicable in more than one situation. The information gained from an experiment or investigation is only valuable if it can be extended to other circumstances. Information with this quality enables sound predictions to be made. It allows us to anticipate the results of our actions and those of the changing events in the world around us.

It is wise to remember that our knowledge of the world is temporary and uncertain: what we believe to be true today may later turnout to be wrong when we reinterpret what we know or have additional information. If this were not so, there would be no point in trying to find out more. The *Scientific Method* allows for this uncertainty; in fact, uncertainty is what it depends on. This is why new discoveries open new questions and why there is never a final answer.

*The process of science*

The *Scientific Method* offers a practical, flexible framework which can be used in lots of different types of investigation. By sticking to it, scientists can be sure that their results will be reliable. They can also be sure that other scientists will trust and understand what they have found out. Application of the *Method* does not guarantee that results will be useful or interesting, but it does ensure that the correct outcome will be achieved.

Many of the world's greatest philosophers and scientists have turned their minds to analysing, understanding and describing the *Scientific Method*. For this reason, the language used may sometimes be unfamiliar and it can be difficult to relate the abstract theory to the everyday process of scientific enquiry. Fortunately, it is possible to translate the philosophy into a practical and easy-to-follow scheme which will guide investigations and experiments.

Here, we will first present the *Scientific Method* in theoretical terms. Then we will list the steps to be followed when applying it to a real investigation. Later, we will look at some of the hidden assumptions underlying the *Method*. These will help to explain why it is so useful and successful.

*The Scientific Method as theory*

**Figure 1** illustrates the *Scientific Method* in the form of a flowchart. Science often starts in an undefined, subconscious way, perhaps as a result of inspiration or feelings or just out of curiosity. Whatever its origin, a scientific investigation quickly finds its place within some sort of *paradigm*.

A *paradigm* is a theoretical framework, made up of currently accepted knowledge and understanding. Research takes place within a paradigm because it uses an agreed set of assumptions, language, techniques and methodology. Usually, the results of research extend the paradigm by adding non-controversial information to it. Just occasionally, new information or a radical re-interpretation of existing information mean that the paradigm has to be rejected and replaced by something completely new. Such events, called "scientific revolutions", are considered to be dramatic points in the history of science. Celebrated examples include the recognition that the planets move around the Sun rather than the Earth (the "Copernican Revolution") and Darwin and Wallace's appreciation that species appear by evolution rather than by design. Smaller, less perceptible adjustments ("paradigm shifts") occur all the time, but these may only be recognised in retrospect.

One's academic training as a specialist in a given area of science (molecular biology, plate tectonics, polymer chemistry, linguistic evolution, criminal psychology…..) involves a great deal of time spent assimilating the current paradigm. Often, the best scientists are those who are prepared to distrust and challenge these assumptions. Good scientists also ensure that apparent oddities or exceptions to a general rule are not discarded as “inconvenient” results. Such anomalies may turn out to be the foundation for challenging an existing dogma or perception of the way the world works.

*The Scientific Method in practice*

Figure 1 and its legend describe the process of a scientific investigation in abstract, theoretical terminology, and it can be hard at first to see what this has to do with practical science. **Table 1** shows how the process can be translated into a series of practical steps. These provide a framework for the everyday work of scientific research and discovery. You can safely use them when planning and carrying out your own research. In **Table 2**, an hypothetical example has been mapped onto the framework to illustrate how the steps translate into action.

*What is an hypothesis?*

To carry out useful research, you need to have a goal. Because you are hoping to find out something new, it is convenient to identify the goal in the form of a question which expresses what you hope to discover. **Table 3** lists various kinds of research goal and the sorts of question that might be asked.

In most of the pure and applied sciences, the first step in an investigation is to turn the question into a *working hypothesis*. The hypothesis can then be tested for its validity. Even where the research appears to be largely descriptive, the most productive approach is often to tackle it by “hypothesis testing”. Much research work in non-scientific fields can also be approached in this manner, although it may not be usual to do so.

The hypothesis is a useful means of identifying whether the right question has been set. More importantly, it ensures that the goal is clear and that you have a coherent method for working out how and when a reliable answer will be obtained.

To use this approach effectively, it is necessary to be quite clear about what a scientific hypothesis is and what it is not:

*An hypothesis is*

- a supposition, a conjecture
- a proposition assumed for the sake of argument
- a theory to be either retained or disproved by reference to observations
- a provisional explanation for something
- uncertain
- only useful if it is capable of being wrong.

*An hypothesis is never:*

- reliable
- self-evident
- certain
- inevitably correct
- the last word
- the final answer
- the complete explanation
- the only explanation.

[In mathematics, "hypothesis" has a slightly different meaning: it is a theory to be either proved or disproved by logic, deduction, mathematical induction or reference to observations.]

*Building a scientific hypothesis*

To make a working hypothesis, *begin* by re-writing the question, this time as a general, substantive statement. The statement should express your new idea as a single, short sentence which is simple and unambiguous. If doing this proves problematical, make sure that you know precisely what the question is and then try to imagine what sort of answer(s) it might have. Be sure, as well, that the question is simple and straightforward: testable hypotheses cannot be constructed from complex, vague or ambiguous questions. Here are some examples of generic statements suitable for use in working hypotheses:

P is caused by....
Q depends on....
R only happens under conditions of....
The rate of change of S is proportional to....
T exists because...
Most people believe that...
The outcome of U would be more useful if...

Notice that these are now statements, not questions. Provided some appropriate definitions and discriminators are applied to the words, they can only be classed as true or false.

*Next*, your working hypothesis needs a counterpart, called the Null Hypothesis ($H_0$). This describes how things are to be if the new idea expressed in the working hypothesis turns out to be wrong. It represents "no change" from the current position in terms of knowledge and understanding or, alternatively, "no difference" between one condition and another. Your working hypothesis is, by definition, speculative and uncertain; if it is incorrect, what remains must represent the status quo, with no advance in knowledge. In fact, it is this Null Hypothesis which will be examined in your experiment, so your original working hypothesis now becomes known as the Alternative Hypothesis ($H_1$).

Once you have defined a working hypothesis and reformulated it as $H_0$ and $H_1$, you can check it for validity by using the following questions

1. Is it testable (can it be falsified, could it be wrong)?
2. If it turns out be wrong, will you be content to accept $H_0$?
3. Is it the simplest explanation consistent with all the known facts?
4. Is it appropriate to the context?
5. In describing how things are, does it move from the specific (the instance you are investigating) to the general (all possible instances of the phenomenon)?

The answer to all of these should be “Yes”. If any of your answers is “No” or “not sure”, you have some more thinking to do.

You should also ask the following questions:

6. Is it the only possible explanation consistent with all the known facts? (Think of as many alternative hypotheses, consistent with 1-4 above, as possible; be prepared for surprises.)
7. Does it imply a causal relationship which will be justified by the evidence available? (Remember: correlations may suggest, but do not prove, causality.)

When you are happy with the answers to these seven questions, you can go ahead and design the rest of your investigation.

*Where do controls fit in?*

The purpose of a control is to provide a comparison. Experiments involve tracking what happens to dependent variables (parameters) when independent variables (factors, treatments) are altered. It is essential to know what would have happened to the dependent variables if the independent variables had not been altered. Controls provide this information.

In many experiments, the control is simply a set of observations made with the independent variables held constant. It will show what normally happens, show whether there is any underlying change or drift, and provide a measure of the inherent variability in the system. This is often called a *negative control*.

In other experiments, especially those in which you need to know if the independent variable has the expected magnitude of effect or any effect at all, it may be necessary to have a *positive control*. This is a control which is deliberately designed to produce a change, so that the effect of the independent variable can be measured in comparison to it. Experiments involving a positive control usually have a negative control as well: taken together, the two controls can show what the limits of the system are.

With either type of control, it essential to keep the conditions the same as those of the rest of the experiment. In fact, most controls are best done at the same time as, and in parallel to, the rest of the experiment. Where the dependent variable is open to subjective interpretation, however slight, it is wise to design a blind experiment in which the operator does not know which is the control and which is the real treatment. This approach is routine in medical experiments but it is good practice in many other sorts of study as well.

It is sensible to put effort and quality time into designing your controls. Controls are non-transferable and it is *never* safe to assume that the outcome of one run of an experiment will be the same as that of another. Indeed, economising on controls is a recipe for disaster: it is a good way to miss, obscure or invalidate the most important, interesting and revealing results.

*Statistics and criteria of discrimination*

The analysis of experimental results usually involves comparing what happened to the dependent variable in the control with what happened to it in the presence of the independent variable (a treatment). The questions to be asked are: How can I tell if the difference I have found is real or not? Is it a large enough difference to be meaningful? Would I be likely to find a similar difference if I ran the experiment again?

To answer these questions, it is necessary to have at least the following two pieces of information:

a) how much inherent variation is there in the system (i.e. how much variation occurs in the absence of the independent variable)
b) what is to be recognised as a difference.

The first of these is estimated statistically; it involves replication and calculations. The second can be a matter of convention (perhaps agreed by those working within the paradigm) but it must at least involve a change which is greater than the variation measured in a).

One common procedure in the biological sciences is to calculate whether the outcome of the experiment (the difference between the treatment and the control) could have been due to chance, rather than to the effect of the independent variable. The result of this calculation is expressed as an inequality, such as $P<0.05$. In this statement, P is the probability (the likelihood) that the result was due to *chance* and not to the independent variable. The value 0.05 is a discriminant point, agreed by convention. It expresses the probability as a fraction. So, $P<0.05$ means that the likelihood that the result could have been the result of chance is less than 0.05 in 1 (or 1 in 20, or 5 in 100, or 5%). There is a close link between variability and probability: the bigger the inherent variation of the system, the more likely it is that a small difference in mean value between two samples is due to chance.

Scientists and statisticians will usually accept the $P<0.05$ level of discrimination as *significant*, i.e., as indicating that the independent variable really did have an effect. If P gets even smaller ($P<0.01$ or even $P<0.001$), it becomes even more likely that the independent variable had an effect. Finding a significant P value usually leads to the rejection of $H_0$ and the acceptance of $H_1$, depending of course on how the hypothesis has been formulated.

Statistical tests, designed to calculate variability and probabilities, have a charm and complexity all of their own which will not be discussed here. In terms of the *Scientific Method*, however, it is essential to know when designing an experiment which tests will be used. This is because they need appropriate amounts of replication and may have to account for complex interactions between variables. Their use also involves assumptions about the shape and arrangement of the data, and this may need to be established before the real work of the experiment starts. If the experiment is inadequately or incorrectly designed, the statistical test may give a misleading conclusion or no conclusion at all.

> *Tip*: Do not shy away from thinking about statistics in the hope that your investigation will work out okay in the end. It won't. You will end up with a pile of data that is impossible to analyse. Effort will be wasted if you do not plan ahead!

*Deduction, induction and the logic of science*

Returning briefly to the philosophy of science and to the formal process illustrated in Fig. 1, it is helpful to consider what actually takes place when research is carried out.

Sometimes, research involves *deduction*. This is the process of moving from a set of existing beliefs, facts or statements to new ones, purely by logic. The key feature of deduction is that the result is an inevitable consequence of the starting events and conditions. Mathematicians and logicians use this process a great deal, especially when deriving proofs and corollaries to theorems. In this form, deduction is effective and reliable: the statements contained in a mathematical proof have absolute validity in any situation in which the starting conditions apply. Mathematicians can therefore make reliable statements about events, including those in the future, about which they have no direct experience.

Scientists use deduction less formally (and less reliably), as a way of making conjectures which can then be tested by experiment. Unfortunately, deduction by itself is not a particularly efficient or creative route to scientific progress. The main reason for this is that the knowledge available to start with may be inadequate or wrong and the conditions may change in unexpected or unseen ways. However, like mathematicians, what scientists really want to do is make statements about the world which are both correct and widely applicable. The conclusions from an experiment may help them to do this, but there is a problem. It is called the problem of induction.

*Induction* is the process of moving from a single observation or result to a general statement about how things are. In other words, it is the assumption that what has been found on one occasion will be found on others. A typical experiment in science is a study of just one event on one occasion, or of a few similar events replicated under tightly controlled conditions. Clearly, it is not possible to study all possible occurrences of the event: an experiment is really a sample of a population of events (this is the language used by statisticians).

Because the scientist has inadequate knowledge at the start of the investigation, it becomes impossible to predict that all events in the future will turn out the same way. Increasing the number of events studied and finding a similar outcome may increase the likelihood that the population is uniform, but doubt always remains. In any case, for all practical purposes, experiments seldom get beyond even a very tiny sample of all possible events (and events in the future cannot be sampled!). There is no way of telling whether the sample is representative of the population. It is also impossible to know that the future will be like the past.

This difficulty is what makes induction dangerous and unreliable as a strategy for scientific progress. It means that positive information is not reliably transferable and that moving from the specific to the general is risky. It also means that science cannot really *prove* things; it cannot be used to conclude that something is definitely, certainly, always, invariably so.

*Resolving the problem of induction*

The *Scientific Method* provides an effective way round the problem of induction. It does so by operating not with proof but with *disproof*. We have already seen how this happens: the working hypothesis is reformulated so that it has a "null" counterpart ($H_0$), and the experiment tests whether the application of some particular variable shows $H_0$ to be wrong. Note that this attempt to invalidate $H_0$ is an attempt at disproof; it is *not* an attempt to prove the correctness of $H_1$. $H_1$ is simply what remains after $H_0$ has been rejected: it advances knowledge by becoming the next working hypothesis, capable eventually of being proved wrong.

This approach avoids the problem of induction because it results in general statements about the world built on what is known *not* to be true. If that sounds too negative to be helpful, think of it as a process of demarcation, of setting some boundaries to confident knowledge. Thought of in this way, the scientist is reporting his/her observations and using them to define the current limits of understanding, not to express universal truths. It also means that exceptions to fundamental rules can be incorporated into our understanding, without threatening the whole edifice of existing knowledge.

*Testability (falsifiability)*

Using disproof to avoid the pitfall of induction presents a useful characteristic for defining scientific theories. If $H_1$ is to be the next hypothesis, it must itself be capable of being tested, just as $H_0$ was tested. If you think about it for a moment, you will see that something which can be tested has the possibility of being *wrong*. If something is not open to test, it cannot be trusted (except possibly by religious belief, social convention or emotion). Conversely, if it is not capable of being wrong there is no way of testing it.

Philosophers of science call this the *criterion of falsifiability*. Once again, this sounds like an uncomfortably negative expression, but it fits perfectly with the notion that correctness can never be proven. The word *testability* has the same meaning as falsifiability in this context and can be used if it sounds more acceptable.

The criterion of falsifiability can be applied to theories in two ways. On the one hand, it separates scientific theories (those of astronomy, for example) from non-scientific ones (those of astrology). On the other, it ensures that working hypotheses are realistic in a practical sense: there must be a (theoretically) feasible experiment that can or potentially could be performed. The latter application ensures that science does not rely on beliefs which sound plausible but could not possibly be open to practical examination. Theories which invoke vast arrays of subject matter (for example in molecular sciences, bioinformatics, epidemiology, cosmology, sociology, macroeconomics etc.), amongst others, could typically fall foul of this stricture if great care is not taken.

In fact, most scientists would be uncomfortable with any theory which is not actually testable – an hypothesis which is theoretically testable but cannot be tested for practical reasons (lack of suitable equipment, time, money, skill, manpower etc) is not very helpful.

*Causality*

We have talked above of independent and dependent variables and implied that changes observed in the latter result from changes made to the former. This is known as the *assumption of causality*. In well designed experiments, with proper controls and adequate replication, the assumption that the independent variable was the cause of the observed response may be entirely reasonable and convincing. However, it is as well to realise that the direct link itself has not been proved and that the relationship remains conjectural. Causes are never reliable or inevitable as conclusions. In fact, in some experiments, especially those which look for correlations between variables, the assumption of causality can be dangerously misleading. On the one hand, it may suggest unexpected relationships which turn out to be false, and on the other it may indicate that that one effect is caused by another when in fact they are both separately connected to something else entirely.

*Objectivity in research*

So far, this discussion of the *Scientific Method* has given the impression that science proceeds in a precise, measured and utterly reliable manner, working from conjecture to hypothesis and from experiment to understanding. It is as if a machine could be designed to do science for us, dispassionately, productively and without value judgements. Of course, this is an unrealistic description of what actually takes place. Science it is not like this at all. Missing from this landscape are the people who do the investigations, use the information and think about the world.

Such people (which includes non-scientists and technologists, as well as those directly involved in scientific discovery) operate within, and occasionally beyond, a paradigm as already explained. In fact, paradigms are intellectual constructs – they exist only in the minds of those who create and use them. Paradigms are thus *subjective*, influenced by the views and opinions of their users and practitioners. By the same token, scientific knowledge and understanding are themselves subjective, influenced by all the social, cultural, emotional and irrational determinants that characterise any human activity.

Does this mean that science can never be objective and fully rational? Yes, partly, but not entirely. One essential property of science, which it gets from the *Scientific Method,* is openness. The results of research are not kept hidden: they are published. They become available for others to use and, most importantly, to test. The subjectively-generated information from one scientist's investigation is there for scrutiny, in the public domain, for all to see and understand. Anyone else can criticise it, challenge it, develop or destroy it. Someone else can take hold of it, apply a new set of subjective influences, and see if it still has validity.

That's about as close as we humans can get to objectivity, and it makes good science as reliable as it can possibly be. It is a key reason, perhaps the main reason, why science flourishes in free societies and why it has been so successful as a human enterprise.

Further reading


Ladyman J (2001)
*Understanding the Philosophy of Science*, Routledge

Gauch H. G. (2002)
*Scientific Method in Practice*, Cambridge University Press


(12/03)

**Table 1**. A practical approach to the application of *Scientific Method*

| | | |
|---|---|---|
| 1 | Identify the topic of interest and formulate a question | The question will usually start with "How.."or "Why..". Occasionally, it could start with "Where.. ", "When.." or "Which..", or even with "Who.." or "What..". |
| 2 | Find out what is already known | This usually involves reading published literature. It is essential to be informed and up-to-date, otherwise you may repeat what is already known, ask the wrong question, use out of date information or make avoidable mistakes. |
| 3 | Formulate a precise question | Make the question as specific and unambiguous as possible. It will invariably turn out to be more focussed, limited and constrained than you first thought. |
| 4 | Rephrase the question as an hypothesis | At least two hypotheses are required:<br>$H_0$ – the Null hypothesis<br>$H_1$ – the alternative hypothesis<br>More alternatives ($H_2$ etc.) may be needed. |
| 5 | Identify and isolate:<br>• independent variables ("factors")<br>• dependent variables ("parameters")<br>• possible interactions | *Independent variables* are the things which you will have control over in your investigation. Simple studies have one; more complex studies may have two. Very complicated studies have more than two, but are extremely difficult to design, analyse and interpret.<br>*Dependent variables* are things which you will measure, monitor or assess in your investigation. You have no control over these: they change in response to the independent variables<br>In experiments with more than one independent variable, it is necessary to take account of *interaction*. Interactions need special analysis and their effects can be difficult to anticipate. |
| 6 | Design an experiment to test the hypothesis<br>["Experiment" means whatever investigation is appropriate to the topic. It may be something which generates new data, such as a lab experiment, a field trial or a survey, or it may be an analysis of existing information.] | The elements of design include:<br>• Measurements/observations to be made<br>• Processes to be carried out<br>• Structure (arrangement of independent variables)<br>• Amount and type of replication<br>• Type of analysis to be carried out on the results |
| 7 | Predict all the possible outcomes of the experiment | This is an essential part of the design process. It ensures<br>i) that the hypotheses are testable,<br>ii) that the design is appropriate,<br>iii) that the data are capable of analysis and interpretation. |
| 8 | Perform the experiment | Follow the design (do not change things as you go along, or you may invalidate your hypothesis) and obtain your data.<br>Detailed records of procedures and data must be kept. This is so that the analysis can be carried out effectively but also so that results and conclusions can be historically justified. |
| 9 | Analyse the data | This includes<br>• number crunching to reduce data to its most useful form,<br>• preparation of descriptive statistics, graphs and tables<br>• statistical analysis of variances and probabilities. |
| 10 | Test the hypothesis | Decide whether the null hypothesis has been falsified or not. If it has, accept the alternative hypothesis. |
| 11 | Make a verbose statement of conclusions | This is a rephrasing of the result of the hypothesis test which relates the outcome of the investigation to the original question. |
| 12 | Decide whether knowledge and understanding have been advanced | If advancement has been made, suggest new questions and hypotheses<br>If advancement has not been made, decide whether this is<br>a) because the question was incorrect<br>b) because the investigation was inadequate |
| 13 | Report | Report your investigation and its conclusions so that others may use the information. This completes a circle back to Step 2. It may also create new questions for Steps 1 and 3 |

**Table 2** Hypothetical example of research (with an eponymous organism!)

| | | |
|---|---|---|
| 1 | Identify the topic of interest and formulate a question | Some yeasts cause skin diseases. How do they manage to live on warm skin? |
| 2 | Find out what is already known | Yeasts are known to be heat-sensitive and will die at the wrong temperature. Some yeasts are pathogenic. Some pathogenic yeasts flourish in warm climates. There is a large literature on this. The yeast *Dermophilus hypotheticae* may cause skin irritation but nothing is known about its sensitivity to temperature. |
| 3 | Formulate a precise question | Do *D. hypotheticae* cells divide more quickly at body temperature than at ambient temperature? |
| 4 | Rephrase the question as an hypothesis | $H_0$: The rates of division of *D. hypotheticae* at 20°C and 37°C are the same. Alternatively, *D. hypotheticae* divides more rapidly [$H_1$], or less rapidly [$H_2$] at 37°C than 20°C |
| 5 | Identify and isolate:<br>• independent variables<br>• dependent variables<br>• possible interactions | Independent variable: temperature<br>Dependent variable: growth rate of yeast culture<br>The independent variable is isolated from interactions with time by setting a single period of test (say, 12h)<br>The dependent variable will be indicated by cell number after 12h culture |
| 6 | Design an experiment to test the hypothesis | Plan:<br>• Grow *D. hypotheticae* cells in culture at 20°C and 37°C. Start with 10 identical cultures and set five at each temperature. After12h, count the number of cells in each culture.<br>• Compare the numbers of cells in each group by Student's t test.<br>• Draw a bar chart of mean cell number at 12h in each group. Illustrate variances with standard error bars.<br>Preparation:<br>• Locate a laboratory suitable for the safe handling of *D. hypotheticae*<br>• Use two identical incubators: set one to 20°C and the other to 37°C; ensure that other conditions are optimal for culture of *D. hypotheticae* for 12h.<br>• Establish and validate a method for counting yeast cells.<br>• Take a single stock culture of *D. hypotheticae* and divide into 10 identical smaller cultures on a suitable growth medium. |
| 7 | Predict all the possible outcomes of the experiment | 1) No significant difference between mean cell numbers after culture at the two temperatures<br>2) Significantly more cells at 37°C than at 20°C<br>3) Significantly more cells at 20°C than at 37°C |
| 8 | Perform the experiment | Perform the experiment exactly as specified in 6 |
| 9 | Analyse the data | Calculate the mean number of cells measured in each group (n=5).<br>Estimate Student's t for the data and determine whether the difference between the means has a greater than 1/20 probability of being due to chance.<br>Calculate standard errors and plot data on a bar chart. |
| 10 | Test the hypothesis (using outcomes predicted in 7) | Outcome 1: Retain $H_0$<br>Outcome 2: Reject $H_0$, accept $H_1$<br>Outcome 3: Reject $H_0$, accept $H_2$ |
| 11 | Make a verbose statement of conclusions | *D. hypotheticae* cells divide<br>[Outcome 1] at the same rate when cultured at 37°C or 20°C<br>[Outcome 2] more rapidly when cultured at 37°C than at 20°C<br>[Outcome 3] more rapidly when cultured at 20°C than at 37°C |
| 12 | Have knowledge and understanding been advanced? | Outcome 1: *No*<br>Outcome 2 *or* Outcome 3: *Yes* |
| 13 | Report | From an investigation of the rates of division of *D. hypotheticae* cells in culture at 37°C or 20°C under specified conditions, it is concluded that skin temperature is (*more / less / equally*) suited to the proliferation of this organism, when compared with ambient temperature. |

**Table 3** Types of research goal and their corresponding questions

| Research goal | Question |
|---|---|
| Find out if an idea or speculation is correct | Is it true that....? |
| Measure something which has not been measured before | What is the size of....? |
| Find out how something works or why something happens | What is the cause of....? |
| Model a possible event | What would happen if....? |
| Solve a practical problem | How can… be achieved? |
| Create a useful product or practical solution | How can…. be done, or done better? |
| Investigate an historical event | When and why did it happen? |
| Investigate an historical character | Who caused it to happen? |
| Investigate a significant place | Where did it happen? |
| Test public opinion | What do people think about....? |
| Study a process or policy | What is the effect of…. and how can it be improved? |

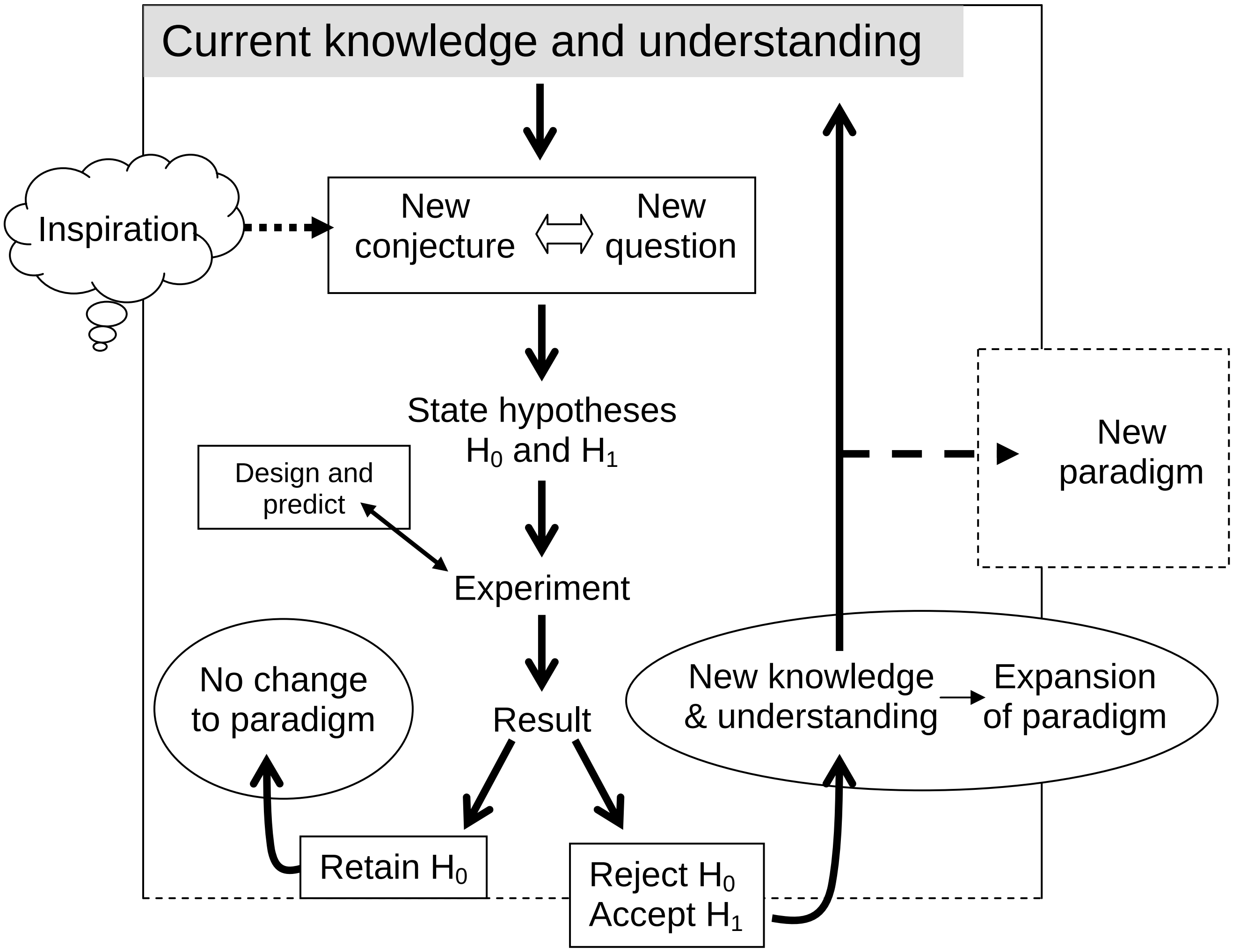


**Figure 1** A schematic representation of the *Scientific Method* in formal terms.

The large rectangle represents the current paradigm, consisting of present knowledge and understanding about a topic or subject area. Accepting that the current paradigm is incomplete, human inquisitiveness leads to conjecture and questioning; often, this process is inspirational and may be influenced by ideas from outside as well as inside the paradigm. Refinement of thought leads to the creation of a well defined, testable hypothesis: $H_0$ is the hypothesis of no difference or no change from current status, whilst $H_1$ is the alternative (there may be more than one of these). An experiment is designed to test the hypothesis (strictly, $H_0$) for validity. The design process is iterative, rests on information supplied by the paradigm and involves the prediction of possible outcomes. The experiment is performed strictly according to the design. The result is analysed and interpreted for its ability to reject $H_0$, often on the basis of the statistical probability that the observed result occurred by chance. If $H_0$ is not rejected, the current status pertains: there is no advance in knowledge or understanding and the paradigm remains exactly as it was at the start of the process. If $H_0$ is rejected, $H_1$ (or another, previously specified, alternative hypothesis) is accepted. In this case, new knowledge and understanding accrue by virtue of the fact that the pre-existing state (represented by $H_0$) has been proven to be invalid in at least one instance (that of the present experiment). The paradigm has consequently to be modified to accommodate and represent the new state. In rare instances, the effect of rejecting $H_0$ may be catastrophic for the current paradigm and a new one emerges. *Note:* the test of the hypothesis occurs at the edge (limit) of, and its rejection falls outside, the current paradigm. A test whose outcome has no possibility of exceeding the current paradigm has no value. In this respect, the concept of confirmatory evidence is unhelpful. All new, testable hypotheses are part of the paradigm until such time as they have been tested and found to be false. Thus the only valid way of extending the paradigm is by rejecting one of its current components.