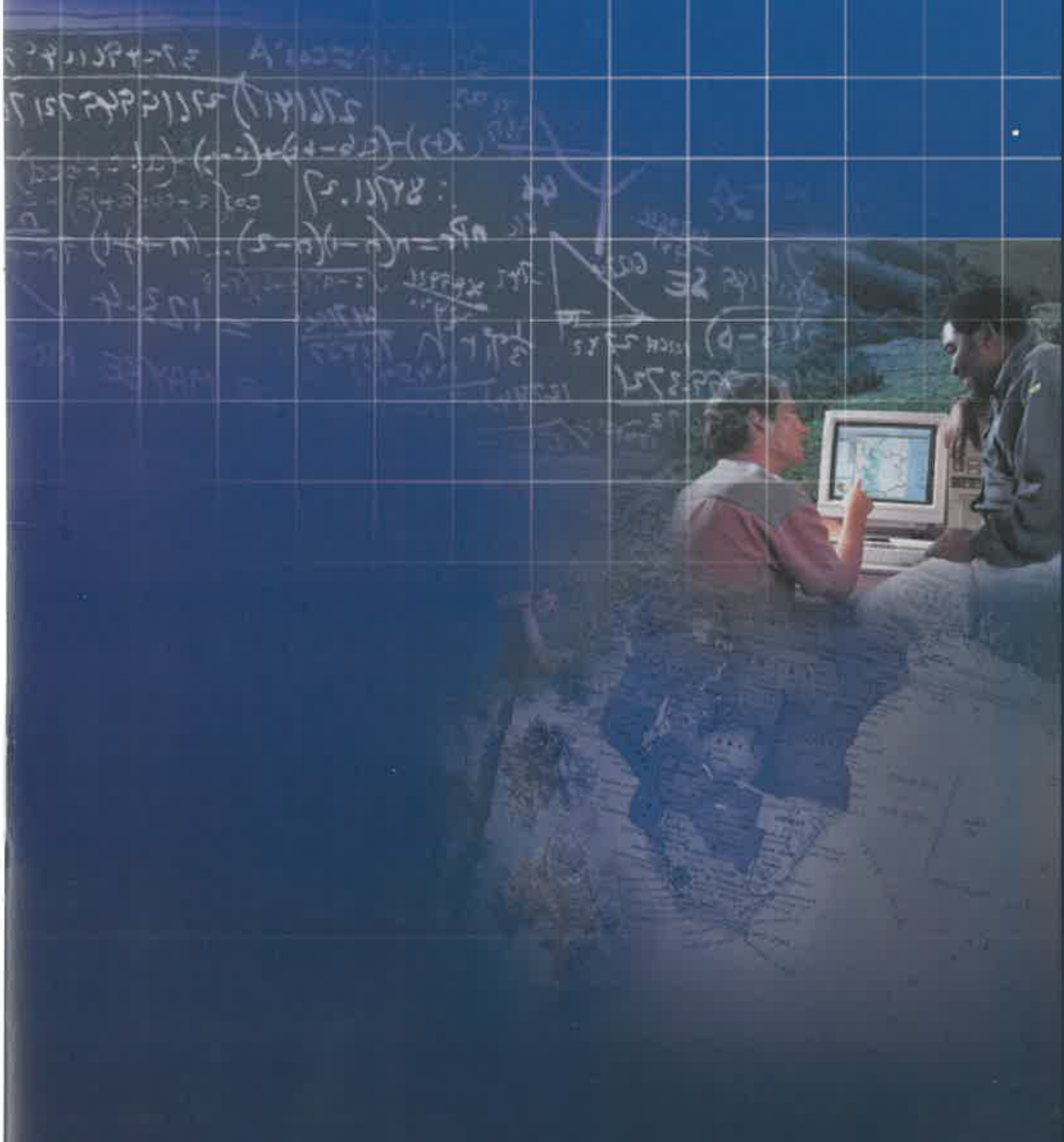
GOOD RESEARCH GUIDE

Second edition

edited by

RJ Scholes

2003



CSIR
Your Technology Partner

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R.J. Scholes

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CSIR

Good Research Guide

Purpose

This guide informs CSIR staff about the standards that they are expected to meet when doing research. Researchers who follow this guide will have satisfied the legal requirement for 'due diligence' in their work.

What is 'good research'?

Good research is objective, verifiable, directed study and analysis, carefully conducted and recorded, and effectively communicated.

Who should use this guide?

All CSIR staff and subcontractors who perform research. This includes scientists, engineers, social scientists and technicians. The word 'scientist' is used throughout to mean any researcher applying the scientific method.

Contents

The scientific method

What is it?

The scientific method is a systematic approach to solving problems and gaining knowledge. It has a long history (Gaardner 1991 gives an easy-to-read overview) and has transformed the world, for better or worse, in the past two centuries.

Why use it?

Applying the scientific method is not the only approach to problem-solving, and it is not always the fastest way. It is, however, the surest way. Its use distinguishes scientists from the many other people offering advice, and qualifies the CSIR for its Parliamentary grant. Its use is not negotiable for CSIR employees while doing CSIR research.

Hallmarks of the scientific research process

Research is 'scientific' if it is both

- predictive, i.e. making a more general statement than the particular observations, thus ultimately concerned with the underlying causes and pattern of the phenomena; and
- falsifiable, meaning that it can potentially be disproved.

Falsifiability

Scientific 'facts' are never proved; they simply fail to be disproved after enough rigorous tests have been conducted that we grow confident in their generality. Statements that cannot, under any circumstances, be tested and disproved are not material for scientific study (Popper, 1959). The requirement that science be falsifiable means that it must be based on observations that can, at least in principle, be repeated. This in turn requires that careful, unbiased observations are made, that methods are recorded and communicated, and that the interpretation is logically consistent.

Eventually most scientific facts, laws or theories are found to be either untrue under particular circumstances, or to be approximations of a more complex reality. This leads to an intellectual crisis, and a breakthrough resulting in a new, more general theory (Kuhn, 1962).

Causality

Science tries to explain everything in terms of underlying mechanisms, which are themselves subject to scientific tests. Science has little to say about ultimate causes (for instance, about the Meaning of Life).

The requirement that all scientific conclusions should be based solely on the data presented plus already accepted findings (ie published in peer-reviewed open literature) leads to a view of the world which is internally consistent and dependent on the minimum set of assumptions. Scientists should have the humility to recognise that their worldview is not the only possible one, and by itself may be incomplete. They should also have the confidence that the scientific method is the most appropriate tool to tackle a wide range of important problems.

References

Gaardner, J. (1991). *Sophie's World*. New York: Farrar Strauss & Giroux.

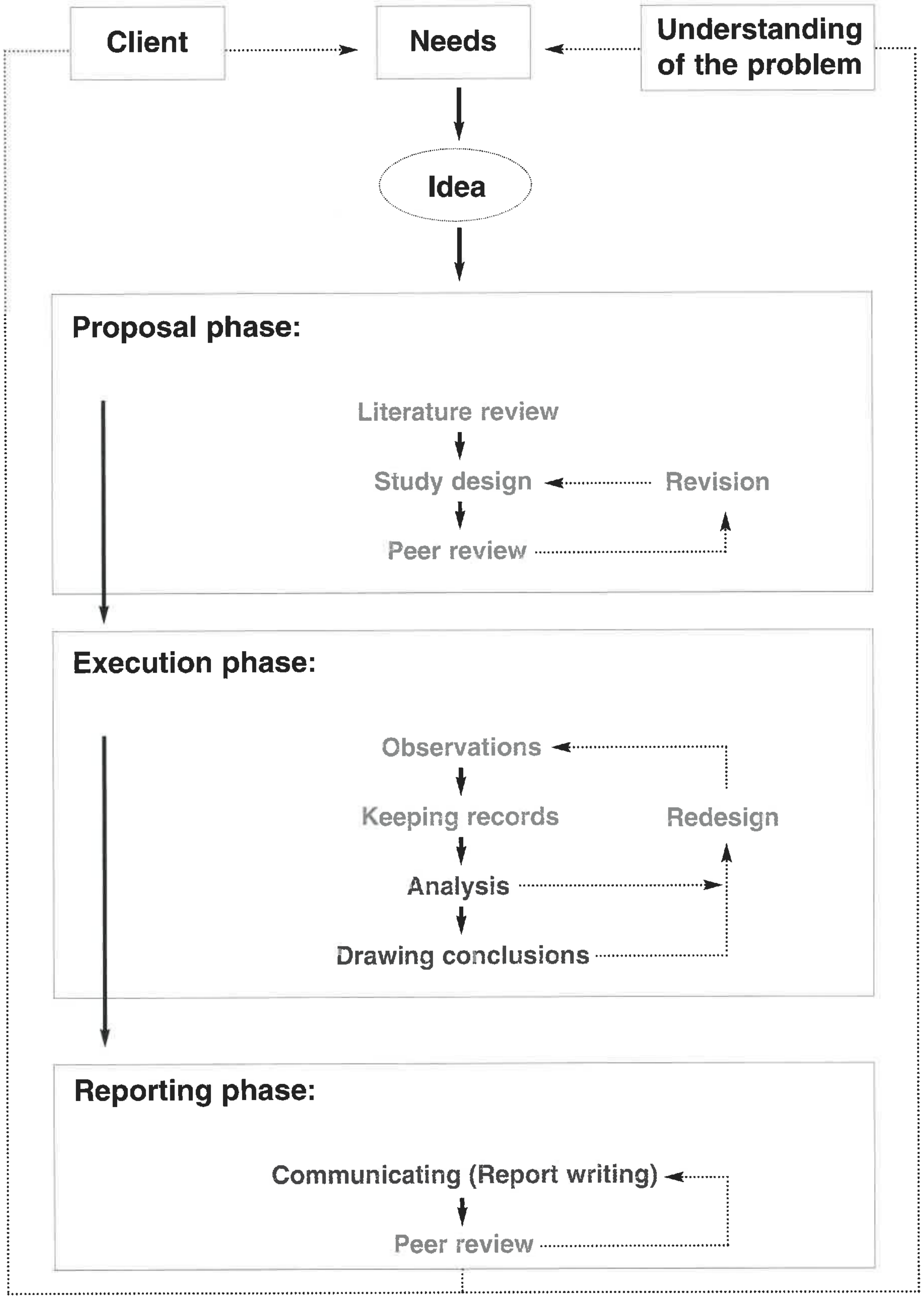
Kuhn, Thomas S. (1962). *The structure of scientific revolutions*. Chicago: University of Chicago Press.

Popper, Karl R. (1959). *The logic of scientific discovery*. London: Hutchinson.

The research process

Steps in the research process

The following diagram summarises the main steps in the research process. Each is addressed in a separate section of this guide.



The initial idea

Creativity in science

Science, like art, is a creative human activity. Unfortunately the scientific method is silent on where to get the bright idea in the first place. No logical procedure leads inevitably to good ideas, but you can create a mental and physical environment that makes them more likely. Good ideas seem to come naturally to people who are interested and immersed in a particular topic, even if they do not have a clear vision of where their research is leading them when they start (for example, read Wilson, 1995).

Stimulating the creation of ideas

Don't work in isolation. Ideas seldom arise in a vacuum - they usually come from reading the literature, talking with colleagues or working on real-world problems. Be reasonably free with your own ideas - it is rare that someone will 'steal' one that is genuinely unique.

Workshops and brainstorming sessions can generate many ideas very quickly. Try to suspend your judgment during the idea-generating period. Logical testing and rejection occur later. De Bono (1992) suggests some techniques to help you create innovative ideas.

Expressing ideas in testable form

Woolly ideas lead to inefficient research. Express ideas as clearly and briefly as possible, as key questions or hypotheses. Split up complex ideas into their components. Beware if your list of key questions is very long; you may be tackling something too large, or not identifying the core issue. Complex interrelations can often be expressed better as a diagram or equation than in words.

Try to get at the essence of the problem, by asking yourself: 'Is it essential that I know the answer to this question to be able to solve the problem?' If the answer is yes, this is a *key question*.

Make sure all your questions are phrased as key questions. Some problems lend themselves to a very formal key question, known as a *hypothesis*, which leads to testable predictions.
For example:

- *Hypothesis:* The world is a sphere.
- *Prediction:* A person travelling in any direction will eventually arrive back at their destination.

Often several *alternate hypotheses* may explain the observed phenomenon. Sometimes it is useful to test the *null hypothesis*, in other words, assuming that an action has no effect. For example, one might propose that the distribution of a particular organism is indistinguishable from a random distribution.

Even if you never look at your hypothesis again, it is useful to go through the discipline of trying to express your ideas as hypotheses during the proposal stage. For more discussion of this topic, see Medawar (1969).

References

De Bono, E. (1992). *Serious creativity: using the power of lateral thinking to create new ideas*. London: HarperCollins.
Medawar, P.B. (1969). *Induction and intuition in scientific thought*. Memoirs of the American Philosophical Society, 75.
Wilson, E.O. (1995). *Naturalist*. London: Penguin.

Designing a study

Mode 1 and Mode 2 research

Classical research, 'Mode 1', is aimed at knowledge production (Gibbons *et al* 1994). Mode 2 research is focussed on the solution of problems arising in society. It uses the best available knowledge, generating it through Mode 1 research if necessary, and combining it with other sorts of knowledge and experience. The problems are typically urgent, and too complex to break down into classical experiments.Thus decisions often need to be taken in the absence of complete knowledge. Modern research organisations are usually involved in both modes. The basic principles of logic, critical treatment of information sources, traceability, honesty with respect to what is known, not known and opinion, good communication and ethics apply in both modes.

Focus: address the question and only the question

The information you collect must be able to answer the question you have posed, with as little doubt as possible.That is why it is important to pose the question clearly and in such a way that it can be tested. Ensure that you record not only the response variable, but also the other factors that may be reasonably be expected to be necessary for interpretation or repetition of the experiment.

Classical experiments

The classic scientific approach to a problem is to conduct a careful experiment in which all factors except one or a few are held constant, and those are increased or decreased by a known amount. This kind of experimental design aims to minimise uncontrolled variation.The method of data analysis used is typically Analysis of Variance (ANOVA) for discrete variables, and regression analysis for continuous variables.

This is still an excellent approach, but is often not applicable in a world of increasingly complex problems. In reality it is often either not possible to separate the variables, or not possible or permissible to manipulate them.

Multivariate, interactive problems

When a problem has many variables it soon becomes impractical to vary each of them, one by one. If the factors interact, the situation is even more difficult, since then they must be varied in all possible permutations. You will probably need to use a 'natural experiment', in other words, rely on the variation that already exists in the sample population to understand the relationships between the variables. In this case variation is to be sought, not avoided.

Analysis can be by multivariate linear or non-linear modelling, if you already have a good idea of the relationships in the data, or a variety of indirect pattern-seeking methods if you do not.

Statistical considerations

When in doubt, ask someone with statistical expertise to help you to design your experiment. No amount of statistical wizardry will extract information from a poorly designed study after it is completed. If there is nobody who can assist in your programme, there are statisticians elsewhere in the CSIR, or in universities or private consultancies.

Further reading

Clark, G.M. (1980). *Statistics and experimental design*. Southampton: Camelot.

Green, R.H. (1979). *Sampling design and statistical methods for environmental biologists*. New York: Wiley.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P. and Trow, M. (1994) *The new production of knowledge: the dynamics of science and research in contemporary societies*. SAGE, London.

Literature survey: What is already known?

Avoid re-inventing the wheel

Research organisations spend a lot of money on information resources such as libraries and computer networks. Use them. Checking what is already known about your topic of interest is time well spent. It is usually quicker and cheaper to modify someone else's approach than to develop one from first principles. This pilot phase, sometimes called 'scoping' the project, should consume 10% to 20% of the total project time and funding.

Ask your colleagues

Your colleagues are often the best people to guide you to useful sources of information, especially semi-formal literature and unpublished studies that you will not find any other way. Don't be afraid to bother senior colleagues; it is part of their role to help you. Discuss your rough ideas informally among your peers before you spend a lot of effort on writing proposals. Consult your librarian - he or she is trained to help you find information that you need.

Keep up to date with the literature

A good working knowledge of the literature in your field saves you a lot of time, wasted effort and embarrassment. Keep up to date by scanning every issue of a few key journals. You may make use of a specialised information service, which alerts you to new articles that match keywords that you provide. Share the effort by exchanging interesting papers with your colleagues. Attend at least one good conference every year, and share your learning by writing a brief trip report when you return.

Literature searches

More formal approaches to finding information include scientific databases, such as Science Citation Index, Physics Abstracts, etc. You can search for articles published on a given topic, or by a particular author. These can be accessed via the CSIR Information Services. Computer searches have largely replaced the paper versions and are quick and powerful. It is most effective to do the search yourself, because only you know all the permutations of the key phrases, and only you can sort the gems from the noise. Most databases include abstracts. When you find a promising one, download the full paper if the CSIR has access to the online version, or order it through the library.

Internet ('Web')

The Internet allows you to connect with a much wider circle of peers, and can get you information that is not yet published. A query placed on an appropriate bulletin board can yield information very efficiently and rapidly. Browsing the World Wide Web in a systematic and directed way can be useful, but can also seduce you into many interesting but unproductive side-alleys. Be wary of information offered on the Internet, since it does not have to pass through any formal peer review process. Only use 'shotgun' emails requesting help from everyone on your mailing list if there is absolutely no alternative.

Make literature searches part of the project

Reviewing the literature takes time and effort. Rather than seeing it as a necessary but boring chore, make it part of the project - either a first deliverable, or a paper to be submitted to a journal. This way you help your colleagues to piggy-back on your effort, and get some credit for it.

Be systematic

You will save yourself a lot of rework by filing your information sources in an organised way, along with all the information you need to reference them. This includes: author/s (name and initials), date of publication, full title, title and editor/s name/s if it appears in a book, journal name and volume if in a periodical, page numbers, publisher and publisher's location (city).

Make brief notes to remind you about the contents of the reference. There are several good software programmes that can handle your reference lists efficiently. Adopt one early in your career.

For informal sources, record the person's name, the date of the communication and some way of communicating with them: an address, telephone/fax number or email address. Ask their permission to be quoted before you do so.

Peer review

Definition

Peer review is a system of self-regulation that has evolved in science. It means that at two important stages - the research proposal and the research report - the work is exposed to people who are knowledgeable in that field for critical assessment. If they find it lacking, the work is unlikely to be funded or accepted until the faults are corrected.

Role of peer review

Peer review is the main quality control system in research. It is intended to keep the research on track. It is very easy to become so locked into your ideas that you miss obvious flaws. Peer review is not perfect, and there are many examples of good ideas that were initially rejected, and flawed ideas initially accepted. Nevertheless, it is a tried and tested approach that is self-correcting and, on balance, has served generations of scientists very well.

When is peer review not appropriate?

Review by peers outside the organisation may sometimes conflict with the need for commercial or national secrecy. In these cases you should look for an acceptable alternative, rather than doing no review at all:

- Use peers within the organisation, preferably one not intimately involved in the project, and perhaps even from another discipline.
- Contract external reviewers, and make confidentiality a condition of the contract.
- Use trusted, recently retired colleagues, who have little to gain from knowing what you are working on.

Getting the most from others

Preparing and reviewing proposals and reports takes time, effort and money. Keep the process efficient by following these guidelines:

Reviewers:

- Do not be needlessly harsh or sarcastic.
- Depersonalise criticisms, for example by saying 'the report claims that...' rather than 'you claim that...'.
- Do not reject anything without providing reasons.
- Where possible, suggest alternatives to things you have criticised.
- Aim to help fix a proposal or report rather than block it, but don't waver on rejecting unacceptable work.
- Do your review promptly.
- Be concise but not cryptic, and as specific as possible.
- Point out minor defects (spelling, typos, etc.) but do not harp on them.

Reviewees:

- Do not take it personally. The work is being reviewed, not you.
- Take reviews very seriously, and do not dismiss them.
- If possible, engage in a constructive discussion with the reviewer, and give feedback on the changes you have made, or why you have not made them. Treat the reviewer as a friend who is helping you produce your best work, not your enemy.
- Plan enough time and resources for the reviewer to do a good job.
- Don't waste reviewers' time and try their patience by sending incomplete or shoddy work. Correcting spelling, style and references is your job, not theirs.

How much effort should be spent on review?

It makes no sense to spend half the project resources on the review process. Scale the level of review to the size of the project and to the consequences of getting it wrong. As a guide, spend a total of 10% of the resources of a small project (a small project is less than one month of work for one person) and less than 5% of large project resources on all stages of the review process. Split the effort half-half between the proposal and reporting phases.

Ethics of reviewing

Ethics in general are discussed later. It is completely unacceptable for reviewers to steal ideas from other people's unpublished work during the review process. The review should be treated as confidential, although you may choose to waive anonymity.

Unbiased observations

Accuracy, precision and bias

Precision is a measure of how close repeated measurements of the same thing are to one another. *Accuracy* is how close their mean is to the true mean of the population. *Bias* is a systematic difference between the observed mean and the true mean. Precision is desirable in science, but accuracy is essential.

Sources of bias

Bias often creeps in because of observer subjectivity. Subconsciously, we sometimes measure certain treatments differently from others, perhaps because we expect the results to conform to some preconceived pattern. To combat this effect, scientists use 'blind' trials where possible, in which neither the researcher nor the subject are aware in advance which treatment has been applied to which sample.

Sometimes there are non-random environmental effects or time-dependent analytical effects. For this reason we randomise experiments and analysis runs (i.e. don't analyse all the replicates of one treatment in one batch - mix them up with other treatments).

Contamination is avoided by scrupulous cleanliness and care during sample collection, transport, storage, preparation and analysis. Blanks help to detect some sources of contamination.

Calibration

Calibration is the process whereby bias is removed. It involves adjusting the method or instrument until the measured value agrees with a reference standard. All instruments require calibration, and new methods need to be calibrated against existing accepted methods. Calibrations need to be ongoing, to check for drift, at a frequency that depends on the stability of the instrument.

Always document the calibrations you have made: the time, the date, the reference standard used, the measurement before calibration and the measurement after calibration. For applications where accuracy is critical, the calibration process must be traceable right back to a *standard* kept in a national or international place of reference.

Controls, blanks, and placebos

The purpose of controls is to detect effects not related to the factors under investigation. A control typically has an unchanged value of the experimental variables you are changing in the treatment. For example, in chemical analysis, a 'blank' is a sample that contains none of the substance for which you are testing . Blanks must be exposed to exactly the same analysis as the rest of the samples. To avoid unconscious bias, controls are sometimes hidden, so that you don't know which they are at the time of analysis. In medical science placebos play a similar role. In some cases, bias can be removed after the experiment by subtracting the value of the control from all the sample values. Scientific trials should always have some form of control, the best that is possible under the circumstances.

Standards

Standards are reference materials with known properties. For instance, you may use a standard set of weights to calibrate your balance, or a standard set of buffers to calibrate your pH meter. Treat them with care to avoid contamination. They are usually expensive, so in some cases you may make up a 'secondary standard', calibrated against the 'primary standard', for everyday use.

References

Anderson, M.A. (1995). *GLP Essentials: A concise guide to Good Laboratory Practice.* Buffalo Grove: Interpharm Press. 51 pp.

How sure are you?

Natural variation and measurement error

In nature, there are always differences (sometimes tiny, sometimes large) between the individuals of a population, or between the properties of a phenomenon measured at different times or places. In addition, scientific observations contain some error. Reducing the error so that true differences can be distinguished from natural variation or 'noise' is a fundamental technique in science.

State your confidence

Scientists must always clearly state how confident they are about the conclusions they have drawn. Good researchers almost never take just one measurement. They report the mean value of several measurements and show the variation (by giving the standard deviation, standard error or the range) and the number of observations it was based on. When you present a graph, illustrate the variation around the sample mean by drawing a bar equal to the standard deviation, standard error, or confidence interval, and state in the caption which of these you are using.

Error

In observing the value of any phenomenon we inevitably include some error, due to the imperfections in our observing methods, and the fact that we are usually only seeing a small sample out of the total population. Good researchers strive to minimise the error by careful observation using the most precise and accurate instruments, and by taking a sample that is representative of the whole and sufficiently large to reduce sampling error to acceptable levels.

Replication

The aim of replication is to assess the variability within a treatment. In conjunction with a control, it allows scientists to separate real effects from natural variation and error. Replicates must be independent of each other: beware of pseudo-replication. For instance, taking one sample and then analysing it three times is not true replication. Independence is usually achieved by randomisation. Sometimes truly random assignment of treatments to samples is not feasible, for instance in some types of 'natural' or social 'experiments' that compare existing differences. Do the best you can to avoid and control hidden biases and effects.

Statistical significance

An observed difference between two sets of results is said to be 'significant' when there is a very low probability that the difference is purely due to chance. The basis of almost all statistical significance tests is a comparison of the observed difference between treatments to the variation within treatments. When reporting the results of such a test, you must say what sort of test was performed, the number of samples in each treatment, and the probability that the difference is purely due to chance. There are conventional codes for this: for instance, the results of an ANOVA test can be reported as $F_{n,m} = 14.1$, $p<0.01$, where n is the degrees of freedom of the 'model', and m is the degrees of freedom of the error term, and p is the probability of getting these results by chance.

The conventions *, ** and *** for $p<0.05$, $p<0.01$ and $p<0.001$ are often used in tables. They correspond to confidence levels of 95, 99 and 99.9% respectively. In general, p values above 0.05 are considered 'non-significant' (ns). Avoid statements such as 'nearly significant' or 'a non-significant trend'; they are scientifically meaningless.

References

Stonehouse, J.M. and Mumford, J.D. (1994). *Science, risk analysis and environmental policy decisions.* Environment and Trade 5. Nairobi: United Nations Environment Program.

Keeping records

Why bother?

There are two main reasons for keeping clear, reliable and traceable records:

1. To ensure that all the relevant information can be assembled to analyse an experiment, or repeat it. Sometimes the study needs to be repeated by someone else, or by yourself years after the event.
2. For legal reasons, to show that you were the first to have a particular idea, or to prove that you performed your professional tasks with 'due diligence'.

Notebook

Keep tidy, up-to-date notes and record raw data in a single, easily located place. Many R&D organisations require every researcher to keep a bound notebook, written in waterproof ink on numbered pages, and signed every few days on each page by the researcher and a witness. CSIR does not require a notebook, but strongly recommends one. No erasures are allowed; mistakes and corrections are crossed out neatly and signed.

Data sheets

It is often convenient to use a standard data sheet for routine observations. Make sure that it includes a date and the observer's name. For outdoor work, print it on coloured paper to avoid glare. Write in pencil or waterproof ink. File the data immediately, preferably with a photocopy or electronic copy somewhere else.

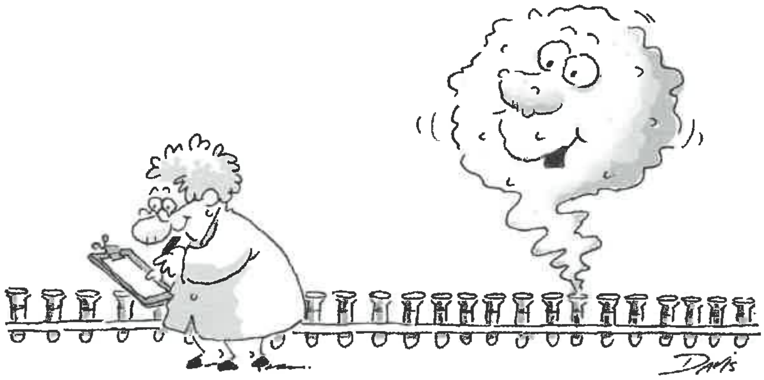
Electronic records

Computer spreadsheets and other electronic records are rapidly replacing paper records. They increase your efficiency, but are susceptible to being lost, corrupted or misinterpreted. If you use them

- keep a paper ('hard') copy as well, if possible,
- ensure that they are 'backed up',
- use non-cryptic filenames and directory names and keep a record of what they are (in your paper notebook, for instance), and
- use the first lines in any spreadsheet or electronic data file to say what it contains, who created it and when, and what each column of data means (including its units).

Archiving and metadata

Both paper and electronic records need to be kept in a safe place and in such a way that they can be located and interpreted later. Keep a photocopy of your notebook and data sheets on file. Back up your hard-drive onto tape or CD. Metadata is information that helps you or others to locate and understand the dataset at a later stage. Follow best practice rules within your Division for recording your project metadata, and make sure that it gets done.



Drawing conclusions

Base conclusions on evidence

Scientific research only draws conclusions that are supported by data with a high level of confidence. This does not mean you may not speculate, but make it clear when you are doing so. You may draw on data and findings from other scientifically tested research, but then you must reference it so that it can be traced. Be wary of 'personal communications', 'unpublished data' and websites, all of which are data sources which have not been tested.

Apply logic

The conclusions you draw must follow logically from the evidence that you offer. The logic must be clear not only to you, but also to whoever is reading your report. Where the data permit another interpretation, you should mention it.

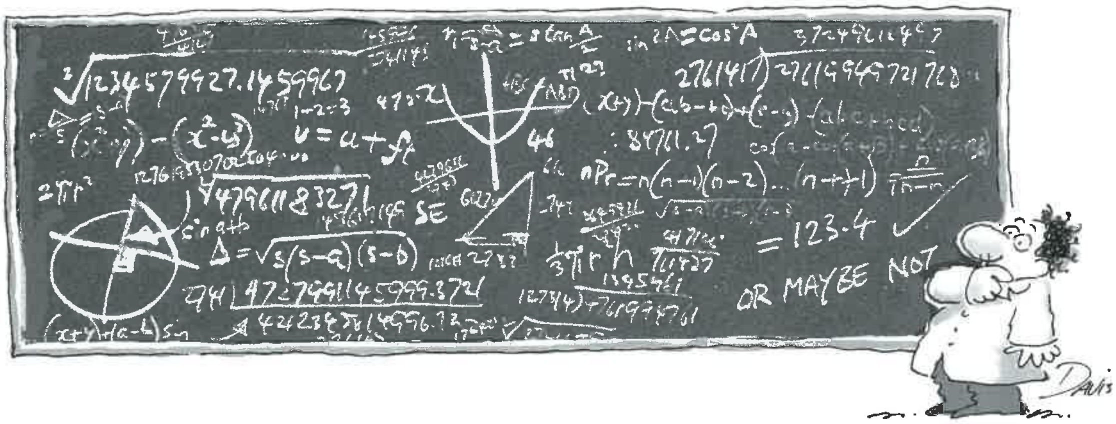
'Occam's Razor' is a useful tool for choosing between two alternative explanations, neither of which can be refuted on the basis of the data alone. It states that the preferred explanation is the one that makes the smallest number of untested assumptions.

State your degree of certainty

Good researchers are open about what they know and what they don't know. It is no disgrace to be unsure, provided you have done whatever you can in the circumstances to reduce that uncertainty. Don't imply that something is a fact when it is only a poorly tested theory.

Be clear about your conclusions

It is often necessary to qualify your conclusions with conditions and uncertainties, but try not to hide them completely among 'ifs', 'buts' and 'on the other hands'. Do not hedge your conclusions so thoroughly that they are by definition true (eg 'It is concluded with high confidence that x may be true...'). Your conclusions should match your study objectives, point for point.



Communicating your findings

The duty to publish

It is every scientist's duty to communicate his or her work in a permanent form. Work that is not communicated is as good as work not done. This duty is to the sponsors of the work, to society, to your scientific peers and not least of all, to yourself, if you wish to follow a scientific career. Successful researchers publish widely and often.

Confidentiality

Some clients or areas of work require confidentiality. This is a poor excuse to not publish at all. Negotiate with the client regarding the bits that may be revealed, and write the communication in such a way that trade secrets are protected. Allow the client to review the paper before it reaches the public domain. Ensure that the contract is clear about what may be published, and when.

Define your audience

Communication is the message received, not the message transmitted. You are responsible for communicating in a way that can be understood. The first step is to define with whom you are communicating, and to understand their expectations, language level and prior knowledge.

If you are communicating to a mixed audience, you will often have to do it in more than one way - for instance, a colourful, illustrated summary brochure for the public, accompanied by a data-packed report for the experts. Choose the media you use carefully - should it be a presentation, a written report, a video, a poster, or some combination?

Length

Write (and speak) just enough to get your point across, without being terse or cryptic. Good communication is not aided by excessive length or detail. For busy decision-makers, two sides of a single page is an effective length. Reports longer than 20 pages are unlikely to be widely read. Try to segment longer reports into digestible chunks. Put the supporting detail into appendices, and provide summaries for the overall report and for each section. Break up solid text with graphics, tables and boxes.

Content

A written scientific report typically has the following structure:

- Title page - descriptive title, authors, addresses, key words, report numbers, date, version number.
- Abstract or Executive summary.
- Introduction - why you did the work, and state the objectives.
- Methods - enough detail to repeat the work to verify it.
- Results - make extensive use of tables and graphics.
- Discussion - make sure you note any uncertainties.
- Conclusion - should address each of the objectives.
- Acknowledgements - of financial, technical and other support or input.
- References - only those used in the document, and in consistent and complete form.
- Appendices - data too extensive for the main text, or topics which are not central to the main argument.

You can alter this pattern to suit a particular report (for instance, by combining results and discussion), but aim to keep a logical flow. Put large volumes of raw data into appendices.

Tables

Give your table a number and self-explanatory heading (above the table), and make sure that every table is referred to in the text. All table columns must be identified with a heading, and given units where appropriate. Tables for publication should not have any vertical lines. Where cells contain no data, indicate this using ‘-’ or ‘ND’, not a zero.

Round numerical values to the significant digit. Be consistent in using the decimal point or comma (the latter is legally correct in South Africa; the former is international general practice).

Graphics

Don’t unnecessarily repeat data in graphs, text and tables - pick the most appropriate format for the type of data and the point you wish to make. The figure captions (below the figure) should be sufficiently self-explanatory that the figures can be browsed without reading the text. Use a simple, clear, consistent font.

Refer to each figure in the text. Use bar charts for data that fall into classes, and line graphs or scatter plots for continuous data. Graph axes must be labelled and given units. The dependent variable goes on the y-axis.

Keep the graph uncluttered - don’t use 3-D effects for 2-D data. Avoid grid lines, or more than three variables per graph. Ensure that there is a legend for symbols and lines, on the graph or in the caption.

References

References fulfil two purposes. They substantiate statements that you make, and they acknowledge work which is not your own. The amount of referencing needed depends on the type of document, ranging from exhaustive in technical review articles, to almost none in popular articles.

In writing for a scientific audience, each key point not based on your presented data should be supported by at least one, and usually not more than three references. Use the earliest appropriate reference that supports the point you are making, and add a more recent one if there have been significant recent developments. A good recent review is often an appropriate second reference.

Use any of the accepted styles for referencing, but be consistent within a document. Every reference must be complete: author/s, date, article title, book or periodical title, book editors if it is a chapter, volume number if a periodical, page range, city of publication, publisher. Personal communications should be treated as footnotes or bracketed in the text, and must include a way of tracing the informant.

Do not include articles in preparation or submitted for review in the reference list; they should be treated as untested personal communications. All references in the reference list must appear in the text, and vice versa (because you have literally referred to them). General references that are not in the text should be in a Reading List or Bibliography.

Web references

Websites, unless they contain the online version of scientific communications that have passed through a rigorous peer-review process, are not equivalent to scientific publications. There is no way of assessing their quality, and they may not be there when you come back to check on them. Treat web references like personal communications. Give the URL (http://webaddress/...) and the date on which it was accessed.

Knowledge management

This is the knowledge age, where knowledge is power; but most knowledge is 'tacit', stored in the heads of the researchers rather than on paper or in electronic databases. You can make this knowledge more available to yourself and your colleagues by informal and formal actions. Informal actions include discussing your work with colleagues, and giving and attending seminars inside and outside your organisation. Formal actions include identifying all the available knowledge *before* project commencement; identifying persons who can be consulted *during* project execution; and reviewing and recording the essential learning *after* completing the project, including not only technical knowledge, but team interactions, political and market insights etc, that typically do not feature in the project report. If your organisation has a formal knowledge management system, use it. Examples are reference and publications databases, client and contact lists and idea registers.

Further reading

Bruckmann, C.G. and Mandersloot, W.G.B. (1977). *Writing Informative Reports on Investigations in Science and Engineering*. CENG 191. ISBN 0 7988 1163 3. Pretoria: CSIR.

CBE Style Manual Committee. (1983). *CBE Style Manual.* Fifth edition. Council of Biology Editors Inc., Bethesda, Maryland, USA. 324 pp.

Ethics

Honesty in science

Science depends for its influence on a public image of reliability and impartiality. Researchers must apply the highest possible standards of integrity with respect to their work. This applies to data collection, analysis and reporting. It also applies to what you choose not to say. Do not sacrifice the long-term viability of the organisation and your reputation to the short-term expediency of satisfying a client's desire for a particular outcome, if the research does not support that conclusion.

Acknowledge sources

Always acknowledge ideas, findings and data that are not your own. This can be done routinely by referencing sources in the text. Data contributions and financial support can be highlighted in a section on 'acknowledgements', usually at the end of the text or at the end of the introduction. A significant intellectual contribution deserves a co-authorship.

Co-authorships

All the individuals who made a significant intellectual contribution to the work deserve a share of the authorship, but don't dilute your own recognition by giving authorships to those who did not earn them. Authors must be prepared to share responsibility for the paper, and they should have made an input to the conceptualisation or data interpretation, and the writing and checking of the article. In some cases, the skilled preparation of samples or collection of data constitutes a significant intellectual input. The person who made the largest contribution should get the first position; the order of the rest does not matter much.

When in doubt, offer a co-authorship; a good researcher will be pleased by the offer, but decline if he or she did not earn it. An administrative or financial contribution requires a suitable acknowledgement, but does not by itself entitle the person to a co-authorship. However, do not underestimate the intellectual contribution made by research managers who may have conceived and guided the entire project. Data collectors (e.g. technicians or field assistants) deserve co-authorship if the work required exceptional skill or diligence.

Experiments on people and animals

Experiments involving the handling of animals must adhere to the animal anti-cruelty legislation and to accepted ethical guidelines. If the CSIR has no guideline on the issue, use those of a respected research organisation that does. For instance, the University of the Witwatersrand (Animal Ethics Screening Committee) has guidelines on experiments involving animals. Experiments on humans must follow the Medical Research Council guidelines, and surveys involving people must adhere to the Human Sciences Research Council guidelines.

Environmental and social impacts

Any CSIR research that has a reasonable possibility of causing significant environmental damage or undesirable social consequences must be subject to an impact assessment. Where the assessment identifies likely environmental impacts, a management plan, including emergency response measures and a rehabilitation plan, must be in place before the research proceeds. In the case of social impacts, adequate mitigation actions must be put in place, or where this is not feasible, refer the research direction to the Divisional Director for a decision regarding the advisability of proceeding.

Additional sources

Medawar, P.B. (1979). *Advice to a young scientist.* New York: Harper & Row.

SA Medical Research Council (1993). *Guidelines on Ethics for Medical Research.* Tygerberg: Medical Research Council. 119 pp.

University of the Witwatersrand (1992). *Guidelines for the use and care of animals in experimental, educational and other scientific procedures.* University of the Witwatersrand, 1 Jan Smuts Ave, Johannesburg.

A good research checklist

During planning

- Have the objectives been clearly stated as 'testable' questions?
- Will the study answer the question and will the results be sufficient to solve the problem?
- Has an adequate review of existing information been undertaken?
- Has the proposal been peer-reviewed and revised?
- Does the design include adequate measurements?
- Have precautions been taken against bias?
- Are controls needed in the design?
- Is the design statistically valid?
- Are the appropriate variables being measured?
- Is animal or human experimentation involved?
- Might there be an environmental impact?

During execution

- Are the instruments correctly calibrated?
- Are there reasonable controls to reveal observational bias?
- Are the treatments adequately maintained and documented?
- Are adequate notes being taken to be able to repeat the procedure?
- Are the data sheets self-explanatory, complete and labelled?
- Have the data been copied and stored in a safe place?

For reports

- Are the conclusions clear?
- Do they match the objectives?
- Are the conclusions supported by the evidence?
- Are sufficient data presented to verify the conclusions?
- Where used, is the statistical analysis valid?
- Does the report state the uncertainties?
- Could the study be repeated from the description of methods?
- Are the medium and style appropriate for the audience?
- Is the report logically laid out?
- Are the tables and graphics clear, sufficient, correct and referred to in the text?
- Is there duplication or redundancy in the report?
- Is the work of others adequately acknowledged?
- Is the reference list adequate and complete?