Editorial

The art of experiment

Scientists use experiments to test ideas and to generate data to support theories. They learn experiment by interaction with their peers and supervisors. If they attend formal courses on experiment, such courses would focus on statistical design and analysis of experiments in the belief that statistical methods are most objective and most reliable. However, disturbing evidence has emerged that a large proportion – over 50% – of the claims published in the top medical and biotechnology journals, fail the test of independent verification. For this, *The Economist* of October 19, 2013 has put the blame on scientists' poor mastery of statistics. This ignores the fact that all the papers, and therefore their research methods and analyses, had passed peer-review in top-ranked scientific journals.

The real problem may be over-reliance on statistical methodologies in which the experiment is the result of detailed statistical planning and design. Ironically, the faith that many scientists place on statistics is not shared by statisticians. The statistician M. J. Moroney in his classic book: *Facts from Figures* made this warning: "For the most part, statistics is a method of investigation that is used when other methods are of no avail; it is often a last resort and a forlorn hope." That was in 1951, but Moroney's warning has been ignored. Scientists publish without determining whether their claims can be verified. Editors and peer reviewers evaluate papers based on method of research, not on the results, in the belief that if a method is logically correct, the results must be

correct, hence the shock when results are now shown to be otherwise.

One of the problems in experiment is how to distinguish 'signals' from 'noise'. Noise is contributed by chance effects and by biological variation. To separate signals from noise with statistics, large numbers of test objects are required. For example, to test whether a particular treatment improves productivity in a crop plant, a statistical design may require 25 plants per treatment. Four treatments would require 100 plants. Replace 100 cheap small plants with 100 trees spread out over several acres of land, or with laboratory rats, or cattle, or humans, and the experiment would become very expensive and fearsome to implement or to repeat. Then, to justify the effort, the authors would spare no effort to interpret the results creatively for publication.

There is a common-sense alternative approach in experiment, which is to work on small numbers or even on single specimens. The experimenter keeps a close watch and responds to feedback by altering or terminating an experiment at any time. New experiments are designed based on feedback. In the life sciences, because living things react to treatment, a good observer can often predict how an experiment will end without waiting for the end. If there are any interesting indications, follow-up experiments are organized to confirm and explore further. Signals and noise are differentiated by personal judgement and the ability to do so improves with experience. This may seem a retrograde step into subjective interpretation, but it is not retrograde because verification is built into the process. If an interesting observation is made on one specimen, the experiment is repeated on a second specimen and so on until the experimenter can account for variation and explain confidently what is happening. In the time it takes to organize and run one big make-or-break experiment, dozens of probes could be carried out, many ideas tested and many lessons learnt at low cost.

Our knowledge of digestion was first obtained by experiments on a single individual. In a gun accident in 1822, part of the stomach and abdominal wall of a Canadian, Alexis St Martin was destroyed, but amazingly, the patient recovered, with a permanent opening to the stomach through which his doctor, William Beaumont could insert and take out different kinds of food for study. Beaumont, recognizing his unique opportunity, carried out over 200 experiments on St Martin in 8 years.

There are many other examples from the history of science to show how famous researchers such as Louis Pasteur and Ernest Rutherford have used experiments as cheap, repeatable and effective tools in scientific exploration.

Great experimenters are distinguished by their ablity to devise 'perfect' experiments, but such perfect experiments are not the result of once-off planning as in the statistical approach. They result from the use of experiments as serial learning tools, in which each experiment is planned according to feedback from previous experiments. During this process the experimenter can learn more about the phenomenon under investigation than by any other method.

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Correction

The picture used to illustrate *Scoparia dulcis* in page 53 of Vol 2 No 2: *Stop That Weed* was incorrect. The correct picture is the one shown here.