Note: The following is a handout I prepared for my freshman seminar on "Biology in Changing Human Environments" as part of the FOCUS program in "Science, Technology and Modern Culture". The goal of the seminar is to use issues in ecology and evolution as a vehicle for explaining what scientists do, what motivates scientists, and how one becomes a scientist. While teaching this course I became frustrated at the absence of any concise, or indeed accurate, explanation of what science is and how it differs from other activities, so I produced this short essay. Some might detect shades of the philosopher Wittgenstein (but without numbers on the paragraphs). The parody is intentionally cryptic because the essay is meant to be serious. Several colleagues have urged me to share it more widely.

WHAT IS SCIENCE?

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A Polemic

Science is the study of the world as it was, as it is, and as it will be. Its goal is to describe, understand, and predict.

It is the study of the past, present and future indicative as opposed to the study of the subjunctive.

Science does not say how the world should be, how it ought to be, how it could be.

Novels tell us what might have happened (but didn't), science fiction tells us what might be some day. Religions tell us how we ought to be, and how we ought to behave, and what we should believe, and what in their opinion is right and wrong.

Science does not aim at proof of a preconceived notion or belief. It may test that belief, and if found untenable, may discard it. (It would be easy to test the efficacy of prayer, experimentally).

Science does not tell us what is morally right, what is beautiful, or what is valuable. It may investigate morality, beauty, value. It may itself be moral or immoral (experiments on humans), it may reveal things that are beautiful or ugly (viruses), and we may make use of it (technology).

Its positive attributes are fewer than the attributes it negates, or is neutral to.
It negates deliberate or passive falsity, it negates oppression, and it negates dogma (why I like it).
It may negate preconceptions, it is neutral to belief (please, do believe in fairies at the

bottom of your garden) and may negate it if the belief is materially contingent (I believe in God, if and only if, the world was created in seven days).
It is neutral to beauty, happiness, fear, loathing, hatred, nationalism.

Is science therefore Faustian? Do we make a pact with the devil to do science, and are scientists therefore immoral, murdering, lascivious degenerates?
Not usually.
The explanation may be that scientists rely on other value sources (religions, mum and dad, fear of prison or disease; science is their "thing apart").
But science by its own rules of operation also generates its own value system.
Why be dishonest, when the goal is to find out how things are?
Why be intolerant of other viewpoints, other personal hypotheses about life, when they may well be correct? When are beliefs extraneous to evidence, when are they evidential?

The Scientific Method

There is no one scientific method. We find out about the world through our senses, just as other animals do. We observe (hear, smell, touch, feel joy), but unlike animals we can record these on a piece of paper (or have automated instruments do this for us).

We also learn. We learn about universal relations among things (put two and two together) and we thus learn to reason (in a science fiction world it is conceivable that when four like objects appear within 1 m of each other, one disappears, thus making two plus two always three). And we learn to recognise generalities because learning is predicated on consistent patterns, on generalisations (a child does not reconfirm everyday whether she will be picked up from school).

We form mental constructs, we form institutional constructs, and we form personality constructs that are models for our lives. We also form abstract constructs (mathematical models), material models (the stick and ball double helix), and laboratory constructs (mites on oranges) that are models for our perceptions of what is.

Words themselves are models that describe collections of like things or relations among things.

There is no secret initiation, no regimen of training, no required piece of equipment, no course prerequisites for becoming a scientist. Science does not require any special method beyond what a child does when it says there are two blocks and they are red.

Why then is science seemingly so difficult (even threatening) to so many people.

1. The world is complex. What is, was or will be is not simple.
Hate, obsession, ideology, anger (in spite of novels and movies exploring the seeming complexity of these things) are simple.

2. Our childhood vocabulary exposes us to what is evident to our senses. New vocabulary is

needed to describe what we were not taught as children. Jargon is necessary because phenomena are not always self-evident.

3. We also run out of steam with our own senses: we need equipment (electron microscopes, observatories) predicated on technology.

4. The relations among things are not always straightforward, intuitive, etc. Sometimes verbal abstractions are inadequate or cumbersome: we may need mathematical descriptions.

5. It is possible to bullshit when things cannot be known or are not known; it is harder to do so when things can be discovered or are known.

6. A lot is already known. It is boring to rediscover what is known. New things, new relations are difficult to establish.

7. Teaching science presents a dilemma. To know what is unknown we have to know what is known; much of undergraduate education is spent learning what is known - often as if knowledge of such a catalogue of information and facts was science.

8. We are tested on what is known, as if to know is good and not know is bad. No wonder the public expects scientists to know, and doctors are ashamed to admit they don't know. For a scientist, to not know is exciting.

9. The actual operations necessary to find out and discover are often boring (counting flies, calibrating equipment). Probably, scientists are a personality type. The practice of science requires persistence, compulsive obsession, delayed gratification, tolerance of frustration, playing by no-ones rules with no preset recipe for success, etc. Playing football, being a marine, or teaching are quite different occupations.

Components of the Scientific Method

It is very hard to rationalise how we know about the world.
Much of the answer will probably come from developmental psychology - because we are animals, a biological interpretation of epistemology seems reasonable.

The scientist (at least while at work) aims not just to know the world, in a sensory knee-jerk fashion. His goal is to understand the world.

Understanding is hard to achieve: children do it by learning through repetition, learning by attraction to novelty , by association (I understand I will be spanked if I spit on my brother - spitting causes spanking), and by analog computers (one potato two potatoes, three potatoes, four).

Description

In science we make observations and record those observations. These observations and descriptions are not random (I have never counted the number of tiles on the wall to the left of my bookcase), but are made with a reason.
The motivation for making observations may be numerous. The observations usually are made in the context of generalisations or expectations based on preconceived ideas (justifiably or not). The phenomenon may be commonplace, but unquantified (longevity of flowers). The phenomenon may be rare and unusual (the flora of hot-springs). The phenomenon may be part of an experiment. The phenomenon may make one rich (where are the oil fields).

Even though the observations are made "in anticipation" of an outcome, this anticipation or expectation should in no way prejudice the outcome.

Induction

We generalise from what we observe (The ducks in my pond all have webbed feet).

We generalise beyond what we observe (All ducks have webbed feet, "probably"). It is always dangerous to do so, but at some point silly not to do so. We, as animals, would be nervous wrecks if we did not do so: but we also make wrong inferences and assess probabilities wrongly.

Such generalisation from specific "instantiations" to a more general statement or law is called "induction".

Deduction

Given that we accept some rules based on causal, mathematical, or logical relations, it is possible to infer, work-out, predict the consequences of initial starting conditions.

This is called "deduction"; assuming the logic, mathematics, etc. are correct, the conclusions follow from the premises.

This is often what we do when we develop theoretical models. We want to know what the consequences are of assumptions about a particular process (spread of an epidemic, change in gene frequency due to selection). Working out a model is "deduction". A theoretical experiment is an exercise in deduction.

Analysis of causal relations

Science analyses what causes things to be as they are or to behave/respond as they do, and tries to predict how things will be, either in the future, or contingent on particular circumstances.

We infer causation from observation of (sequential) correlations among phenomena.
This is problematic using purely descriptive information. It is made easier if we can do

experiments. (Astronomy, geology are not very experimental, but are still considered sciences).

The study of causal relations is motivated in the same way as our observations - by the expectation of some generality or non-generality in time or space.

Experiments

When we artifially generate a condition to study its effect on a particular variable, we carry out an experiment.

All manipulations are not experiments.

When we artificially generate a condition to reveal a phenomenon (e.g. dissect an animal, or extract DNA and run it out on a gel to sequence it) this is sometimes called an experiment, or an experimental study, but it is really an observation requiring a special technique (using binoculars to identify a bird).

Experiments are useful because we can generate conditions not normally found in nature. This enables us to minimise spurious non-causal correlations, enables us to minimise "noise" due to extraneous factors, and enables us to generate fancy designs that test specific hypotheses. The drawback, especially in biology, is that experimental manipulation may introduce artifactual and or unrealistic circumstances.

Natural experiments are the result of a confluence of unusual circumstances in nature that permit one to study the consequences of these circumstances (solar eclipses, introduced pathogens).

Statistical experiments are where we try and identify independent contributions of variables to particular outcomes. (This approach is widely used in the social sciences).

Theoretical experiments are where we develop models of particular systems, and try and assess the consequences of changing variables (flight and forest simulators).

Generalisations, Laws, and Theories

Sometimes, science aims at generalisations and rules that are broadly applicable (all mammals are warm-blooded), and therefore have extensive explanatory and heuristic value.

At other times, science (or is it technology?) aims at detailed descriptions, predictions and understanding of particular cases.

The rules and generalisations that emerge are sometimes formalised as laws, but they need not be.

When these rules and generalisations refer to processes or inter-relations among things, the processes or inter-relations can also often be represented in symbolic form as models.

Without these generalisations, facts and the relations among things have less meaning, and in this sense are less useful.

If the models are not translatable across individuals (I had a vision...), or across individual studies (it works only for me and only in my laboratory) they are not useful. Science is a public enterprise, where results and ideas are exchanged and open to scrutiny.

And models, generalisations or laws that are combined into a broader body of explanation, are collectively called theories, whether considered correct or not (*The* phlogiston theory, *the* theory of evolution, *the* theory of relativity).

In biology, models and generalisations that apply to a particular field of study, but on which there is as yet no consensus or where the whole area is in an investigative phase, is called 'theory' (without a definite article), e.g. life-history theory, neuronal network theory.

A hypothesis is a supposition regarding the nature of things that is deemed clearly in need of (further) testing.

In common parlance, a hypothesis is a hunch, an idea, an educated supposition. In common parlance, a theory (I have a theory about this; hey, evolution is just a theory) is usually a hypothesis, and the usage of the word is quite different from its usage in science.

Objective, subjective, or just plain relative

We observe through our senses, or through our senses augmented with various aids and devices. In that we all have similar senses, we also at some level have a similar, common view of the world. This is the objective external world. (The Cardinals beat the Saints by two touchdowns, or did I just imagine it).

In life, we describe using words, pictures, symbols, that are muddles of what we actually observe, feel, and think. (Damn the Saints last night, one less touchdown and I would have made the spread). Scientists strive for models (rather than muddles) of what they actually observe. But (lets admit it) they do feel better about some models than others, and think some models are better than others. Subjectivity seeps in at some point.

These models are accumulated into broader constructs, rejected or accepted, (ideally) according to lofty epistemological principles. These princples include usefulness, generality, precision, explanatory power. But there is no one criterion, no linear scale of excellence, regarding a scientific idea or finding.

Because of this, acceptance of theories, admiration of experiments, and crowning of scientists is often according to fashion, dominant personalities, or social conditions (they all laughed at Christopher Columbus, and poor Galileo; and who was the German chap that thought the continents were once joined like a jig-saw puzzle?).

I find the journal "Science", which includes commentary as well as scientific articles, most enjoyable as a great gossip magazine. (Will Gallo be exonerated after all, or did he cheat to get the Nobel prize? Read next week's juice).

Knowledge, understanding and insight ain't subjective or relative. (Read a turn of the century biology text and ask if we nowadays know or understand more). But they are the product of people's actions, people's motivations. How can these be objective?

Science requires tolerance of alternative possibilities, a commitment to truth, and a disdain for polemics, power, and emotion as critera for determing what actually is the case.

Science presumes freedom. It also presumes a degree of liberalism and non-conviction.

Anyone with freedom can be a scientist: without freedom, science has to be faked sooner or later.

And when science is faked, distorted or suppressed, freedom suffers in its turn.

Future Installments: don't miss them in your local magazine rack

What is good science vs. bad science?

Why is reductionism in science equated with quality in science?

What is modern science vs. old-fashioned science?

What is science, social science, humanities, arts? Do they differ in their epistemological essentials or expectations or only in their social norms?

Are scientists creative? Why aren't they artists, or are they?

If science is public knowledge but religion personal knowledge, then why is religion so public and intrusive, yet science so private and reclusive?

What is the difference between technology and science?

Does science have a goal? Does art have a goal?

When is science a bad thing?

Should science be banned? What would be so bad if all federal funding for science were stopped?