How To Do Science

In Theory & In Practice - 1

Jonathan Wright

The Scientific Method

- an ongoing project

Francis Bacon

- **Science is a unique way of understanding the world**
  - Rooted in the origins of Western intellectual thought
    – Ancient Greek philosophers (e.g. pre-socratic, Socrates, Plato, Aristotle)
  - The existence of objective reality & avoiding subjectivity
    – mathematics, argument & evidence (not belief, superstition or prophets)
- **Baconian unbiased description – the first step**
  - Objective & repeatable observations
    - the descriptive result is *independent* from the observer
  - Looking for patterns in observations – a very human characteristic

Current Science vs
Non-Science

Karl Popper

- **Popperian hypothesis refutation = The Scientific Method**
  - Progress through theories that survive critical tests
  - Unambiguous hypothesis - tested using *falsifiable* predictions
    – ultimately requires controlled experimentation
  - Predictive power in terms of future events
    – the demonstrable success of science (e.g. useful technology)

- **The non-scientific method of advocacy**
  - Seeking evidence that supports a theory, explanation or agenda
  - Looks like science, but it is *not* science (e.g. politically motivated ‘science’)
  - Confusion arises when science becomes merely advocacy

Asking Questions in Biology

- **Description vs hypothesis testing**
  - Natural history of species, structures, genotypes, etc
    - cataloguing what is there, what variation exists
  - Hypothesis testing in order to understand biological systems
    - explanations for what is there, how it works & why

- **‘How’ versus ‘why’ questions**
  - *How* does the biology work the way it does?
    - “Proximate” explanations of the mechanism
    (e.g. behaviour produced *because* of hormones)
  - *Why* has the biology evolved the way it has?
    - “Ultimate” explanations via adaptation
    (e.g. behaviour produced *because* it results in more offspring)

Reductionism & Choice of a Hypothesis

- **Holistic science is just not possible**
  - ‘Science’ – asking the biggest question possible that you can still find an answer to (D. Adams: Hitchhiker’s Guide to the Galaxy)
  - Problems need breaking down into smaller answerable questions, and then we can integrate the answers at a later date
  - Phenotypes are conveniently divided into quasi-independent ‘traits’, & at different levels from molecules to life histories to ecosystems

- **Not every question is a good scientific hypothesis**
  - Each question, however small, has to fit into a wider framework (e.g. biology within chemistry, chemistry within physics, so psychology within biology?)
  - A coherent series of mutually compatible scientific questions - <u>the importance of reviewing the literature at the start of every study</u>

Evolution
THE Theory of Biology

Charles Darwin

Alfred Russell
Wallace

- **Biology is about evolved systems**
  - Biology as a science requires theory, by definition
  - All aspects of biology evolved, from molecules to ecosystems
  - Evolution is not just for ecologists!
- **The theory of evolution**– simple, but with powerful implications
  - (i) things vary, (ii) things are inherited, (iii) things with a reproductive advantage will be selected for
  - All of biology is a series of attempts to refute this theory…?
  - How does your hypothesis relate to the rest of your field, the rests of biology & the theory of evolution?

Mathematics
in Biology

- **Formulating theory is an area of study in itself**
  - Mathematics - an unambiguous language for theory
  - Mathmatical theory provides clear testable predictions
  - Mathematical modelling - a neat area to get involved in…
- **Statistics – unambiguous mathematical comparisons**
  - Test if observations are different from chance frequencies
    - i.e. everything is probabilities, so did the theory predict correctly?
  - For biology the unit of analysis is often the individual organism
    - i.e. independent genomes when testing evolutionary hypotheses, but perhaps the social group, the population, the species, or the community?

Testing Theoretical Predictions

- **Unbiased data collection…**
  - Question-driven vs system-driven research
- **Descriptive studies**
  - Within species studies – patterns consistent with theory?
  - Across species comparative studies (need to control for phylogeny)
  - But... “correlation is not causation!”
- **Experimental studies** (and the beauty of experimental design)
  - Testing the direction of causes & effects
  - Control treatments, within- vs between-subjects designs
  - Laboratory studies – controlled, but artificial conditions
  - Field studies – natural, but lots of noise in any measurement

Cycles of Research in Biology

- **The sequence of events in biological research**
  - Observational natural history (e.g. Linnaeus, gene sequencing)
  - Formulation of theory to explain observations (e.g. Darwinian evolution)
  - Collection of data to refute theory, if possible (e.g. altruism)
  - Reformulation of theory, if necessary (e.g. Hamiltonian kin selection)
  - Critical experimental test of theory (e.g. kin discrimination studies)

- **Science = Data-Theory-Data-Theory Cycles**
  - New theories open up new data opportunities…
  - New data stimulate new theories…
  - The aim here is *understanding* and each answer just stimulates more & better questions…

How To Do Science

In Theory & **In Practice** - 2

see also – **BI3052**
Study Design in Biology
(Mon & Wed 14-17, U33, weeks 38-47)

Jonathan Wright

How Science is Actually Done

- **Learning by doing…**
  - Practical experience is the only way to learn – hence your masters project
  - Constantly striving to ensure objectivity in your own research
  - Recognising ethical conflicts of interest – e.g. financial, political, etc.
- **A training in the scientific method**
  - Not just in order to become a researcher (*if* you decide you want to…)
  - Everyone in society should understand the scientific process
  - The ability to properly interpret scientific evidence - e.g. statistical results
- **The social aspect**
  - Science is mostly a cooperative, social & international activity
  - The problem of personal feelings & individual egos…
  - Seeking advice from others & giving constructive criticism

Asking Scientific Questions & Knowledge of Previous Research

(see lectures by Trond Amundsen and Thorsten Hamann on Weds
and Jo Kristen Breivik Forthun on Thurs)

- **Framing your scientific question**
  - The precise question is often more important than the answer
    - D. Adams: Hitchhiker's Guide to the Galaxy
  - Fitting in with the wider aims of your supervisor & research group…
- **The scientific literature (on-line & in print)**
  - A massive resource to search through…
  - Always work within the context of previous scientific research
    - issues of plagiarism & correct citation
- **Engaging with the work of others, & *vice versa***
  - Choice of courses, special pensum & wider reading
  - Masters seminars, study groups, etc…

How to Actually Do Science

(see Trond Amundsen and Christophe Pelabon on Weds)

- **Data collection**
  - Independent samples & unbiased data collection design
  - Experimental design & unambiguous conclusions
  - Statistical power – ability to refute not confirm hypotheses
- **Statistics – the real heart of doing science (“don’t panic”)**
  - A few basic principles (e.g. types of data, variances, p-values, normality)
  - A personal repertoire of tests – a circle of light in a darkened room
  - Separating issues with statistical programs (R!) from statistics…
- **Reaching appropriate conclusions**
  - Problems like pseudoreplication come only with the conclusion
  - Making sure you answer the question that was first asked *a priori*

Safety & Ethics

(see HSE Course on Tues,
Jon Wright and Thorsten Hamann on Weds, and Claus Bech on Thurs)

- **Health & Safety**
  - Dangerous science is usually bad (and unrepeatable) science
  - Duties of care & collective responsibilities
- **Ethics in Science**
  - Personally policing oneself against intentional & unintentional acts
  - Rules, regulations & policing each other against transgressions
  - The accredited university, plus other ethical & legal standards
- **Animal welfare & environmental ethics**
  - All biological research has welfare & ethical implications
  - Scientific gains vs harmful effects – an objective assessment
  - Regulatory frameworks and national & international standards, but also personal choices & responsibilities…

Masters Project Proposals

(see the group discussions, etc.)

- **Designing your project**
  - Choosing a topic – what is your aim in obtaining a masters?
  - Designing an appropriately sized task for a masters project
  - Working with your supervisor(s) & other researchers
- **Writing your proposal**
  - A good introduction to thinking & reading about the topic
  - Often a collaborative exercise with your supervisor
  - Essentially a first draft of your thesis introduction & methods
- **Evaluation of masters projects proposals**
  - The study committee within each research area
  - Assessing the quality & viability of the masters project proposal
  - Comments & replies to comments from the study committee

The Masters Thesis

(see Claus Bech and Christophe Pelabon on Thurs)

- **Scientific Writing**
  - Not just for scientists, but a useful skill for everyone
  - Experience useful when then reading the scientific literature
  - Skills in the presentation and interpretation of results
- **Publishing & Presenting**
  - Ownership of data & time-lines for publication
  - Authorship & the value of scientific publication
  - Public speaking, constructive criticism & oral interaction
- **The Mark**
  - Hopefully the mark is not the be all and end all…
  - Course & thesis marks - gateways to future research opportunities
  - Excellence, elitism & perfectionism in science