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
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 - the importance of reviewing the literature at the start of every study
Evolution

THE Theory of Biology

• 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
  • Mathematical 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