MSc Research Skills

Lecture: Science and research

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Topics

1. **What is science?**
2. **What is research?**
3. **The scientific enterprise**

Topic: What is science?

You are aiming at a **Master of *Science*** degree:

- not Master of Technology
- not Master of Engineering
- not Master of Regional Planning
- not Master of Business Administration
- . . .

so, what do we mean by the term **"science"**?

What does it mean to "do science"?

- To "do science" is to follow a prescribed **method** to arrive at knowledge.
- The ***"scientific method"*** is a manner of **thinking and working** towards more complete knowledge of the world
  - including the built world
  - including systems in the world
  - including humans in the world
- It is not a **belief system**

Must one "believe" in science?

Science has proven successful in:

- **explaining** the world as we observe it;
  - explanations continue to improve (explain more, in more detail)
- **predicting** what can be further observed
  - e.g. new observations, new locations, repeat observations, the effect of interventions;
- **engineering**
  - i.e. building things that work.

So it's not a question of **belief**, rather of **evidence**. But . . .

Naturalism

> "All of us who participate in science must share one common faith. We believe that the **material-energetic** world is **knowable**, at least in large part, by the concerted activity of **research**: exploration, reconnaissance, observation, logic, detailed study that includes careful **measurement** against standards."
>
> – Lynn Margulis, *American Scientist* 93:482)

It is impossible for science to investigate anything which does not conform to this assumption; 'Super-natural' means just that, 'outside of nature'.

Note: The type of measurement etc. depends on the scientific discipline and object of study.

Characteristics of scientific knowledge

1. **Self-criticism**
   - Inherently **self-critical**; never "complete"
   - Built-in mechanism to **check and revise** itself
   - **self-consistent**, same methods used to reach conclusions can be used to challenge or revise them
   - Does not allow for any **super-natural** reasoning

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Characteristics of scientific knowledge (2)

2. **Evidence-based**
   - Knowledge is built up step-by-step from **experience**, including experiments and systematic observations.
   - Can not be deduced from abstract ideas of how the world "should" work or on folk "wisdom"
   - (these can provide hypotheses to be investigated)

Scientific knowledge advances by **accumulating more evidence**

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Characteristics of scientific knowledge (3)

3. **Theory-based**

- Science is not a disorganized collection of facts
- It is a way of explaining the world
- So, must construct **theories** (also called **models**) that explain the available evidence

Scientific knowledge advances by **constructing better theories** from the available evidence.

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Characteristics of scientific knowledge (4)

4. **Transparent**

- All **methods** used in a scientific investigation . . .
- and all **results** of applying the methods . . .
- must be unambiguously **specified** and **communicated**

Implications of these characteristics

- Science is **reproducible**: another worker can perform the **same** experiment or observation, and expect to obtain the **same** result, within the limits of experimental error.

  Note: In **social sciences**, and with **historical** approaches it may be impossible to exactly reproduce an observation; however the methods used are **traceable**.

Traceability: it is clear how observations were made (transparency); so, another worker could follow the **same** procedure in a different setting and expect to obtain **similar** results, with differences due to the differences in the two situations.

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Implications (continued)

- Science has a built-in **self-correction** mechanism – other scientists can verify, modify, contradict or extend 'surprising' or controversial results
- There is no **occult** (hidden) knowledge in science – in principle any person can acquire all the knowledge needed to do and understand science
- No appeal to **authority**
- Science is **not prescriptive** ("normative")
  - It can not say what is a "right" course of action
  - That is the province of human value systems, including secular humanism, ethical systems, tradition, and supernatural religions.

Types of sciences

1. **Experimental**
   - controlled conditions under which measurements are made
   - quantifiable level of control
2. **Observational**
   - No experiment is possible
   - but observations are made in uncontrolled or semi-controlled conditions
   - Sampling design: the observations are **representative** of the process to be modelled.

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Types of sciences (continued)

3. **Historical**:
   - Evidence from the **past**, which can not be re-created experimentally (e.g. geology, archaeology):
   - these can be **related to current processes**
   - some of the supposed processes can be reproduced in the lab.
   - explanation relies heavily on **inference**

Science vs. engineering

- **Scientific research**
  - a method to **discover** facts about nature . . .
  - and to put these in a theoretical context: **why**
- **Engineering**
  - the **design** and **manufacture** of objects
  - may be virtual, e.g. a computer program

» Science **investigates** the world as it is and tries to explain it

» Engineering **changes** the world

Topic: What is research?

An essential element of a thesis in partial fulfillment of a "Master of Science" degree is that it must:

1. formulate **research problems** and **research questions**, and then . . .
2. . . . **report** on the results of applying **research methods** to these.

But, what do we mean by **"research"**?

1. Definition
2. Abstract structure of research
3. Research stages
4. Types of research (experiments, observations, synthesis, design, modelling, data mining)

Definition

"research" from the French *rechercher*, "to look for (again)", by extension "to investigate", "to [attempt to] find out".

To do research is to **discover** something that was previously completely or partially **unknown** or **not understood**.

What is something new?

The "something new" to be discovered may be:

- new **facts** about the **natural** world, the **built** (engineered) world, or human **society**;
- new understanding of the **processes** in these;
- new or improved **methods** to investigate the above;
- new or improved **systems**;
- new or improved **models**; or
- a new **synthesis** (conceptual framework) of existing facts.

Reasons to do research

In order of understanding:

1. to **explore** a poorly-understood situation or phenomenon, generate research questions and hypotheses
   - only applicable in situations of ignorance (no previous systematic study)
2. to **describe** a situation or phenomenon
   - phenomenon is known but not systematically described
3. to **explain** (to some level of understanding) the **causes** of a phenomenon
4. to **predict** the future or at unobserved locations
   - this requires a **computational model** which can simulate **scenarios**
5. to guide **decisions** which must be taken

Abstract structure of research

1. raising (or, posing) **questions**;
2. providing **evidence** to answer these questions; this requires some appropriate **methods** to gather the evidence;
3. making **claims**: a statement of what has been achieved, based on this evidence;
4. a **discussion** of the **reliability** and **relevance** of the claims.

Questions $\Longrightarrow$ **Evidence** $\Longrightarrow$ **Claims** $\Longrightarrow$ **Context**

Research stages

In the long view, research can be divided into three stages:

1. A **reconnaissance** stage of unstructured observation;
2. A **reflective** stage, during which **hypotheses** are generated;
3. A **testing** stage, where experiments or structured observations are designed to verify these hypotheses.

Reconnaissance $\Longrightarrow$ **Reflection** $\Longrightarrow$ **Testing** $\Longrightarrow$ **Conclusions**

An MSc project typically skips the reconnaissance stage; enough is known from the **literature review** to formulate hypotheses.

Inductive vs. hypothesis-driven research

Inductive inquiry Unguided and unlimited exploration, attempting to collect facts.

This is speculative and with no guarantee of success – certainly facts will be collected but can they be put into a meaningful framework?

Hypothesis-driven Built on previous scholarship (published hypotheses with evidence for their validity), and fundamentally driven by theory.

If the hypothesis is well-formulated and reasonable in light of previous results, and the methodology is well-designed to address it, a valid scientific result (positive or negative) is almost guaranteed.

These must be balanced: no induction means no fresh ideas; no hypotheses means unguided and inefficient research.

Words of wisdom

"About thirty years ago there was much talk that geologists ought only to observe and not theorise; and I well remember some one saying that at this rate a man might as well go into a gravel-pit and count the pebbles and describe the colours. How odd it is that anyone should not see that **all observation must be for or against some view if it is to be of any service**!"

– Charles Darwin, letter to Henry Fawcett, 18 Sept 1861

Types of research (1/3)

1. **Designed experiments**, e.g. laboratory or field research;
   - The researcher imposes the **treatments** in a (semi-)controlled situation and measures the system response;
2. **Systematic observations**, e.g. resource survey or community meetings;
   - The researcher makes **measurements or observations** according to a plan but without complete control of the process;
3. **System design**;
   - The researcher **designs** a system (database, visualization, modelling . . .) and shows that it is somehow "better" than previous designs; this includes design of **algorithms** and **methods**.

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Types of research (2/3)

4. **Synthesis**;
   - The researcher imposes a new **conceptual framework** on previous data and establishes that this is a better or more unifying explanation;
5. **Modelling**.
   - The researcher builds a conceptual or computational model of a process; the model is evaluated by its success in **reproducing the behaviour** of the natural or social system.
6. **Comparative studies**.
   - The researcher compares existing situations in order to determine the reasons for the observed differences.
     Note: the researcher must argue that all relevant factors have been considered; thus only close analogues should be used

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Types of research (3/3)

7. **Data mining**;
   - The researcher looks for **unexpected patterns** in **large datasets**, without preconceptions;

Natural vs. social sciences

- **Natural** sciences: The principal object of study is “nature”, i.e. physical reality;
  - There is a clear **separation** between observer and observed;
  - It is easier to be **objective**.
- **Social** sciences: The principal object of study are humans and human society (including **organizations** and **governments**).
  - We can not impose treatments at will;
  - We are studying ourselves or our social constructs;
  - It is difficult to avoid subjectivity;
  - Argumentation grades into humanities.

Main focus of study

Research can investigate either:

- An **object** or **thing in itself**: Something about the natural world, the built world, or society; e.g.
  - changes in land use in a study area;
  - commerce patterns in a district;
  - audit of a reconstruction project after a natural disaster;

  or,
- The **methodology**: How the “thing in itself” is best studied, e.g.
  - **How to** assess land-use changes with multiple satellite sensors of different resolution;
  - **how to** visualise spatio-temporal commerce patterns;
  - **how to** map reconstructed buildings from high-resolution imagery using image segmentation techniques.

Topic: The scientific enterprise

Your MSc research project is a small part of a much larger **scientific enterprise**:

1. Within the University
2. Within a field of study
3. Within the scientific community in general
4. Within society

(See separate lecture on how research is embedded within UT/ITC).