BCS 206: Research Lab Course

Introduction & Scientific Method

Course outline

- Goals:

  - Teach how to perform scientific research

  - Replication & critical evaluation of existing study

  - Generate original research results

- Course structure:

  - In-class: general lectures + progress reports

  - In-group: research + meetings with external advisor

- General: interactive, discussion-based, learning-by-doing

- Course in development, your feedback is needed!

Marr's levels of understanding (the brain)

Goal

Process/algorithm

Implementation

Goal of science

- Generate knowledge/understanding
  - hypotheses, models, theories
- Allow predictions
  - e.g. weather (physical), behavior (biological)
- Enable interventions
  - e.g. engineering, medicine

Marr's levels of understanding

Goal — Understanding

Process/algorithm — Scientific method

Implementation

Scientific Method: elements

- **Data characterization**

- Hypotheses generation

- Predictions

- Experimentation/observation

Data characterization

- Summarization of existing data

  - as predictors & to be predicted

- Precise definition/mathematical formalization

- Accounting for uncertainty

  - observed and inferred variables

  - ignorance and stochasticity

- Limited by technology

- Depends on existing understanding ("theory-laden")

Scientific Method: elements

- Data characterization

- Hypotheses generation

- Predictions

- Experimentation/observation

Hypothesis generation

- Hypothesis: empirically falsifiable conjecture

  (Conjecture: unproven assertion, partially supported)

- Practical considerations

  - Testability (ex. Democrit, string theory)

  - Parsimony (Occam's razor)

  - Scope (ex. sheep)

  - "Fruitfulness" (ex. neural variability)

  - Conservatism (ex. gravity)

- Mathematical formalization, qualitative vs quantitative

Scientific Method: elements

- Data characterization

- Hypotheses generation

- Predictions

- Experimentation/observation

Prediction

- Deductive reasoning

- Can be probabilistic

- Postdiction vs prediction (see scope)

- Should be unlikely under alternative hypotheses

  - Differential diagnosis in medicine

  - "Crucial experiments"

  - Bayes-factors

Scientific Method: elements

- Data characterization

- Hypotheses generation

- Predictions
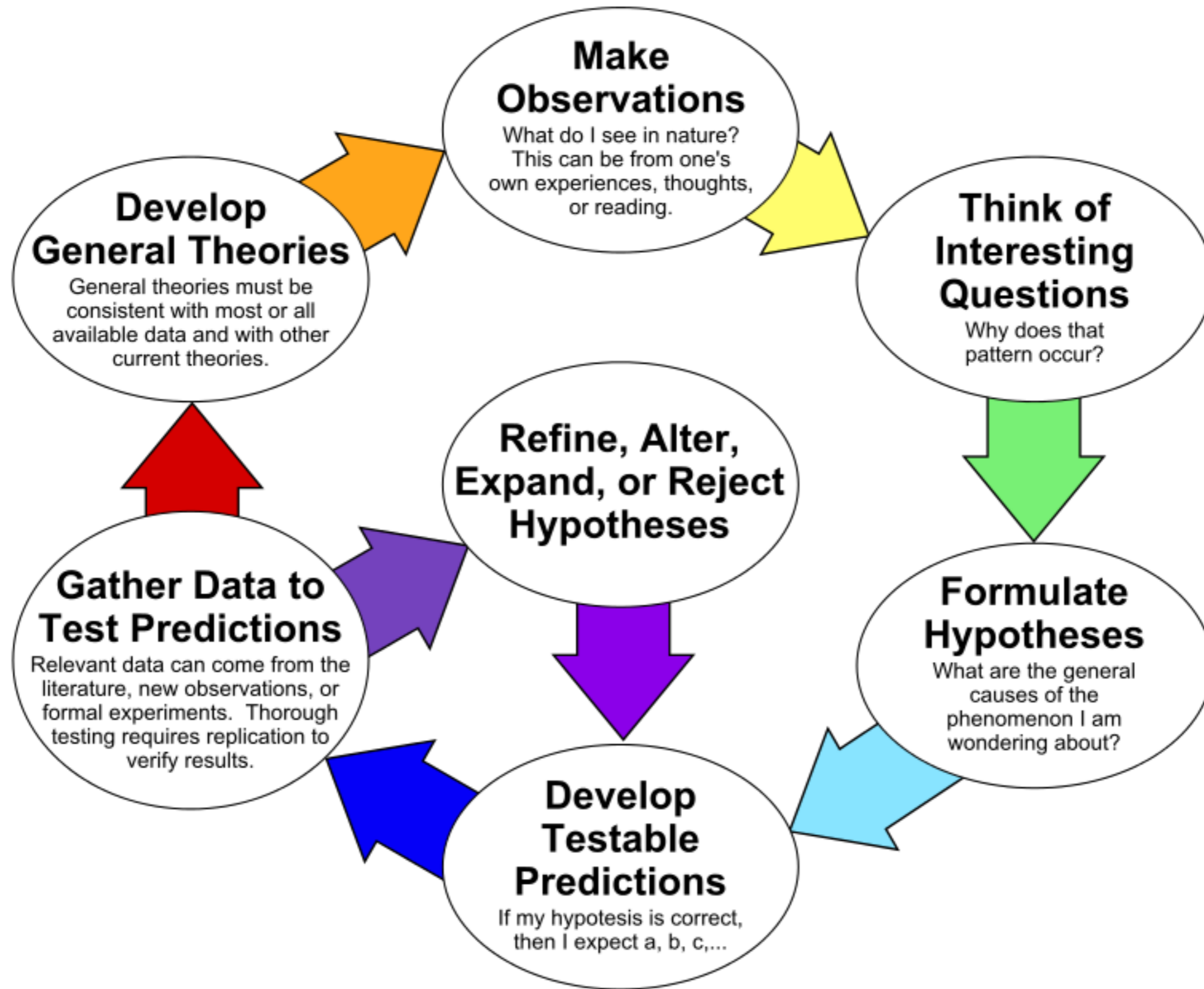
- Experimentation/observation

Experimentation/observation

- Goal: evaluation of hypotheses

- Aim to:

  - falsify (hypothesis-testing)

  - differentiate (model comparison)

- Types:

  - Controlled experiment (ex. medicine)

  - Natural experiment (ex. Vietnam draft by lottery)

  - Observation (ex. astronomy)

- Confirmation holism (ex. Neptun & Vulcan)

Scientific Method: elements

- Data characterization

- Hypotheses generation

- Predictions

- Experimentation/observation

The Scientific Method as an Ongoing Process

Make Observations
What do I see in nature? This can be from one's own experiences, thoughts, or reading.

Think of Interesting Questions
Why does that pattern occur?

Formulate Hypotheses
What are the general causes of the phenomenon I am wondering about?

Develop Testable Predictions
If my hypotesis is correct, then I expect a, b, c,...

Gather Data to Test Predictions
Relevant data can come from the literature, new observations, or formal experiments. Thorough testing requires replication to verify results.

Refine, Alter, Expand, or Reject Hypotheses

Develop General Theories
General theories must be consistent with most or all available data and with other current theories.

Source: wikipedia

Marr's levels of understanding the brain

Computational goal	Understanding
Process/algorithm	Scientific method
Implementation	Scientific community

-> Replication crisis