Fundamentals of experimental design and analysis

BIOL2022 - L01

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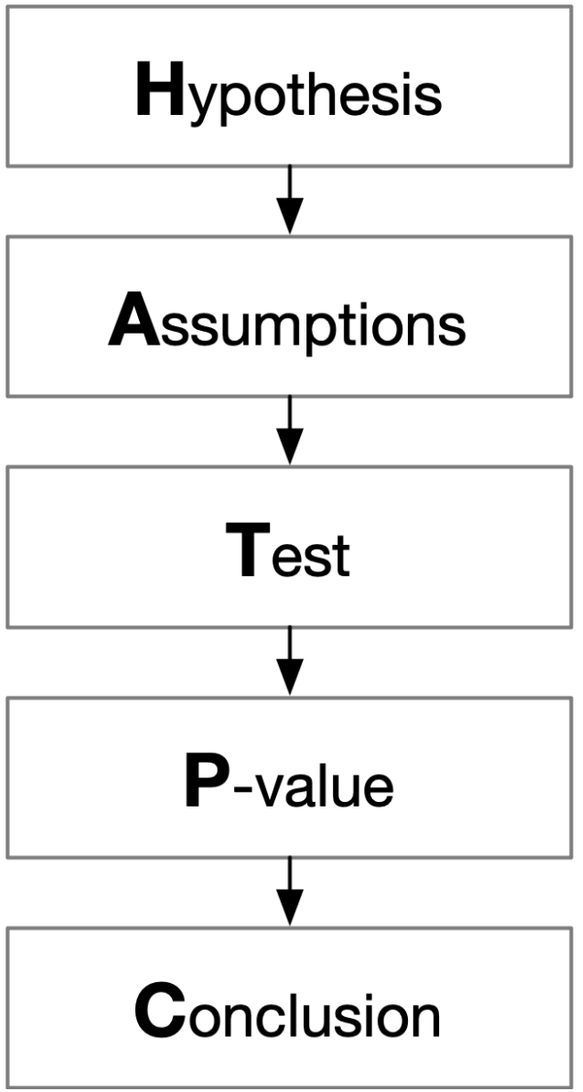
Learning outcomes

By the end of this lecture, you should be able to:

1. Explain why planning must happen before data collection.
2. Describe experimental design and analysis as an iterative process.
3. Use a graph to propose a relationship between two variables.
4. Write that relationship as a simple empirical model.

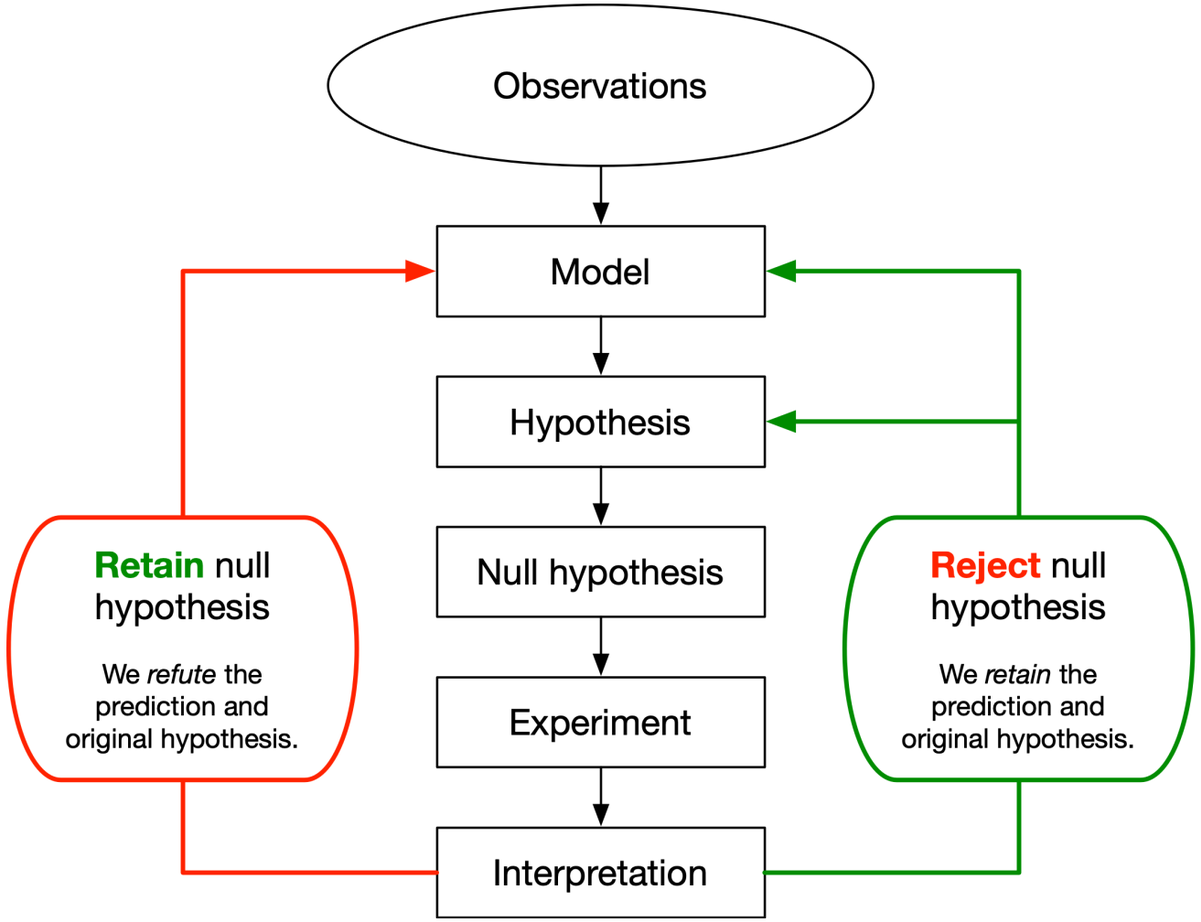
Workflows?

HATPC



HATPC, used in several data science units at the University of Sydney.

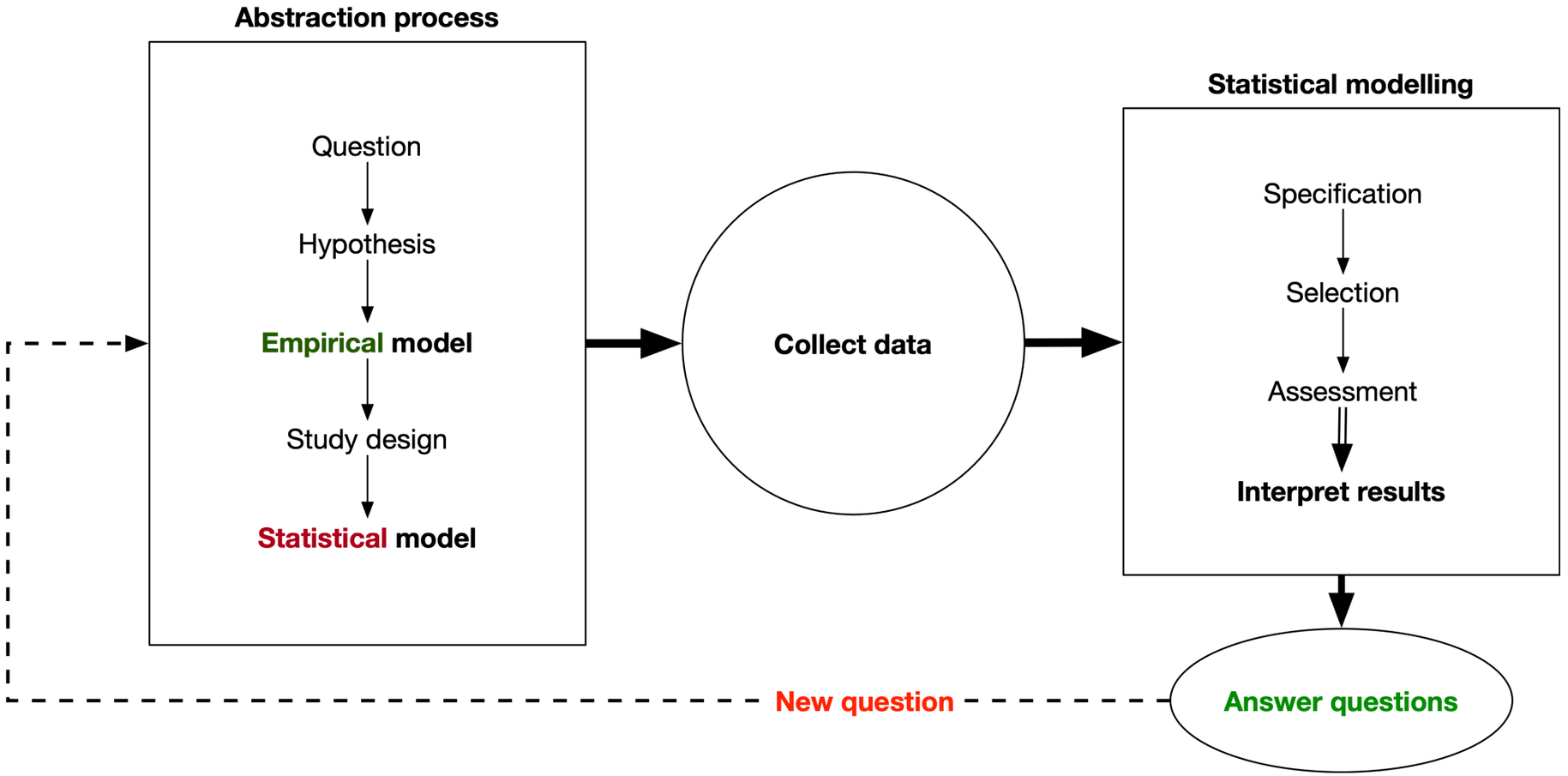
Logical framework[1]



A logical framework for ecological research proposed by Underwood (1997).

[1]Underwood AJ (1997) Experiments in Ecology: Their Logical Design and Interpretation using Analysis of Variance. Cambridge University Press, Cambridge.

Experimental design workflow[2]



A model-centred approach to experimental design from Fox et al. (2015).

[3]Fox, G. A., S. Negrete-Yankelevich, and V. J. Sosa. (2015). Ecological statistics: contemporary theory and application. Oxford University Press, USA.

What do the workflows have in common?

Planning is *fundamental*

There is no magical statistical method that will make up for a poorly designed study.

🗑️ *Garbage in* → *Garbage out* 💩

Why do we care?

> *"A single poor design choice can make an experiment nearly worthless."*
>
> – Lazic et al. (2018)

> *"Far better an approximate answer to the right question … than an exact answer to the wrong question."*
>
> – John Tukey (1962)

Planning the study

We need to think about:

1. What question are we trying to answer?
2. What data would answer that question?
3. What relationship do we expect between the variables?

The relationship we expect is our starting **model**.

We may revisit these decisions as the study develops.

What are models?

What does this represent? Licensed from Adobe.

This model retains enough information to describe the terrain without showing any value.

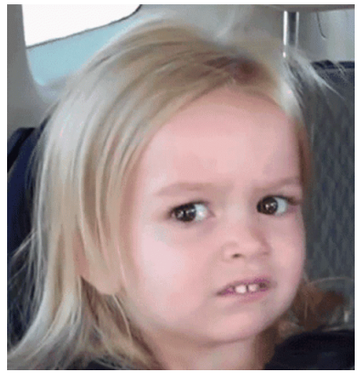
Models:

- focus on relationships between variables.
- help us explain patterns and make predictions.

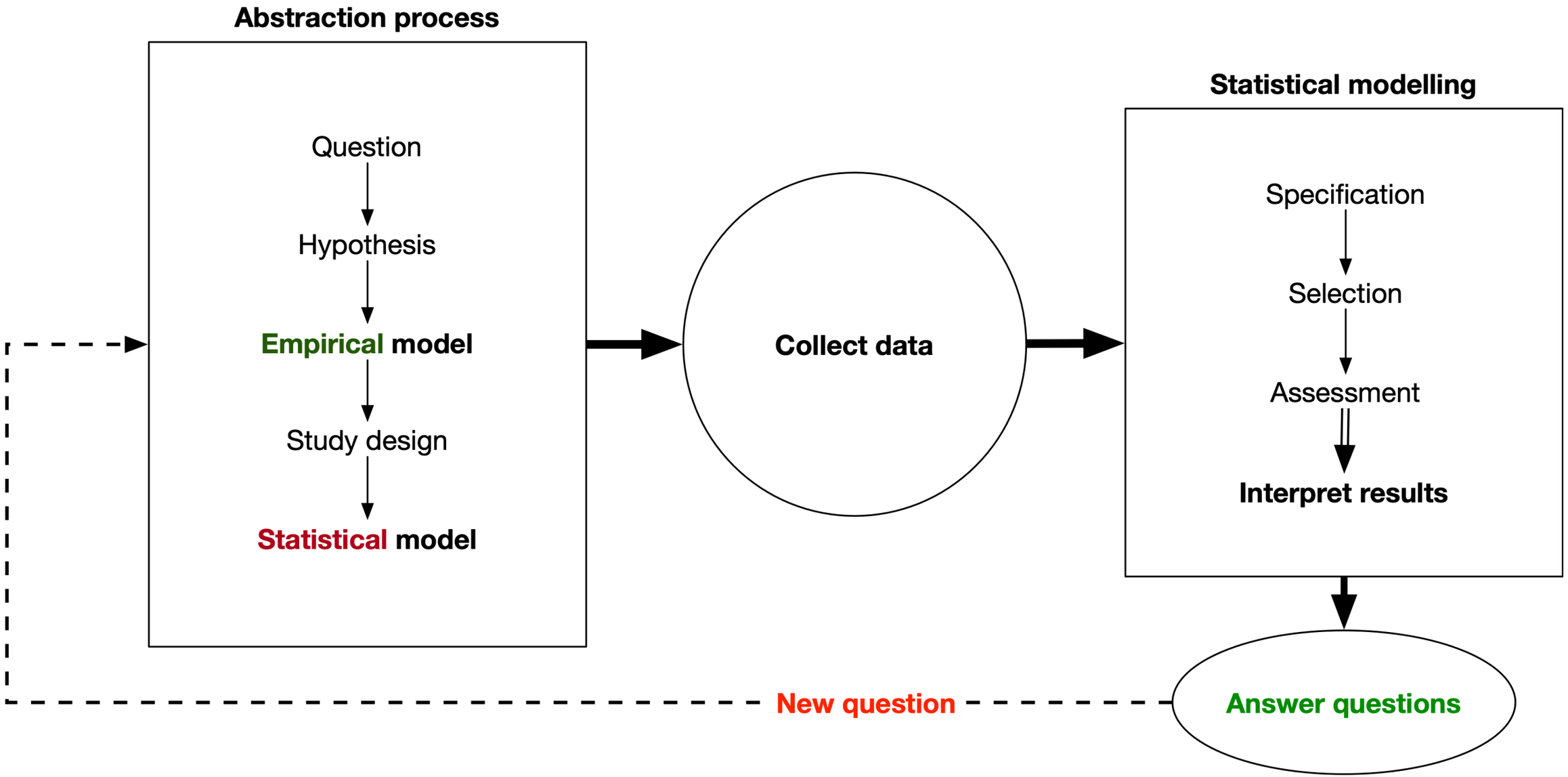
Traditional statistics

Biological question	Predictor	Technique
Do two groups differ?	Two categories	t-test
Do several groups differ?	Several categories	ANOVA
Is there a “relationship”?	Continuous measurement	Linear regression

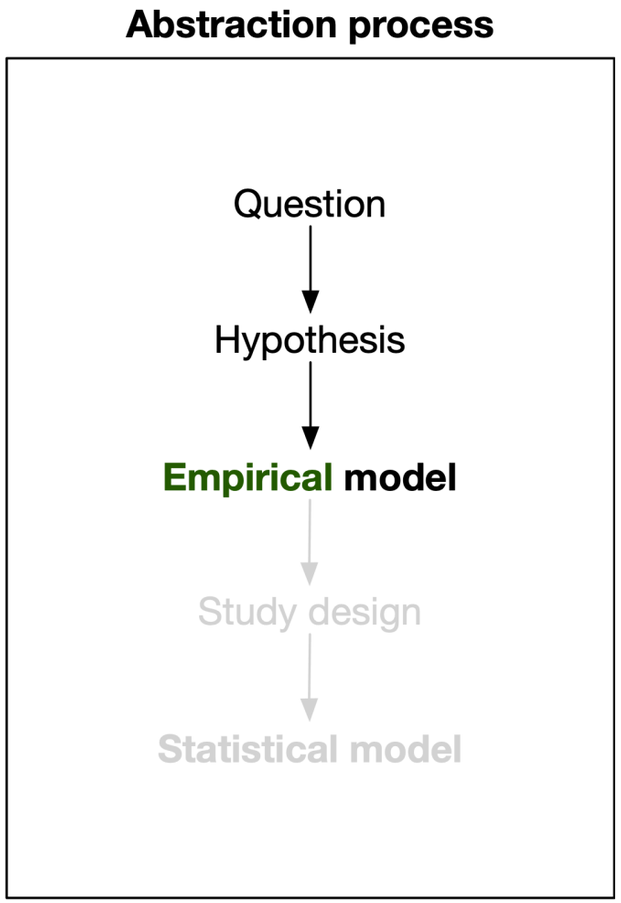
Many of us have learnt statistics as a set of techniques, often relying some kind of decision tree.



A model-centred view



A model-centred view



- No data or statistics to worry about (yet)
- Focus on the relationship between variables

1. Question: “Is there a relationship?”
2. Hypothesis: “There is a relationship between the variables.”
3. Empirical modelling:
    - **Response** variable is what we want to explain.
    - **Predictor** variable(s) are what we think might explain the response.

The statistical model will *eventually* be a general linear model (GLM) with special cases, but we do not necessarily need to identify the “formal” name.

Example - sea urchins

Short-spined sea urchin (*Heliocidaris erythrogramma*). Photo: Julian Finn / Museums Victoria, CC BY 4.0.

Research question

Heliocidaris erythrogramma lives on rocky reefs along the NSW coast.

Experiments show that its metabolic rate can be affected by:

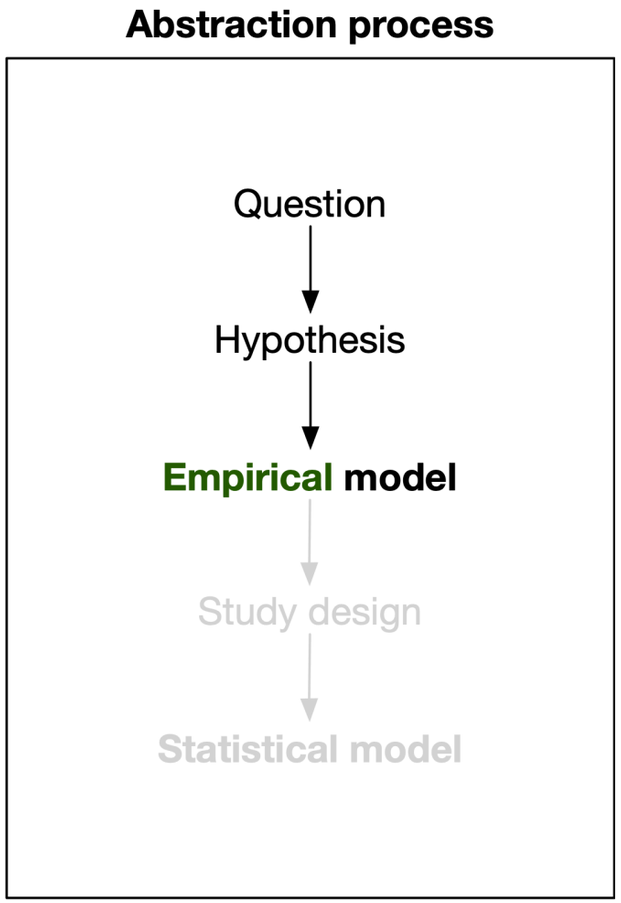
- water temperature
- body size
- seawater pH

For now, we will isolate one relationship:

> **How does water temperature affect metabolic rate?**

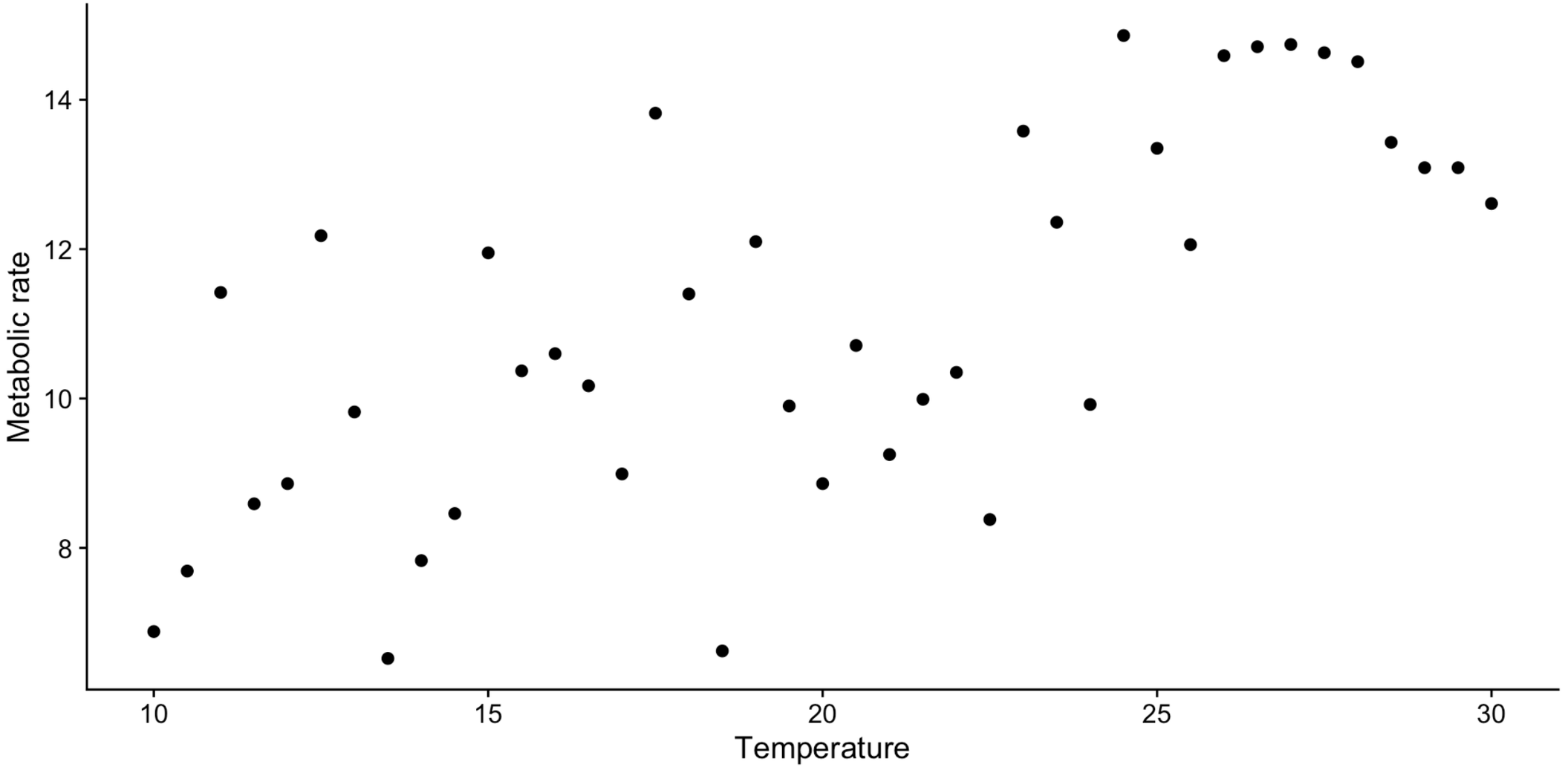
Carey et al. (2016)

Building the empirical model



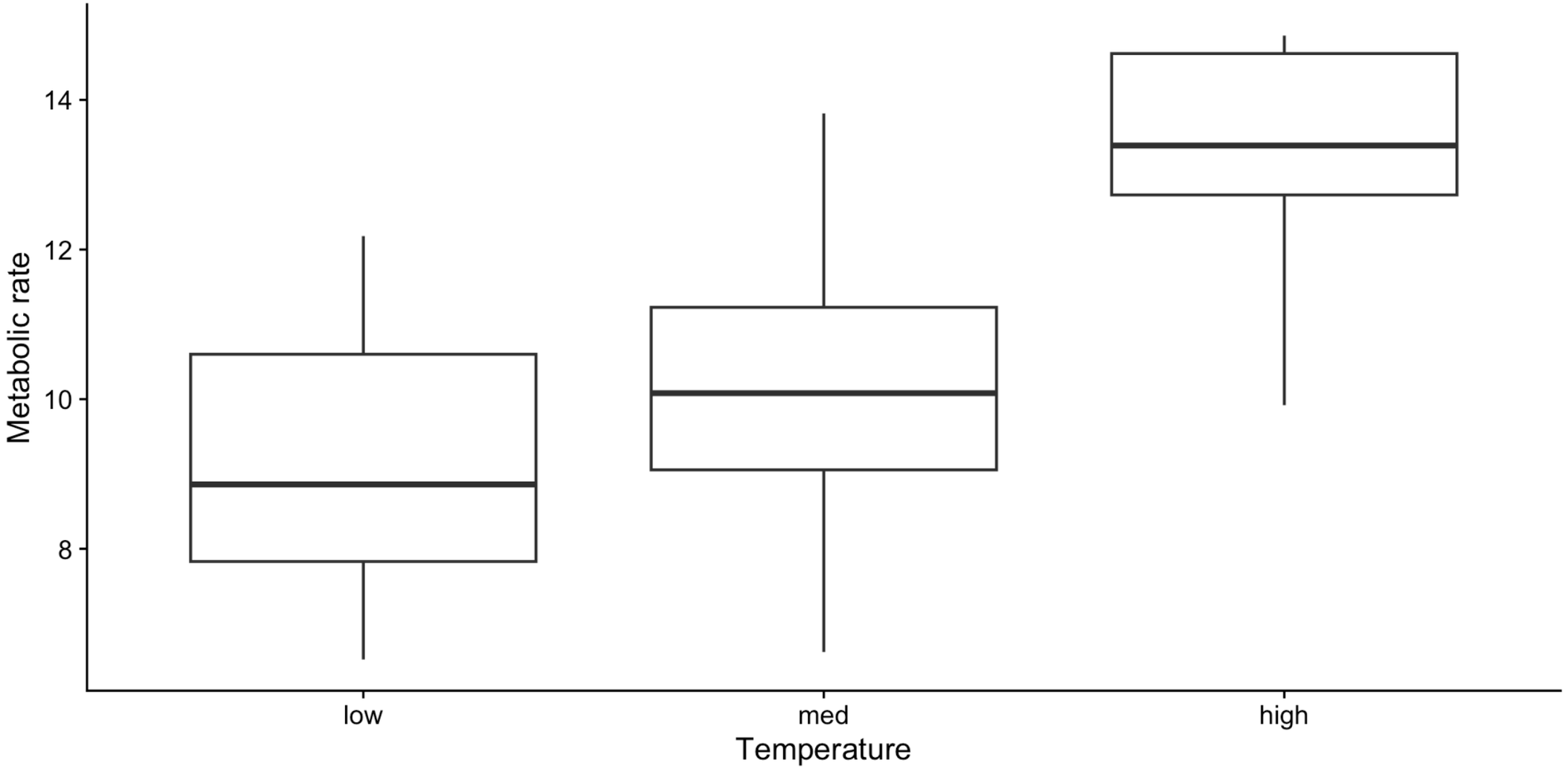
1. Question: “How does water temperature affect metabolic rate?”
2. Hypothesis: “Metabolic rate will increase as water temperature increases.”
3. Empirical model:
    - **Response:** metabolic rate
    - **Predictor:** water temperature
    - **Expected relationship:** positive

Temperature along a gradient



We could expose urchins to a range of temperatures and ask how their metabolic rate changes.

Temperature as treatment groups



Or we could choose a few temperatures and compare metabolic rate among the groups.

How we define the variable determines the experimental design

Both studies begin with the same biological idea, but they treat temperature differently.

- Across a gradient, we ask how metabolic rate changes with temperature.
- With treatment groups, we ask whether metabolic rate differs among temperatures.

The analyses will look different, but they share the same modelling framework.

Variables have roles and types

Variable	Role in the model	How we can represent it
Metabolic rate	Response	Continuous
Temperature	Predictor	Continuous or categorical

- A variable's **role** describes what it does in the model.
- Its **type** helps determine how we design the study.

Defining the model

- $y = f(x)$
- y is influenced by x.
- A **response** is influenced by a **predictor**.
- **Metabolic rate** is influenced by **temperature**.
- $\text{Metabolic rate} = f(\text{Temperature})$
- $\text{Metabolic rate} \sim \text{Temperature}$

The chosen model

$$\text{Metabolic rate} \sim \text{Temperature}$$

- The **response** variable is on the left of the tilde (~).
- The **predictor** variable(s) is on the right of the tilde (~).
- Easy to interpret, modify (e.g. add more predictors) and refer to.

Designing the study

The design must give us data that can answer the biological question.

- What temperatures will we study?
- What is the experimental unit?
- How will we replicate and randomise?
- What other sources of variation should we measure or control?
- How many independent experimental units do we need?

The model can grow

Begin with the relationship in our question:

$$\text{Metabolic rate} \sim \text{Temperature}$$

Account for another important biological variable:

$$\text{Metabolic rate} \sim \text{Temperature} + \text{Body size}$$

Add pH if it is part of the question or design:

$$\text{Metabolic rate} \sim \text{Temperature} + \text{Body size} + \text{pH}$$

We add variables because the biology and study design require them, not simply because they are available.

Just the beginning...

Did we do *any* statistics today?

We will cover more on models and study design in the next few weeks, but I hope you are less intimidated by the process!

Do not forget...

🗑️ *Garbage in* → *Garbage out* 💩

Thanks!

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