Research Design

Planning the experiment before you run it



Dinesh Ganotra · Research Methodology

What is a research design?

> *The arrangement of conditions for collection and analysis of data in a manner that aims to combine relevance to the research purpose with economy in procedure.*
>
> — Selltiz et al., quoted in C.R. Kothari, Research Methodology

In one line

A research design is the blueprint of a study — fixed before the first measurement is taken.

It decides **what, where, when, how much** and **by what means**.

A bad design cannot be rescued by good statistics. If the data were collected so that two causes are mixed up, no test can separate them afterwards.

The ten decisions a design settles

1. What is the study about?
2. Why is the study being made?
3. Where will it be carried out?
4. What type of data is required?
5. Where can the data be found?
6. What period of time will it cover?
7. What will the sample design be?
8. Which techniques of data collection?
9. How will the data be analysed?
10. In what style will the report be written?

Kothari groups them into four parts: sampling design · observational design · statistical design · operational design

Five words you need before any design

Dependent variable

The outcome you measure.

e.g. *Panel output power (W)*

Independent variable

The presumed cause — what you change.

e.g. *Coated or uncoated*

Extraneous variable

Also affects the outcome, but is not what you are studying.

e.g. *Sunlight, temperature, dust*

Control

Designing the study to minimise extraneous influence.

e.g. *Measure both panels at the same time*

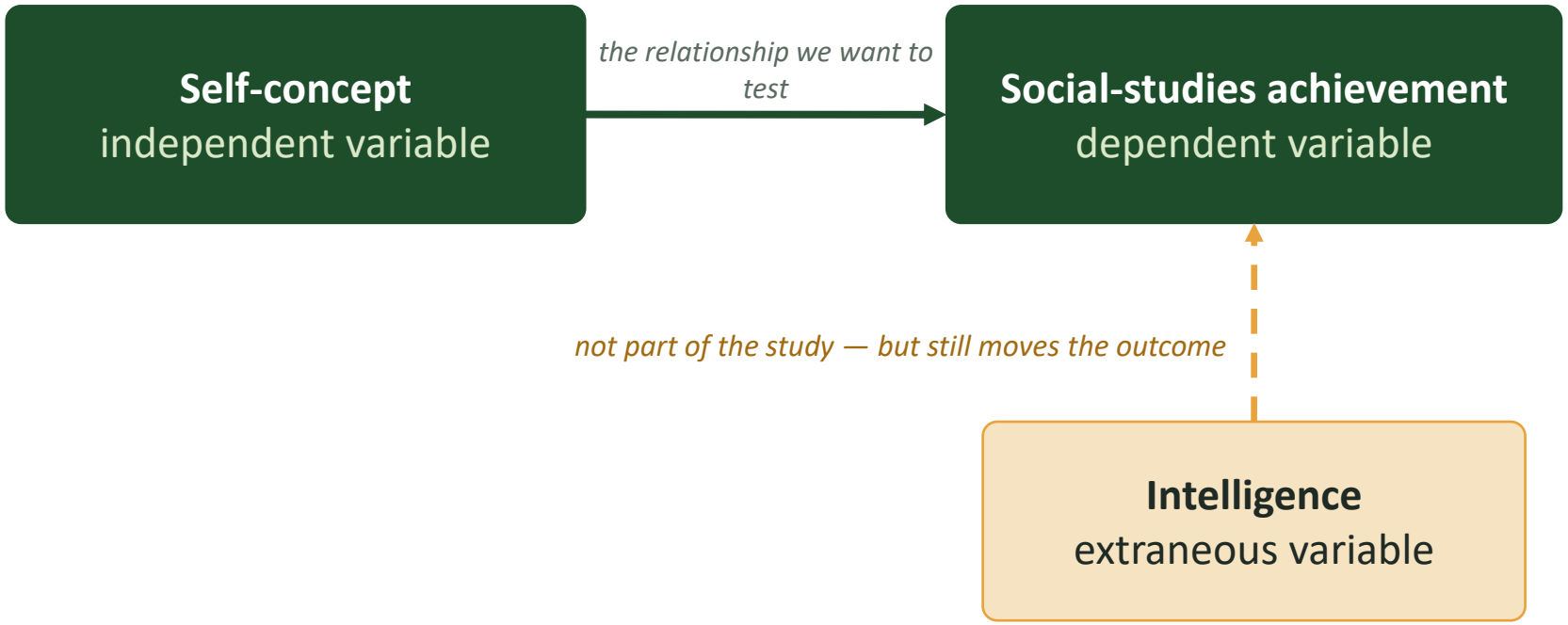
Confounded

The IV and an extraneous variable change together, so their effects cannot be separated.

e.g. *Coated on a sunny day only*

Research hypothesis: a predictive statement relating an independent variable to a dependent variable — *"An anti-reflection coating increases panel output."*

An extraneous variable at work



What this means

The effect of extraneous variables on the DV is called **experimental error**.

A good design **controls** it.

If it cannot be separated from the IV's effect, the relationship is **confounded**.

Example from C.R. Kothari, Research Methodology, Ch. 3



Our running example

Does an anti-reflection coating increase the power output of a solar panel?

We will test it with every design, and watch the answer change.

Independent variable

Coating applied: yes / no

Dependent variable

Output power of the panel, in watts

Extraneous variables

Sunlight on the day, panel temperature, dust, panel age, manufacturer

The designs we will build

Informal designs

Compare groups or time points; simple differences

1. Before-and-after without control
2. After-only with control
3. Before-and-after with control

Formal designs

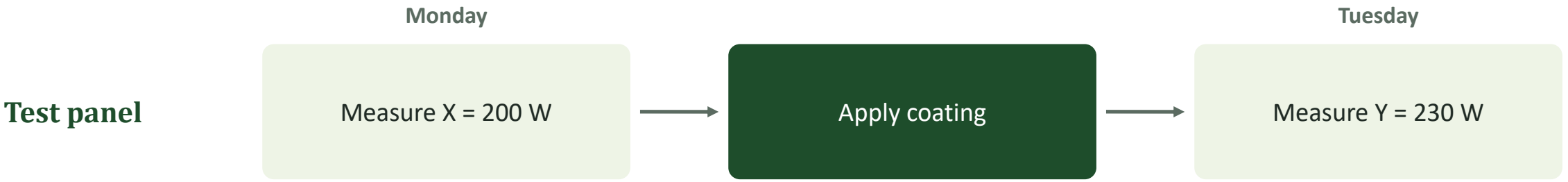
Randomisation + statistical analysis (t-test, ANOVA)

4. Completely randomised design (CRD)
5. Randomised block design (RBD)
6. Latin square design (LSD)
7. Factorial design

Each design fixes a weakness of the one before it.

1 Before-and-after without control

One panel. Measure, apply the coating, measure again.



Estimated effect

$Y - X = 30$ W

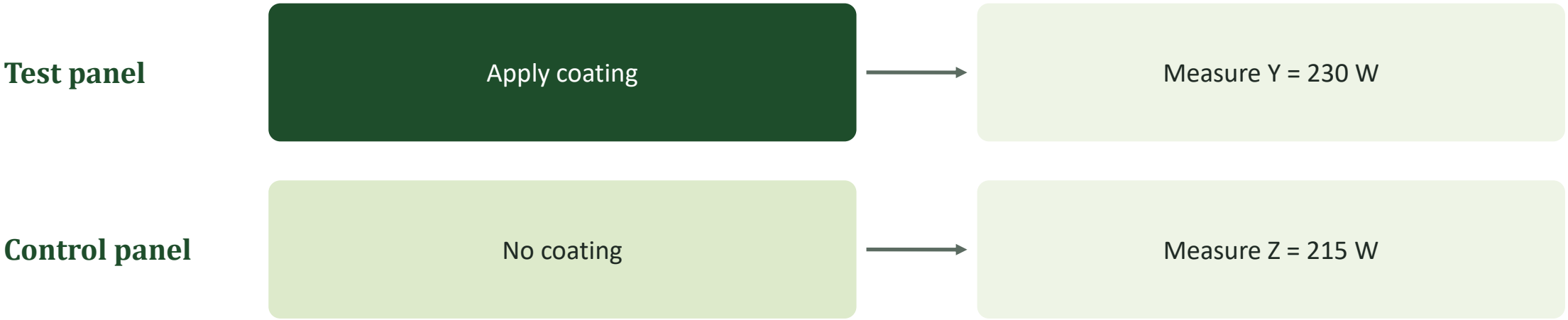
The coating “adds” 30 W?

The weakness

Tuesday was sunnier. Every change between the two measurements — sunlight, temperature, dust — is credited to the coating. Time is confounded with treatment.

2 After-only with control

Two panels, measured at the same moment. Only one is coated.



Estimated effect

Y − Z = 15 W

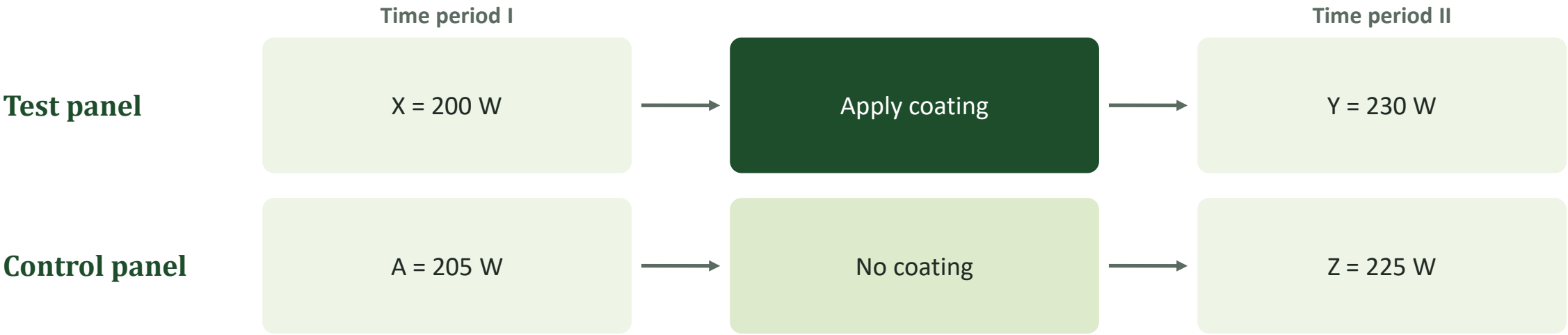
Same sunlight for both — better.

The weakness

It assumes the two panels were identical before the experiment. If the test panel was simply the better panel to begin with, that difference is credited to the coating.

3 Before-and-after with control

Both panels measured twice; only the test panel is coated in between.



Estimated effect

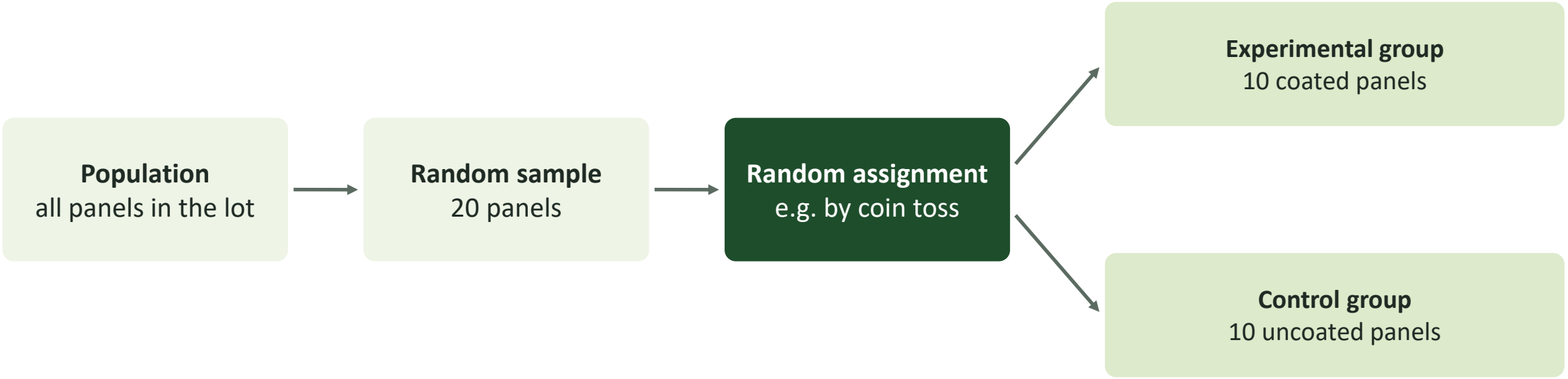
$(Y - X) - (Z - A) = 30 - 20 = 10$ W

The control panel gained 20 W from sunshine alone. The honest answer is 10 W, not 30 W.

The weakness

Still only one panel per group — we cannot tell a real effect from panel-to-panel noise. We need many panels, assigned at random.

4 Completely randomised design (CRD)



Why randomise? Every panel has the same chance of landing in either group, so extraneous differences — manufacturing quality, age, dust — spread evenly across both groups instead of piling up in one.

Analysis: compare the two group means with a two-sample t-test; for more than two groups, one-way ANOVA(will study later).

5 Randomised block design (RBD)

Five manufacturers (blocks) × four coatings. Each cell is a different panel.

	Maker 1	Maker 2	Maker 3	Maker 4	Maker 5
Panel 1	**TiO_2** 261 W	**MgF_2** 242 W	**Uncoated** 219 W	**SiO_2** 214 W	**TiO_2** 206 W
Panel 2	**Uncoated** 250 W	**SiO_2** 241 W	**TiO_2** 231 W	**MgF_2** 217 W	**SiO_2** 199 W
Panel 3	**SiO_2** 254 W	**Uncoated** 236 W	**MgF_2** 229 W	**TiO_2** 223 W	**Uncoated** 194 W
Panel 4	**MgF_2** 259 W	**TiO_2** 248 W	**SiO_2** 226 W	**Uncoated** 211 W	**MgF_2** 204 W

Within each maker, which panel gets which coating is drawn by lot. Illustrative data.

Principle of local control. Group similar units into blocks; every treatment appears exactly once in every block.

Randomised: inside each block, treatments are assigned to units at random — note the order differs in every column.

Maker 1 panels are simply better than Maker 5 panels. Comparing coatings ***within*** each column removes that difference.

Question for the class: **What is the extraneous variable here? How is it nullified?**

6 Latin square design (LSD)



A, B, C, D = four coatings

Two extraneous variables at once. Roof position (shade, tilt) varies by row; sunlight varies by day.

Each coating appears exactly once in every row and every column — so neither position nor day can favour any coating.

Limitations: the number of treatments must equal the number of rows and columns, and it assumes the factors do not interact.

Kothari's classic example: 5 fertilisers across 5 seed varieties and 5 soil-fertility levels.

6 Latin square design (LSD)

	Day 1	Day 2	Day 3	Day 4
Position 1	Uncoated	MgF_2	SiO_2	TiO_2
Position 2	MgF_2	SiO_2	TiO_2	Uncoated
Position 3	SiO_2	TiO_2	Uncoated	MgF_2
Position 4	TiO_2	Uncoated	MgF_2	SiO_2

Colours match the RBD slide

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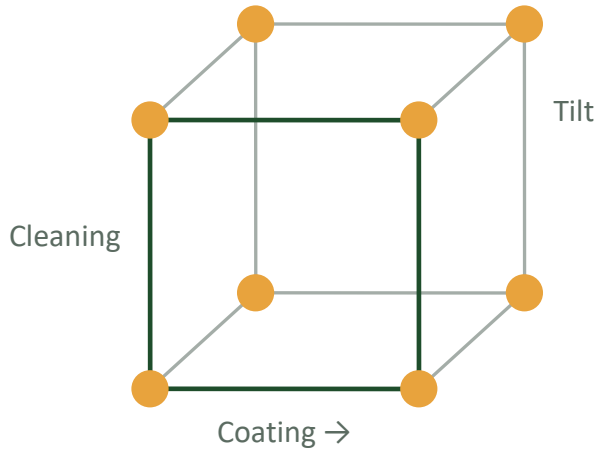
Factorial design: count by multiplying

Choose the factors, choose their levels, then test every combination. The name comes from "factor", not from n!

	Uncoated	Coated
Dusty	200 W	205 W
Clean	220 W	235 W

2 × 2 = 4

coating × cleaning: a square



2 × 2 × 2 = 8

add tilt: one condition per corner

Factors	Levels	Conditions
2	2 each	$2^2 = 4$
3	2 each	$2^3 = 8$
3	3, 2, 2	$3 \times 2 \times 2 = 12$
4	2 each	$2^4 = 16$
4	3 each	$3^4 = 81$
5	3 each	$3^5 = 243$

Rule: multiply the levels of every factor. Three 2-level factors give 2 × 2 × 2 = 8 conditions — a cube, not a 6 × 6 matrix. More levels grow fast: four factors at 3 levels each already need $3^4 = 81$.

Why a factorial design is economical

Three factors (coating, cleaning, tilt). Goal: estimate each effect as a mean of 4 runs minus a mean of 4 runs.

One factor at a time

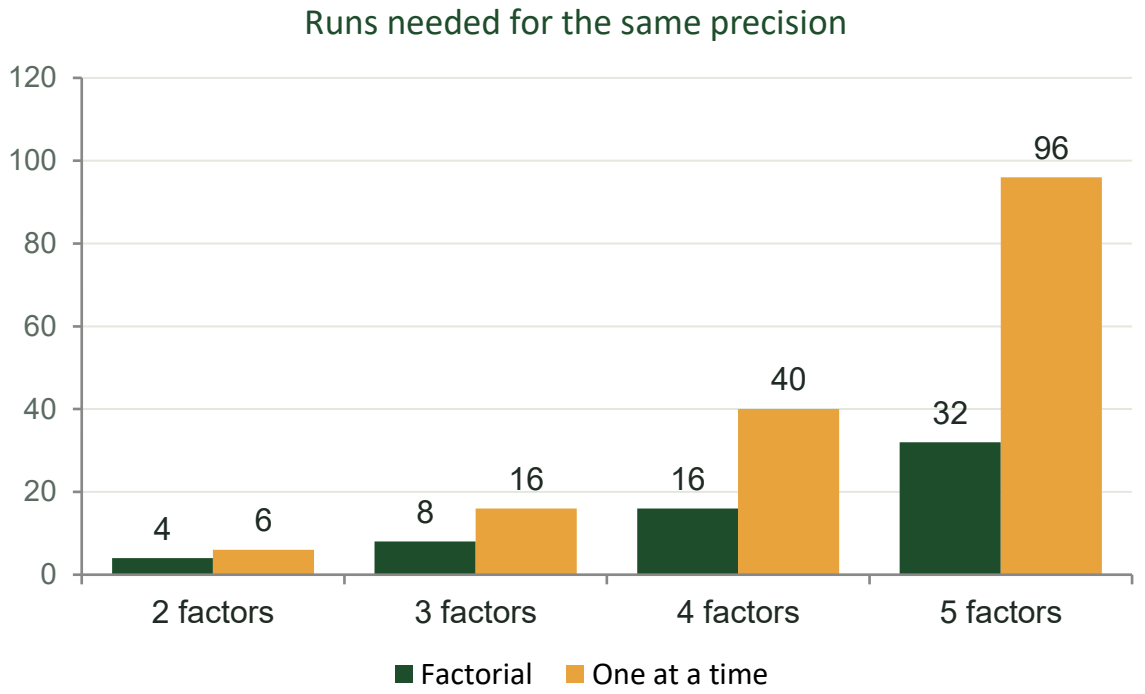
Baseline, then change coating, cleaning, tilt: 4 conditions.

4 conditions × 4 repeats = **16 runs**. Each effect uses only 8 of them.

Factorial (2^3)

All 8 combinations, each run once: **8 runs**.

Every run counts towards every effect: each comparison is 4 runs vs 4 runs, reusing the same 8.



Bonus: only the factorial can see interactions. One-at-a-time never tests two changes together.

The catch: levels multiply ($3^4 = 81$). Engineers then use fractional designs — Taguchi's L9 array tests four 3-level factors in 9 runs, main effects only.

7 Factorial design

Two factors studied together, in every combination. Here: does a defendant's attractiveness change the sentence a jury gives?

Type of crime →

Attractiveness ↓	Robbery	Swindle
Ordinary	5.1 years (mean)	6.4 years (mean)
Attractive	2.2 years (mean)	10.5 years (mean)

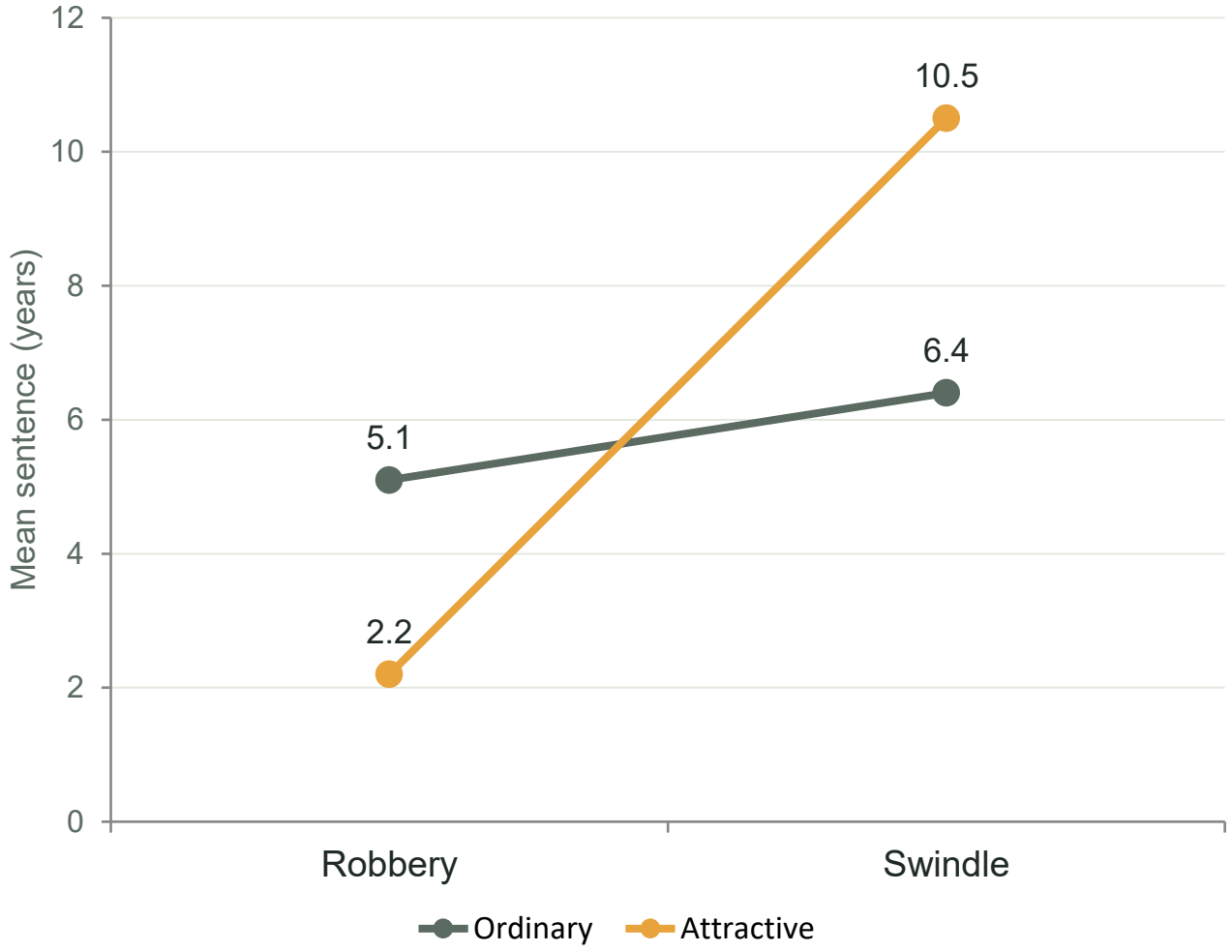
A 2 × 2 design: 2 levels of attractiveness × 2 types of crime = 4 conditions.

One experiment answers three questions:

- Does attractiveness matter?
- Does the type of crime matter?
- Does the effect of one depend on the other? (interaction)

Illustrative data in the style of Sigall & Ostrove's (1975) jury study.

Reading an interaction



The lines cross → interaction.
Attractiveness lowers the sentence for robbery but raises it for swindle — perhaps because charm was the swindler's tool.

Why averages mislead

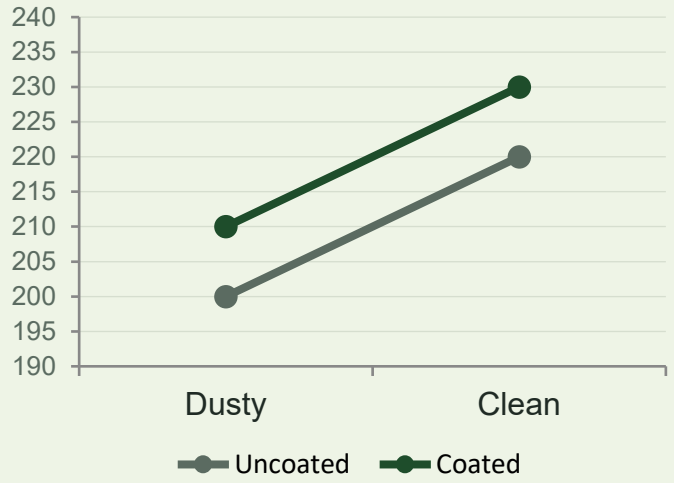
Averaged over both crimes: attractive 6.35 years, ordinary 5.75 years — a small difference that hides two large, opposite effects.

Only a factorial design can reveal this.

Parallel, diverging, crossing

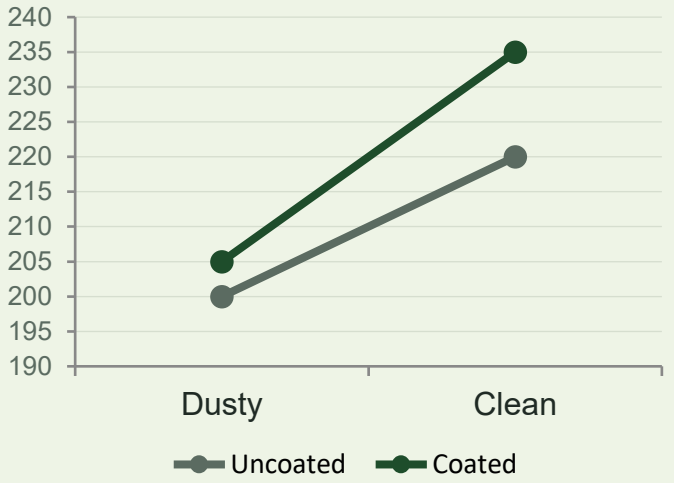
Plot one factor on the x-axis and draw one line per level of the other. The shape of the lines tells you about the interaction.

Parallel: no interaction



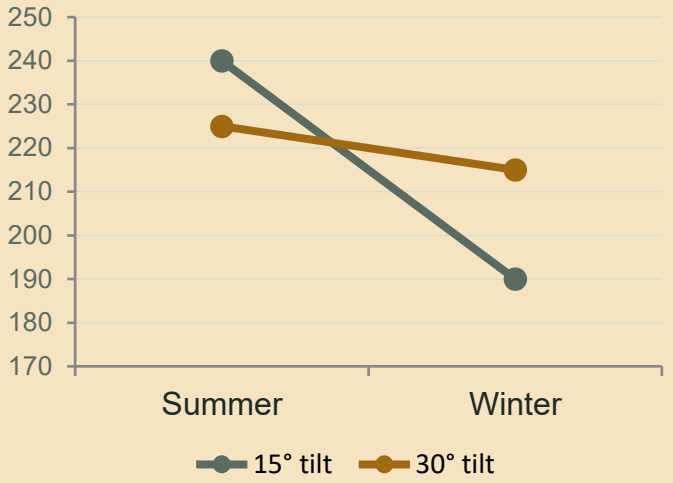
Coating adds 10 W whether dusty or clean.
Difference of differences = 10 − 10 = 0.

Diverging: interaction



Coating adds 5 W dusty, 15 W clean.
Difference of differences = 15 − 5 = 10 W.

Crossing: effect reverses



15° wins in summer, 30° wins in winter.
Asking “which tilt is better?” has no single answer.

Interaction = difference of differences. Zero → parallel lines. Non-zero → the lines tilt. Large enough to flip the sign → they cross.

Choosing a design

Design	What it controls	Main weakness
Before-and-after, no control	Nothing beyond the unit itself	Changes over time are credited to the treatment
After-only with control	Changes over time	Assumes the groups were equal to begin with
Before-and-after with control	Time and initial differences	Too few units to separate effect from noise
Completely randomised (CRD)	Unknown extraneous variables, by chance	Large known differences between units remain as noise
Randomised block (RBD)	One known extraneous variable	Needs sensible blocks; one treatment per block
Latin square (LSD)	Two known extraneous variables	Treatments = rows = columns; assumes no interaction
Factorial	Several factors and their interactions	Number of conditions multiplies quickly



Design it yourself

Does listening to music while typing change typing speed?

1. State H_0 and H_1, the independent and the dependent variable.
2. List three extraneous variables — and how you would control each one.
3. Choose a design from today's lecture and justify it. Would blocking help?
4. In this study, what would a Type I error be? And a Type II error?