LESSON 6.3.1

Evaluating Experimental Limitations

A useful evaluation explains what restricts confidence in a result, how the physics produces that restriction, and what evidence would test the explanation.

BUILD A CAUSAL EXPLANATION

1. IDENTIFY	Name a specific feature of the apparatus, method, data or model.
2. EXPLAIN	Describe the mechanism: what quantity changes, and why?
3. TRACE	Use the result equation to predict bias, scatter or restricted scope.
4. TEST	State a targeted check and what change you would expect to see.

MATCH THE CLAIM TO THE EVIDENCE

SCATTER	Repeated readings reveal variation. Averages can reduce random effects but cannot remove a shared bias.
BIAS	A reference check or an independent method may expose a consistent shift even when repeats agree closely.
SCOPE	A narrow range or an untested model assumption limits how widely the conclusion can be applied.

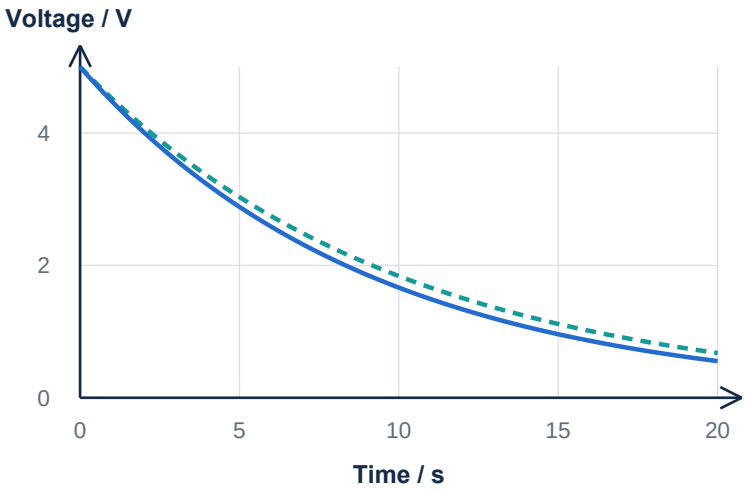
Avoid a list of generic “human errors”. Distinguish observed evidence from a plausible mechanism, and do not claim an error direction when competing effects make it uncertain.

Curriculum reference: Pearson IAL Physics specification, Unit 6 evaluation.

1 The instrument can change the system

Example: a capacitor discharges through a resistor R. A voltmeter across the capacitor has finite input resistance, providing an additional parallel discharge path.

ILLUSTRATIVE DISCHARGE: SAME INITIAL VOLTAGE



Dashed teal: ideal meter, time constant 10.0 s.

Solid blue: finite input resistance, time constant 9.09 s.

A. CALCULATE THE EFFECTIVE RESISTANCE

$$R_{eff} = \frac{R\,R_m}{R + R_m} \qquad \tau = R_{eff}\,C$$

Let R = 1.00 MΩ, meter input resistance = 10.0 MΩ and true C = 10.0 μF. These are illustrative values; assume all resistances and the capacitance are constant.

B. IGNORING LOADING MAKES THE INFERRED C TOO SMALL

$$R_{eff} = 0.909\ \text{MΩ} \qquad C_{inferred} = \frac{\tau}{R} = 9.09\ \mu\text{F}$$

9.09 μF is 9.1% below the true 10.0 μF in this model.

C. TEST THE MECHANISM

Repeat with a higher-input-resistance meter. If loading matters, the measured time constant should increase towards the unloaded value. Alternatively include the measured input resistance in the model.

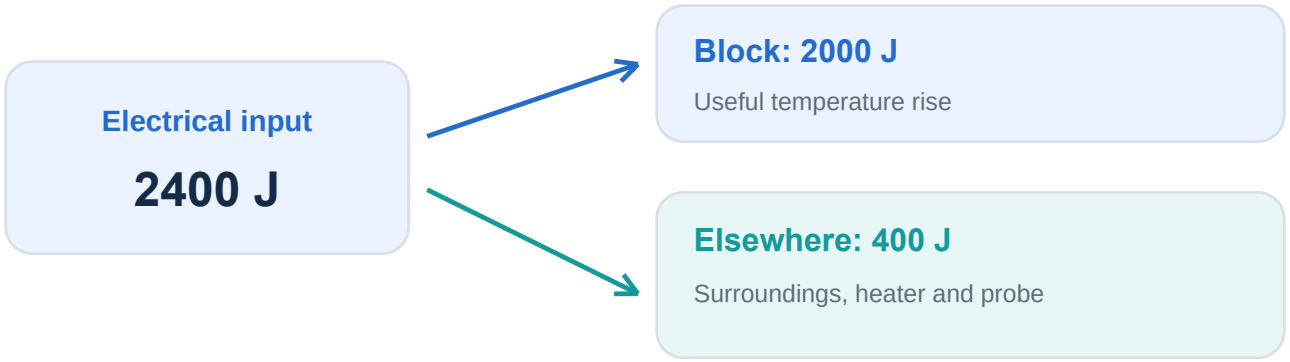
More repeats with the same meter will not remove this bias. An exponential curve can still look excellent because a constant parallel resistance preserves the exponential form.

Physics reference: OpenStax University Physics 2, §10.4 Measuring instruments.

2 Trace energy that the model leaves out

Example: an electrical heater warms a metal block. Calculating specific heat capacity from electrical energy assumes that all of that energy raises the temperature of the block.

ILLUSTRATIVE ENERGY ACCOUNT OVER ONE HEATING RUN



The 400 J is specified for this worked illustration. In a real experiment, it must be estimated or measured, not assumed from the final answer.

A. FOLLOW THE RESULT EQUATION

$$c_{calculated} = \frac{E_{electrical}}{m\,\Delta T} = \frac{2400}{0.200 \times 20.0} = 600\ J\ kg^{-1}\ K^{-1}$$

$$c_{true} = \frac{E_{block}}{m\,\Delta T} = \frac{2000}{0.200 \times 20.0} = 500\ J\ kg^{-1}\ K^{-1}$$

For a 0.200 kg block with a 20.0 K rise, ignoring the energy transferred elsewhere overestimates c by 20%. For the same input, that transfer reduces the observed temperature rise.

B. DISTINGUISH PLAUSIBLE COMPETING EFFECTS

A probe that lags the block during heating can underestimate the final temperature rise and raise the calculated c. But poor probe placement may create temperature differences whose effect depends on where the probe sits.

Check an insulated repeat and the cooling trend; compare probes at different positions or allow temperatures to settle while accounting for cooling. A change supports a mechanism but does not isolate every effect.

Physics reference: OpenStax University Physics 2, §1.4 Heat and calorimetry.

3 Judge which limitations matter most

Rank effects by their impact on the final quantity, not by the number of decimal places on an instrument. A small percentage uncertainty in an input can be amplified by a power.

WORKED EXAMPLE: A MASS ON A LIGHT SPRING

m = (0.200 ± 0.001) kg; 20 cycles take (20.0 ± 0.2) s.

Assume the count is exact, spring mass negligible and damping weak.

$$T = 1.00\ \text{s} \qquad k = \frac{4\pi^2 m}{T^2} = 7.90\ \text{N m}^{-1}$$

$$\frac{\delta k}{k} \times 100\% \approx 0.5\% + 2(1.0\%) = 2.5\%$$

From these stated inputs: k ≈ (7.9 ± 0.2) N/m.

Timing contributes 2.0 percentage points to the estimate, compared with 0.5 from mass. It is the larger quantified contribution here. Unknown systematic effects are not included in this budget.

THREE CHECKS BEFORE CLAIMING CONFIDENCE

1. CONTRIBUTION

Timing more cycles lowers fractional timing uncertainty only if the absolute start/stop uncertainty stays similar and the period stays stable. It does not correct a timer scale error.

2. MODEL

If the spring mass is appreciable or damping is strong, the simple period equation is limited. Compare with a static force-extension measurement or test different masses.

3. DATA RANGE

Closely spaced masses may not discriminate between models. Test a useful range while staying in the spring's elastic regime; do not extrapolate beyond the tested conditions.

Write a balanced judgement: the dominant evidenced limitation, its mechanism and likely effect, a targeted check, and what remains uncertain. Agreement alone does not prove that all limitations are negligible.

References: Pearson uncertainty guidance; OpenStax §15.1 Simple harmonic motion.

Next: 6.3.2 Improving precision, validity and reliability.