

3.3.2 Uncertainty, evaluation and statistics

Name: _____ Class: _____ Date: _____ Total: **24 marks**

KEY WORDS random error • systematic error • anomalous result
• error bars

Objective

Evaluate results the way WBI13 credits: random versus systematic error, percentage uncertainty, anomalies, realistic improvements, and named statistics (mean, SD, range, error bars) for variability and comparison. Original practice for the Unit 3 evaluation criteria.

1 Key knowledge and worked examples

■ Errors and what repeats can and cannot fix

Random error makes readings scatter either side of the true value; repeating and averaging reduces its effect on the mean. A **systematic error** shifts every reading the same way (a zero offset on the colorimeter, a mis-calibrated graticule); averaging does not remove it – zero the instrument on a blank, calibrate against a standard.

■ Uncertainty in arithmetic

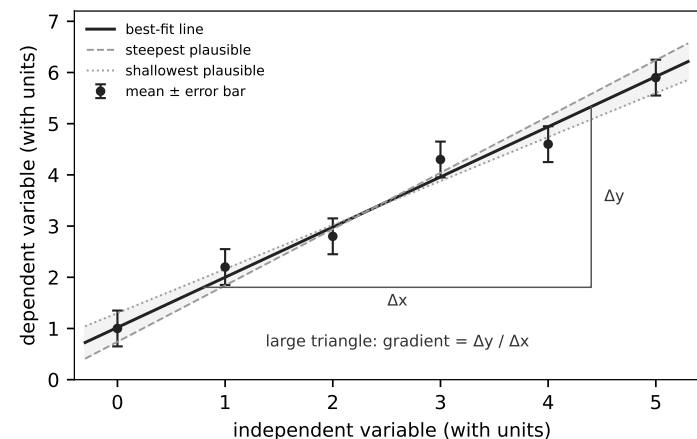
Percentage uncertainty of one reading = $(\text{absolute uncertainty} \div \text{value}) \times 100\%$. For a product or quotient of independent measurements, add the percentage uncertainties; for a difference, add the absolute uncertainties first. Quote results to the significant figures the inputs support.

$$\frac{1.0 \text{ mm}}{50.0 \text{ mm}} \times 100\% = 2.0\%$$

■ Anomalies and improvements

An **anomalous result** is inconsistent with the other readings – a point far from the line of best fit. Check it by repeating that treatment; do not delete it silently. Improvements are named and realistic: a colorimeter replaces eye-judged colour (quantitative, removes judgement); zeroing removes an offset; more values within the range narrows interpolation; a thermostatted water bath holds temperature

better than a beaker.



■ Statistics the scheme names

For variability: standard deviation (SD), standard error, range, or error bars – name one and use it. Comparing organisms: repeat on *different* individuals under the same conditions, then report the mean with the spread. Overlapping error bars mean the difference is not secure.

2 Practice

2.1 State one thing repeat readings improve, and one kind of error they cannot remove, naming a fix for that kind. [3]

2.2 A length of 50.0 mm is measured with an absolute uncertainty of 1.0 mm, and a time of 20 s with 1 s. Calculate each percentage uncertainty and the maximum percentage uncertainty in a rate found by dividing length by time. [3]

2.3 Five replicate absorbance readings are 0.42, 0.44, 0.43, 0.41 and 0.62. Identify the anomaly and state what to do about it. [3]

2.4 A student compares pigment loss at two temperatures with three repeats each. State two statistics that would make the comparison convincing, and what overlap between them would mean. [3]

3 Exam-style questions

3.1 Describe how an investigation of starch content in one cassava root could be extended to determine the variability of starch concentration between different cassava roots, naming the conditions, the summary statistic and one measure of variability you would report. [3]

3.2 A gradient is determined from a best-fit line, with a steepest plausible gradient of 1.10 and a shallowest of 0.86 a.u. per hour. Explain how these lines were chosen, what they tell you about the gradient’s uncertainty, and why the triangle used should span at least half the line. [4]

3.3 A membrane-permeability method reports “colour was judged by eye against a printed scale; one reading per treatment”. Give three improvements, each with the weakness it removes, and state which one changes the method from semi-quantitative to quantitative. [5]

Solutions

Original-task marking: M1 method, A1 accuracy, B1 reasoning.

2.1 Repeats improve reliability and give a mean with an estimate of spread. They cannot remove a systematic error; fix it at the source – zero the colorimeter on plain solvent / calibrate the graticule against a stage micrometer.

2.2 Length: $1.0/50.0 \times 100 = 2.0\%$. Time: $1/20 \times 100 = 5\%$. Quotient maximum: $2 + 5 = 7\%$.

2.3 0.62 is inconsistent with the tight 0.41–0.44 group. Repeat that treatment; if confirmed, treat it separately – never delete silently, and report its cause if identifiable (e.g. an unshaken sample).

2.4 Mean absorbance per temperature with SD (or standard error, or range/error bars) per temperature. Overlap of the spreads means the two temperatures' difference is not secure – the means alone cannot support a conclusion.

3.1 Take roots grown under the same conditions and use the same equipment and measurement method throughout; repeat the measurement on several different roots and calculate each root's concentration, then the mean of the roots; report a named variability measure – SD, standard error, range or error bars.

3.2 The steepest and shallowest lines are the extreme plausible lines that still pass acceptably through the error bars; their gradients bound the best-fit gradient – the true gradient lies between 0.86 and 1.10, so the uncertainty is about ± 0.12 around the best-fit value. A small triangle magnifies reading error in Δy and Δx ; a triangle spanning at least half the line keeps the read-off error small relative to the values.

3.3 Improvements, each with its weakness: a colorimeter instead of the eye – removes subjective judgement and gives an objective value, this is the change from semi-quantitative to quantitative; zero on plain solvent – removes the systematic offset; repeat each treatment and take the mean – reduces random error / shows reliability; shake before sampling – uneven pigment distribution biases single readings.