Science, grade 12

All units for this subject and grade (unreviewed AI drafts)

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Grade 12 science: the extended investigation (planning, uncertainty, reporting, peer review)

> **Unreviewed AI draft.** Written by Claude Opus 5.5 (an AI agent) for the K-12 curriculum drafts project. No teacher has reviewed or taught it. Check every fact, number and safety note before use.

Band: 9-12 (ages 17-18) · **Strand:** Inquiry (all strands) · **Length:** 5 lessons, then a multi-week independent investigation

Big idea

A scientific result is only as good as the way it was found and reported. Before collecting data, a scientist decides what to measure, how, and how the data will be analysed. While measuring, they estimate how far each number can be trusted. Afterwards they report enough for someone else to repeat the work, and they let other people check it. This unit practises each step on one shared experiment (a simple pendulum) so that students can then run their own extended investigation.

Outcomes

By the end of the five lessons, students can:

1. Turn a broad question into a testable one, naming the independent, dependent and control variables, and write a short plan (including the analysis) **before** collecting data.
2. Tell random error from systematic error, and precision from accuracy (trueness), using an example from their own measurements.
3. Calculate a mean and an uncertainty (half the range) from repeated readings, and explain why timing ten swings beats timing one.
4. Plot data, linearise a relationship (T^2 against L), find a gradient, and use it to calculate a quantity (g), stating an uncertainty.
5. Write a report in the IMRaD structure (Introduction, Methods, Results, Discussion) that another student could repeat.
6. Give and respond to a specific, kind, written peer review.

Prior knowledge

- Fair tests and variables (grades 3-8 in the science progression).
- Means, graphs and gradients; the grade 9 trolley unit's $a = 2d/t^2$ analysis (grade 9 forces and Newton's laws).
- Squares and square roots; rearranging a formula.

Lessons

1. From a question to a plan — testable questions, variables, a pilot run, and writing the plan and analysis down first.

2. Measurement and uncertainty — random vs systematic error, precision vs accuracy, reaction time, repeats, mean and half-range.
3. Analysing data honestly — T^2 against L, gradient, g, outliers, and correlation vs causation.
4. Writing the report — IMRaD, methods someone can repeat, uncertainties, limitations, and why replication matters.
5. Peer review — reviewing a report with a checklist, responding to reviewers, and launching the extended investigation.

Materials

- Per group of 2-3: clamp stand, boss and clamp (G-clamped or weighted to the bench), thin string (about 1.2 m), a small bob (50-100 g mass or a metal washer stack), metre rule, stopwatch or phone timer, protractor, graph paper or a spreadsheet.
- Lesson 5: printed or shared copies of each group's report, the review checklist, and coloured pens.

Assessment

- **Closing check (lesson 5):** 10 questions, 20 marks, with an answer key. It checks skills, not memorised facts. No pass mark is set; use it to decide what to reteach.
- **The extended investigation (after the unit):** each student (or pair) plans, carries out, writes up and peer-reviews their own investigation over several weeks. A suggested timeline and approval steps are in lesson 5. Assess the plan, the honesty of the uncertainty and limitations, the report's repeatability, and the response to review — not whether the result was "right" or exciting.

Sources

All facts were checked against these Wikipedia articles on 5 November 2026. Wikipedia is a starting point; a teacher should confirm against a textbook or primary source.

- Scientific method
- Hypothesis
- Dependent and independent variables
- Pilot experiment — "a small-scale preliminary study conducted to evaluate feasibility, duration, cost, adverse events, and improve upon the study design".
- Observational error — random errors "can be mitigated by repeated measurements"; systematic errors cannot.
- Accuracy and precision — precision describes random error; trueness describes systematic error (bias).
- Measurement uncertainty
- Significant figures
- Standard deviation
- Mental chronometry — simple human reaction times are "usually on the order of 200 ms".
- Pendulum — period $T = 2\pi\sqrt{(L/g)}$ for small swings; the period is nearly independent of amplitude (isochronism); Galileo studied pendulums from around 1602.
- Pendulum (mechanics)
- Gravity of Earth — standard gravity is 9.80665 m/s² by definition; surface gravity varies by around 0.7%, from about 9.780 m/s² at the Equator to about 9.832 m/s² at the poles.
- Outlier — "there is no rigid mathematical definition of what constitutes an outlier"; a measurement error may justify discarding one.

- Correlation does not imply causation — the ice cream and drowning example of a third (confounding) variable.
- IMRAD — Introduction, Methods, Results, and Discussion.
- Peer review
- Preregistration (science) — registering hypotheses, methods or analyses before a study is conducted; aims include distinguishing confirmatory from exploratory analysis.
- Replication crisis — the 2015 Reproducibility Project: Psychology redid 100 studies; of 97 original studies with significant effects, 36% replicated successfully.

Known gaps and cautions

- The pendulum data in lessons 2-3 are **made up to be realistic**, generated from $T = 2\pi\sqrt{(L/g)}$ with $g = 9.81$ m/s² plus small timing scatter. Real class data will be messier; that is the point.
- The uncertainty method (half the range) is deliberately simple. Some courses expect standard deviation or standard error; lesson 2 mentions standard deviation as an extension only.
- The extended investigation needs time the timetable may not have (the suggestion is about six weeks of part-time work). Shorten it to a two-week mini-investigation if needed.
- Investigations involving people (surveys, reaction tests on classmates), animals, microorganisms, heat, electricity above battery voltage, or chemicals beyond those in earlier units need explicit teacher approval and the school's own safety and ethics rules. This draft does not replace them.
- No human educator has reviewed this unit.

Lesson 1: From a question to a plan

Back to the unit

Goal

Students turn a broad question about a pendulum into a testable one, name the variables, run a short pilot, and write a one-page plan — including how they will analyse the data — **before** collecting any real data.

Materials

- Per group: clamp stand (G-clamped or weighted), string, small bob (50-100 g), metre rule, stopwatch or phone timer, protractor.
- A one-page plan template (headings below) on paper or in a shared document.

Steps

✎ Opening (5 min)

Swing a pendulum at the front. Ask: "What do you think decides how long one swing takes?" Collect ideas on the board without judging them (for example: length of string, mass of the bob, how far you pull it back, the type of string).

Point out that "what decides how long a swing takes?" is a good question but not yet a testable one. A testable question changes **one** thing and measures **one** thing.

✎ Main activity (35 min)

1. **Pick one variable (5 min).** Each group chooses one factor from the board. Most groups should choose length; one or two can choose mass or release angle, which gives a useful comparison in lesson 3.
2. **Name the variables (5 min).** For the length investigation:
3. Independent variable (what you change): length L, from the pivot to the **centre** of the bob.
4. Dependent variable (what you measure): the period T, the time for one complete swing, there and back.
5. Control variables (kept the same): mass of the bob, release angle (small, about 10°), the same string, the same timer.
6. **Write a hypothesis and a prediction (5 min).** A hypothesis is a proposed explanation that can be tested; a prediction says what you expect to measure if it is right. Example: "Longer pendulums swing more slowly, so if L increases from 0.20 m to 1.00 m, T will increase."
7. **Pilot run (10 min).** Groups set L to about 0.60 m and try timing **one** swing three times, then **ten** swings three times. They write down all six readings. Most groups notice that single-swing times jump around by a noticeable fraction of the swing, while ten-swing times are steadier relative to their size. A pilot is a small trial run to check

that the method works before the real data; this one usually changes the method to "time ten swings, divide by ten".

8. **Write the plan before the data (10 min).** On one page, under these headings:
9. Question
10. Variables (independent, dependent, controls, and how each control is kept the same)
11. Method (numbered steps someone else could follow)
12. Range and repeats (for example, five lengths from 0.20 m to 1.00 m, three repeats of ten swings each)
13. **Analysis, decided now:** what you will calculate and plot (for example, "mean of three repeats, T = mean ÷ 10, plot T against L, then T^2 against L")
14. **Rule for odd readings, decided now:** for example, "if one repeat differs from the other two by more than 0.5 s, recount and retake it; if we cannot retake it, report it and say whether we left it out"
15. Risks and how to control them

Scientists sometimes register a plan publicly before collecting data; this is called **preregistration**. Its purpose is to make it clear which analyses were planned and which were tried afterwards.

✓ Discussion questions (with example answers)

1. Why measure to the centre of the bob, not to the top of it? The swinging mass acts roughly at its centre, so that is the length that matters. Measuring to the top would make every length a little too short — a systematic error, the same in every reading (lesson 2).
2. What did the pilot change about your method? Usually: timing ten swings instead of one, because human start/stop errors are a smaller fraction of a longer time. Some groups also find they need a fixed mark to count swings from.
3. Why write the analysis down before collecting data? So you can't choose, after seeing the numbers, the graph or the rule that makes the result look best. It also shows a reader which conclusions were planned and which are new ideas to test later.
4. Is "mass doesn't matter" a hypothesis you can test? Yes: change the mass with length and angle fixed, and see whether T changes by more than the uncertainty. If it doesn't, you can say "no change was detected within our uncertainty", not "mass has no effect at all".

✓ Closing check (5 min, with answers)

1. In the length investigation, name the independent variable, the dependent variable and two control variables. (Length; period; any two of mass, release angle, string, timer.)
2. What is a pilot run for? (To test the method on a small scale and improve it before the real data.)
3. Give one thing a good plan decides before any data are collected. (Any of: the analysis, the number of repeats and range, the rule for odd readings.)

Vocabulary

testable question, independent variable, dependent variable, control variable, hypothesis, prediction, period, pilot run, preregistration

Differentiation

- **Support:** give a partly filled plan with the variables named, so students complete the method and analysis lines.
- **Stretch:** ask students to predict the shape of the T against L graph before measuring and record the prediction in their plan.

⚠ Safety

- Clamp or weight the stand so it cannot tip; keep the bob small (50-100 g).
- Keep faces out of the swing path; release from the side, don't throw.
- Keep floor space clear of bags; tie back long hair near the stand.

Teacher notes and misconceptions

- Many students expect a heavier bob to swing faster. Let the mass groups test it rather than telling them.
- "Period" is one full there-and-back swing. Some students count half-swings; agree the definition before the pilot.
- If students' first plans are vague, ask: "Could another group follow this method without asking you anything?"

Lesson 2: Measurement and uncertainty

Back to the unit

Goal

Students tell random error from systematic error and precision from accuracy, see why timing ten swings beats timing one, and calculate a mean and an uncertainty (half the range) from repeated readings.

Materials

- One demonstration pendulum at the front, length 0.60 m (pivot to centre of bob).
- Every student needs a stopwatch or phone timer.
- The worked data below, on a slide or handout.

Steps

✎ Opening (5 min)

Ask: "If ten of you time the same pendulum, will you all get the same number?" Take a show of hands, then test it.

✎ Main activity (35 min)

1. **Everyone times the same thing (10 min).** Start the front pendulum swinging from a small angle. Every student times ten swings at once, starting and stopping on the same count. Collect all the readings on the board. Then repeat with **one** swing.

If your class's numbers are hard to use, use this example set, ten students timing ten swings:

Student	A	B	C	D	E	F	G	H	I	J
Time for 10 swings (s)	15.3	15.6	15.5	15.8	15.4	15.6	15.2	15.7	15.5	15.6

And three students timing **one** swing: 1.3 s, 1.8 s, 1.5 s.

1. **Mean and uncertainty (10 min).** Work through the ten-swing set together:
2. Mean = 155.2 ÷ 10 = **15.52 s**.
3. Range = largest − smallest = 15.8 − 15.2 = **0.6 s**.
4. Uncertainty (half the range) = **±0.3 s**.
5. Report the mean to the same decimal place as the uncertainty: **15.5 ± 0.3 s** for ten swings.
6. Divide both by ten for one period: **T = 1.55 ± 0.03 s**.

Now the single-swing set: mean 1.53 s, half-range 0.25 s, about **16%** of the swing. For ten swings the uncertainty is 0.3 s out of 15.5 s, about **2%**. Ask students to explain the difference: human reaction times are about 0.2 s (simple reaction times are usually on the

order of 200 ms), and that start/stop error is about the same whether you time one swing or ten, so it is a much smaller fraction of a longer time.

1. **Random vs systematic (10 min).** Use two short scenarios:
2. Scenario 1: the ten students' readings scatter on both sides of the mean. Some react a little early, some a little late. This is **random error**: it varies from reading to reading, and repeating and averaging reduces its effect.

3. Scenario 2: one group measured every length to the **top** of a 4 cm bob instead of its centre, so every length is 2 cm too short. Repeating does not help; every reading is wrong the same way. This is **systematic error**. It is found by checking the method or the instrument, not by taking more readings.

4. **Precision vs accuracy (5 min).** Draw two targets on the board:

5. Tight cluster away from the centre: **precise but not accurate** (small random error, a systematic error).
6. Wide scatter around the centre: **accurate on average but not precise** (no systematic error, large random error). Precision describes random error. The closeness of the mean to the true value (called trueness in the ISO terms) describes systematic error. Good measurements need both.

✓ Discussion questions (with example answers)

1. Student G's 15.2 s is the lowest. Was G "wrong"? Not necessarily. All ten readings are within 0.3 s of the mean; G's is part of the normal scatter, so it stays in. A reading would only be suspicious if it were far outside the others (lesson 3).
2. Why not time 100 swings to make the uncertainty even smaller? It would shrink the reaction-time part further, but the swing slowly dies away, counting errors become likely, and it takes far longer. Ten to twenty swings is a sensible trade-off; a good report says why the number was chosen.
3. Would taking more readings fix the "top of the bob" error? No. It is systematic: more readings give a more precise wrong answer. Fix the method (measure to the centre) or correct each length by adding 2 cm.
4. Is ±0.3 s "the error" in the measurement? It is an estimate of how far the mean could reasonably be off because of scatter. It does not include systematic errors nobody has noticed, so it can be too small.

✓ Closing check (5 min, with answers)

1. Times for 10 swings: 12.6 s, 12.9 s, 12.7 s. Find the mean and the uncertainty (half the range). (Mean 38.2 ÷ 3 = 12.73 s ≈ 12.7 s; range 0.3 s; uncertainty ±0.15 s, so about 12.7 ± 0.2 s.)
2. Give one example of a systematic error in the pendulum experiment. (Measuring to the top of the bob; a stopwatch that runs fast; always starting the watch late for the same reason.)
3. Why does timing ten swings give a smaller percentage uncertainty than timing one? (The reaction-time error is about the same either way but is a smaller fraction of a longer time.)

Vocabulary

random error, systematic error, precision, accuracy, trueness, mean, range, uncertainty, reaction time, significant figures

Differentiation

- **Support:** give a table with columns for each reading, total, mean, largest, smallest and half-range.
- **Stretch:** calculate the standard deviation of the ten-swing set (about 0.18 s with a calculator or spreadsheet) and compare it with the half-range. Discuss why courses use different measures of spread.

⚠ Safety

- Only the teacher handles the front pendulum; students stay seated while timing.
- Keep the swing area clear.

Teacher notes and misconceptions

- Students often think an uncertainty means someone made a mistake. Stress that every measurement has one; stating it is honest, not an admission of failure.
- "Human error" is not an explanation in a report. Ask: which human action, and does it push readings randomly or always one way?
- Rounding: the closing check answer gives ±0.15 s, which many courses round to ±0.2 s. Accept either if the reasoning is clear.

Lesson 3: Analysing data honestly

Back to the unit

Goal

Students process repeated readings, deal with an odd reading using the rule they wrote in advance, linearise the pendulum relationship by plotting T^2 against L, find the gradient, calculate g with a rough uncertainty, and explain why a correlation alone does not show a cause.

Materials

- Groups' own data from their investigation, or the worked data below.
- Graph paper or a spreadsheet; calculators.

Steps

✎ Opening (5 min)

Show the formula for a simple pendulum swinging through small angles: **$T = 2\pi\sqrt{(L/g)}$**, where g is the gravitational field strength. Ask: "If this is true, what graph should give a straight line?" Squaring both sides gives $T^2 = (4\pi^2/g) \times L$, so **$T^2$ against L** should be a straight line through the origin with gradient $4\pi^2/g$.

✎ Main activity (35 min)

1. **Process the length data (10 min).** Worked example (times for 10 swings, three repeats each):

L (m)	Run 1 (s)	Run 2 (s)	Run 3 (s)	Mean (s)	± half-range (s)	T (s)	T^2 (s^2)
0.20	9.1	8.8	9.0	8.97	0.15	0.897	0.804
0.40	12.8	12.5	12.7	12.67	0.15	1.267	1.604
0.60	15.6	**14.0**	15.4	see below			
0.80	17.8	18.1	17.9	17.93	0.15	1.793	3.216
1.00	20.2	19.9	20.1	20.07	0.15	2.007	4.027

1. **The odd reading (8 min).** At 0.60 m, run 2 (14.0 s) is 1.4-1.6 s below the other two. The group's plan said: "if one repeat differs from the other two by more than 0.5 s, recount and retake it; if we cannot retake it, report it and say whether we left it out." Ask groups what might cause it. One check: nine swings would take about $0.9 \times 15.5 \approx 14.0$ s, so a miscount of nine swings as ten fits exactly.

The group could not retake the run, so, following their rule, they leave it out **and say so in the report**: - Mean of runs 1 and 3 = 15.50 s, half-range 0.10 s, T = 1.550 s, $T^2 = 2.403\ s^2$. - If they had kept it, the mean would be 15.0 s and $T^2 = 2.25\ s^2$, a point clearly below the line.

There is no rigid mathematical definition of an outlier; deciding is a judgement. That is why the rule is written before the data and every exclusion is reported with its reason. Leaving out a point **because** it spoils the result you hoped for is not allowed.

1. **Graph and gradient (10 min).** Plot T^2 (y-axis) against L (x-axis). The points lie close to a straight line through the origin. A best-fit line gives a gradient of about **4.03 s²/m** (a spreadsheet least-squares fit gives 4.029 with an intercept of −0.006 s², effectively zero).

Then $g = 4\pi^2 \div \text{gradient} = 39.48 \div 4.03 \approx$ **9.80 m/s²**.

1. **A rough uncertainty in g (7 min).** The largest percentage uncertainty in a ten-swing time is at 0.20 m: 0.15 ÷ 8.97 ≈ 1.7%. Squaring T doubles the percentage, about 3.3%, so g is uncertain by roughly 3% of 9.8, about ±0.3 m/s². Result: **g = 9.8 ± 0.3 m/s²**. The accepted value used in physics classrooms, 9.81 m/s², lies inside this range. (This is a rough, worst-point method; the stretch task uses steepest and shallowest lines.)

The mass and angle groups

Ask these groups to share their results. Example data at L = 0.60 m (ten swings, mean of three, each about ±0.2 s):

Mass (g)	**50**	**100**	**200**
Time for 10 swings (s)	15.5	15.6	15.5
Release angle	**10°**	**20°**	**30°**
Time for 10 swings (s)	15.6	15.7	15.8

The mass results show no change larger than the uncertainty. The angle results rise slightly, by about the size of the uncertainty. The full theory predicts that the period does depend a little on amplitude (about 1.7% longer at 30° than for a tiny swing), which is why the formula $T = 2\pi\sqrt{(L/g)}$ is called the small-angle approximation. A class experiment can just about see this, so a fair conclusion is "a small increase, close to our uncertainty", not "angle has no effect".

✓ Discussion questions (with example answers)

1. Why plot T^2 against L instead of T against L? T against L is a curve, and it is hard to tell by eye whether a curve matches a formula. A straight line is easy to judge, and its gradient gives g directly.
2. Was the group right to leave out 14.0 s? Yes, because they used a rule written in advance, found a likely physical cause (a miscounted swing), and reported it. They should also show what difference keeping it would make.
3. The mass group found "no effect". What exactly may they claim? That no change larger than about 0.2 s in ten swings was detected for masses from 50 to 200 g. They cannot claim mass has no effect at all, or outside the range they tested.
4. A survey finds that towns with more ice-cream sales have more drownings. Does ice cream cause drowning? No. Hot weather increases both (a third, confounding variable). In the pendulum experiment we changed L ourselves and kept the rest fixed, which is why we can say length affects the period. Data that are only observed, not controlled, need much more care before claiming a cause.

✓ Closing check (5 min, with answers)

1. Repeats of 11.2 s, 11.4 s and 12.9 s. The plan's rule is "more than 0.5 s from the other two → retake or report". What should the student do? (Retake the 12.9 s run; if that's impossible, report it and its likely cause and state whether it was left out.)
2. A gradient of T^2 against L is 4.10 s^2/m. Calculate g. (39.48 ÷ 4.10 ≈ 9.63 m/s^2.)
3. Name the third variable in the ice-cream example and say what it does. (Hot weather/ temperature; it increases both ice-cream sales and swimming, and so drownings.)

Vocabulary

linearise, gradient, best-fit line, intercept, outlier, exclusion rule, small-angle approximation, correlation, causation, confounding variable

Differentiation

- **Support:** provide axes already scaled and the processed table; students plot and read the gradient.
- **Stretch:** draw the steepest and shallowest lines that still pass through the error bars, find g from each, and use half their difference as the uncertainty. Compare with the ±0.3 m/s^2 estimate.

⚠ Safety

- No practical work in this lesson beyond any remaining data collection; follow lesson 1's precautions if pendulums are used.

Teacher notes and misconceptions

- Students often think a "good" result means matching 9.81 exactly. Praise an honest uncertainty that includes the accepted value, and an honest discussion when it doesn't.
- Some students discard every inconvenient point. Ask them to show the rule they wrote in lesson 1 and to report each exclusion.
- g varies with location by around 0.7% over Earth's surface (about 9.780 m/s^2 at the Equator to about 9.832 m/s^2 at the poles at sea level); 9.81 m/s^2 is a rounded classroom value of standard gravity (9.80665 m/s^2). Don't treat a result of 9.79 or 9.83 as wrong.

Lesson 4: Writing the report

Back to the unit

Goal

Students write up the pendulum investigation in the IMRaD structure (Introduction, Methods, Results, Discussion), with methods another group could repeat, results with uncertainties, and an honest discussion of limitations. They learn why repeatable reports matter to science as a whole.

Materials

- Each group's plan (lesson 1), data and graph (lessons 2-3).
- The "weak report" extract below, printed or on a slide.
- A report template with the headings below.

Steps

✎ Opening (5 min)

Tell students: in 2015, a project called the Reproducibility Project: Psychology redid 100 published psychology studies. Of 97 original studies that had reported significant effects, only 36% replicated successfully, and the effects found were on average about half the original size. Ask: "What would you need from a report to be able to repeat it?" Collect answers: exact method, equipment, numbers of repeats, raw data, how the data were analysed, what was left out and why.

Make clear that this does not mean those scientists were dishonest or that psychology is uniquely unreliable. It shows that repeating work is how science checks itself, and that clear reports make repeating possible.

✎ Main activity (35 min)

1. **Fix a weak report (10 min).** Groups improve this extract, listing every problem they find:

   We did the pendulum experiment. We changed the length and timed it. The results are in the graph. Longer ones were slower. Our answer for g was 9.8 which is basically right, so it worked. There was some human error.

Problems to find (example answers): no question or hypothesis; method too vague to repeat (which lengths? measured to where? how many swings and repeats?); no table or units; "slower" not quantified; no uncertainty on g; "basically right" is not a comparison; "it worked" judges by the answer, not the method; "human error" names no specific error, so it can't be fixed; nothing about the excluded reading.

1. **Write the report (25 min).** Each student writes their own report, using their group's data. Headings and what goes under each:

2. **Title:** says what was measured, e.g. "How the length of a simple pendulum affects its period, and an estimate of g".
3. **Abstract (3-4 sentences, written last):** the question, the method in one line, the main result with its uncertainty, and the main conclusion.
4. **Introduction:** the question, why it matters, the formula $T = 2\pi\sqrt{(L/g)}$, and the hypothesis and prediction from the plan. Cite any source used.
5. **Methods:** equipment and numbered steps in enough detail for another group to repeat the work: how L was measured (pivot to centre of bob), release angle, number of swings timed, number of repeats, the rule for odd readings. Say what changed after the pilot and why.
6. **Results:** a table of raw readings with units, means and uncertainties; the T^2 against L graph with a best-fit line; the gradient and the calculation of g. Report every excluded reading and the reason for it. No interpretation here, just what was found.
7. **Discussion:** compare the result with the prediction and with the accepted value, using the uncertainty (does 9.81 m/s^2 lie within 9.8 ± 0.3 m/s^2?). Name specific random and systematic errors and which way each would push the result. Say what you would change next time. Separate planned conclusions from new ideas ("the angle data suggest a small effect; a planned test with more angles would check this").
8. **References:** every source used, in a consistent format.

✓ Discussion questions (with example answers)

1. Why write the abstract last? It summarises results and conclusions, which you only know at the end.
2. What goes in Results and what goes in Discussion? Results: what was measured and calculated (tables, graphs, numbers with uncertainties). Discussion: what it means, how far it can be trusted, and what to do next.
3. Your g came out as 9.5 ± 0.2 m/s^2, so 9.81 is outside your range. Should you change your data or leave out points until it fits? No. Report it honestly and look for a systematic error that would explain it (for example, lengths measured to the top of the bob make every L too short; work out which way that pushes g). A report that explains a mismatch well is better science than one that hides it.
4. Why report the excluded 14.0 s reading at all? So a reader can judge the decision, and repeat the analysis with or without it.

✓ Closing check (5 min, with answers)

1. What do the letters IMRaD stand for? (Introduction, Methods, Results, and Discussion.)
2. Give two details that must be in the Methods section for the pendulum. (Any two of: how L was measured, number of swings timed, number of repeats, release angle, bob mass, the rule for odd readings.)
3. Rewrite "there was some human error" as a useful sentence. (Example: "Starting and stopping the stopwatch by hand adds a random error of a few tenths of a second; timing ten swings reduced its effect on T to about 2%.")

Vocabulary

IMRaD, abstract, methods, results, discussion, limitation, reproducibility, replication, reference

Differentiation

- **Support:** provide sentence starters for each section ("We measured … by …", "Our value of g, … ± … m/s², is within/outside …").
- **Stretch:** read the Methods section of a short published school-level investigation or a science-fair report and identify one detail you would need to repeat it that is missing.

⚠ Safety

- No practical work in this lesson.

Teacher notes and misconceptions

- Students often treat the accepted value as the goal. Mark the honesty and quality of the uncertainty and discussion, not closeness to 9.81 m/s².
- Avoid presenting the replication figures as "most science is wrong". The figure is about one project in one field; the lesson is that checking and clear reporting matter everywhere.
- Some students copy each other's reports because the data are shared. Shared data are fine; the writing, graph and discussion should be each student's own.

Lesson 5: Peer review

Back to the unit

Goal

Students review another student's pendulum report using a checklist, write specific and kind comments, respond to the review of their own report, and take the closing check. The lesson ends by launching the extended independent investigation.

Materials

- Each student's report from lesson 4, with names replaced by a number.
- The review checklist below, printed.
- The closing check (10 questions, 20 marks).
- The extended investigation timeline and topic list below.

Steps

✎ Opening (5 min)

Explain that before most scientific papers are published, other experts in the field read them and recommend changes or rejection. This is **peer review**, and in academic publishing the reviewers are usually anonymous. Peer review catches many problems, but not all: reviewers usually see only the report, not the lab, which is why clear methods and repeating work still matter (lesson 4).

Today's reviews use numbers, not names, so that comments are about the report rather than the person.

✎ Main activity (25 min)

1. **Review (15 min).** Each student gets one report and fills in the checklist:

Question	Yes / partly / no	Where in the report? Comment
Could I repeat the method from this report alone?		
Are units and uncertainties given for every result?		
Is every excluded reading reported, with a reason?		
Does the graph match the table?		
Is the calculation of g correct? (check one step yourself)		
Does the discussion compare the result with the accepted value **using the uncertainty**?		
Are specific errors named, with the direction each would push the result?		
Are sources referenced?		

Then write a short review: **one thing done well; up to three most important changes, each specific** (say where, what, and why); and any small corrections.

Model the difference: - Not useful: "Your method is bad." - Useful: "Methods, step 2: you don't say where L was measured to. If it was the top of the bob, every L is short by the bob's radius, which would make g too small. Please state it."

1. **Respond (10 min).** Students read the review of their own report and write a short response, one line per comment: what they changed, or why they disagree. Disagreeing politely with a reason is acceptable; ignoring a comment is not.

✓ Closing check (15 min, 10 questions, 20 marks)

Answers and mark guidance follow each question. Two marks each.

1. A student asks: "Does the temperature of water affect how fast sugar dissolves?" Name the independent variable, the dependent variable and two control variables. Answer: independent: water temperature; dependent: time to dissolve (or mass dissolved in a set time); controls: any two of mass of sugar, volume of water, stirring, sugar grain size. 1 mark for IV and DV both correct, 1 mark for two valid controls.
2. What is a pilot run for? Give one change a pilot might lead to. Answer: a small trial to test the method before real data (1); e.g. timing ten swings instead of one, changing the range, adding a marker to count from (1).
3. Times for ten swings: 24.6 s, 24.9 s, 24.3 s. Find the mean time, its uncertainty (half the range), and the period T with its uncertainty. Answer: mean 24.6 ± 0.3 s (1); T = 2.46 ± 0.03 s (1).
4. Classify each as a random or systematic error: (a) a thermometer that always reads 2 °C too high; (b) stopwatch readings that scatter above and below the mean because of reaction time. Answer: (a) systematic (1); (b) random (1).
5. What does "precise but not accurate" mean? Give an example from the pendulum experiment. Answer: readings close to each other but all away from the true value (1); e.g. every length measured to the top of the bob, giving consistent repeats but a g that is too small (1).
6. A graph of T^2 against L has a gradient of 3.98 s^2/m. Calculate g, showing the formula you used. Answer: $g = 4\pi^2 \div$ gradient (1) $= 39.48 \div 3.98 \approx 9.92$ m/s^2 (1).
7. Ten-swing repeats are 30.1 s, 30.3 s and 27.2 s. The plan's rule is "more than 0.5 s from the other two → retake, or report and explain". What should the student do, and what is a likely cause? Answer: retake it, or if that's impossible exclude it and report it with the reason (1); a miscount of nine swings as ten, since $0.9 \times 30.2 \approx 27.2$ s (1).
8. A survey finds students who sleep more get higher test marks. Give one possible third (confounding) variable, and one way to test whether sleep itself makes a difference. Answer: any reasonable confounder, e.g. less screen time late at night, health, fewer after-school jobs (1); a described design, not one to run in class: either a controlled comparison where sleep is changed and other factors are kept as similar as possible, with appropriate ethics approval, or an observational comparison that also records the confounder and compares students who are similar on it (1). Accept either.
9. Which IMRaD section should contain (a) the table of raw readings, (b) an explanation of why your g came out lower than expected? Answer: (a) Results (1); (b) Discussion (1).
10. Rewrite this review comment so it is specific and useful: "Your graph is wrong." Answer: any comment that says where, what and why, e.g. "On the graph, the point at L = 0.60

m is plotted at 2.25 s², but the table gives 2.40 s². Please check which is right." 1 mark for a specific location/problem, 1 for a reason or suggested fix.

No pass mark is set. Use the results to decide what to reteach before the extended investigation.

✎ Launching the extended investigation (5 min, then several weeks)

Suggested timeline (about six weeks of part-time work; shorten to two weeks if needed):

Week	Student does	Teacher checks before the next step
1	Chooses a question; writes a one-page plan (lesson 1 headings), including the analysis and the rule for odd readings, and a risk assessment	**Approves plan and risk assessment** before any data are collected
2	Pilot run; revises plan	Revised plan
3-4	Collects data; keeps a dated lab notebook with all raw readings	Notebook spot-check
5	Drafts IMRaD report	Draft submitted
6	Peer review in pairs; writes response to review; submits final report and response	Final mark

Example questions, chosen because they need only equipment from earlier units and are low risk:

- How does drop height affect the bounce height of a ball? (physics; links to grade 9 forces)
- How does the number of layers of insulation affect how fast a cup of warm water cools? (use warm tap water, not boiling)
- How does light intensity affect the rate at which leaf discs float? (links to grade 7 photosynthesis)
- How does surface area or concentration affect a reaction rate, using only the reactions and concentrations in grade 11 rates of reaction?
- How does the density of a plant species change along a transect from a path? (links to grade 10 ecology)
- How does the amount of salt in water affect the germination of cress seeds?

Vocabulary

peer review, reviewer, response to reviewers, anonymous review, lab notebook, risk assessment

Differentiation

- **Support:** reviewers answer only the first four checklist rows; authors respond to the two most important comments.
- **Stretch:** reviewers check the g calculation from the raw data themselves and say whether they get the same answer.

⚠ Safety

- No practical work this lesson.
- For the extended investigation: no data collection before the teacher approves the plan and risk assessment. Investigations involving other people (surveys, reaction-time tests), animals, microorganisms, mains electricity, heating beyond warm tap water, or chemicals not used in earlier units need explicit teacher approval under the school's own safety and ethics rules.

Teacher notes and misconceptions

- Some students write only praise, others only criticism. Require one strength and specific changes.
- Students may treat a reviewer's comment as an order. Say clearly that authors may disagree with a reason; reviewers can be wrong too.
- Anonymity is easy to break in a small class. Its point here is to keep comments about the work; remind students that kindness rules still apply.