

WORK LIKE A PHYSICIST

PART 3 OF 3

LESSONS 6–8: SOLO FLIGHT · YOUR INVESTIGATION

3

LESSONS

2

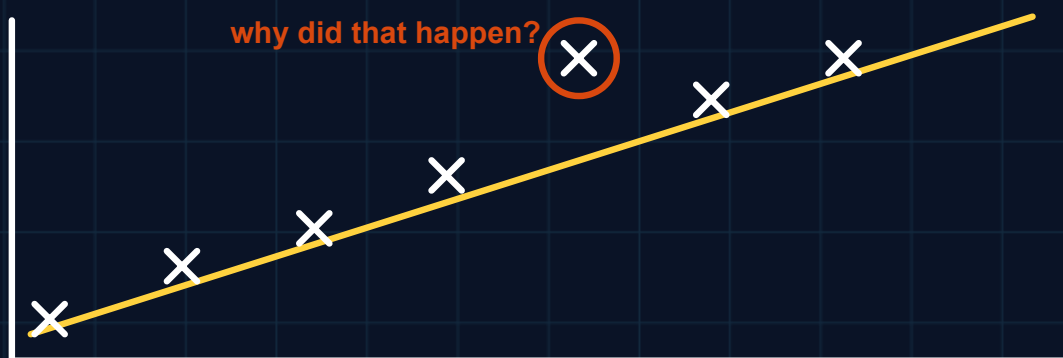
PRACTICALS

3

KEY WORDS

“The first principle is that you must not fool yourself, and you are the easiest person to fool.”

RICHARD FEYNMAN, PHYSICIST



NAME

CLASS

TEACHER

LAB PARTNER

HOW THIS BOOKLET WORKS

Anyone can have an opinion about how the world works. A physicist has to do something harder: produce **evidence** that convinces people who were not there. This unit teaches you how. Keep the booklet: it is your classwork book *and* your revision guide.



DO NOW

Quick questions from earlier lessons. Remembering again is what makes it stick.



LEARN IT

The explanation, diagrams and worked examples. Read this again when you revise.



TRY IT

Practice that builds up: first with support, then on your own.



PRACTICAL

Plan, record your measurements and work out results from them.



EXAM CORNER

AQA-style questions with a tip on how the marks are given.



REVISE IT

Summary, cover-and-answer questions and an “I can” check to colour in.



Two kinds of question to know. When a sentence has a gap, the choices are printed straight after it, like this: The thing you change is the _____ (independent / dependent / control) variable. When you see a box of choices, **draw a ring around the correct one**, as AQA exam papers ask. The thing you measure is the

independent

dependent

control

variable.

THE ROUTE THROUGH THIS PART

#	LESSON	PRACTICAL
06	Solo flight The whole process on your own: plan, table, graph, prediction, evaluation	Paper helicopter, on your own
07–08	Your investigation Design, run, graph and defend your own investigation, in a pair or a three	Your own, from a shared set of equipment

This booklet is Part 3 of 3: Lessons 6–8. The **Physicist’s toolkit** on the last page has every rule, calculation and checklist you need.

SOLO FLIGHT

AQA Working scientifically WS 2.2, 2.7, 3.1 · Physics and Combined Science

BIG QUESTION Can you run a whole investigation with nobody telling you what to do next?

BY THE END YOU CAN

- identify all three types of variable on your own
- design your own results table with units
- collect three trials for each of five values and calculate means
- plot a graph with a best-fit line and read a prediction from it
- write a conclusion and an evaluation using your own numbers

plan

prediction

range

evaluation

improvement

THE CASE (2021)

A helicopter on Mars. In April 2021 the small helicopter Ingenuity flew on Mars, where the air is about 1% as dense as Earth's. The engineers could not just try it and see. They pumped air out of a chamber until it was as thin as on Mars, then changed one thing about the rotors at a time, measured the lift and plotted the results.

This one is on you. Booklet, ruler, brain.



REMEMBER

DO NOW

From earlier lessons. No notes!

1

An anomalous result with no cause found should be

(deleted / kept, circled and reported).

2

A best-fit line should have the points

(all on it / balanced above and below it).

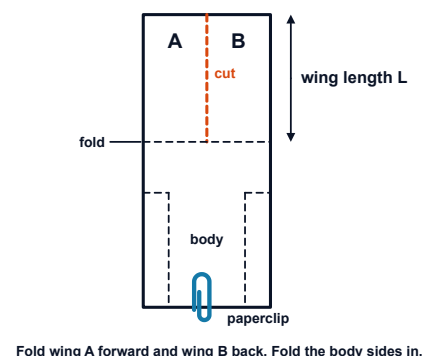
3

Write a conclusion for: 5 cm ramp → 20 cm; 25 cm ramp → 80 cm.



Your question: **How does wing length affect the fall time of a paper helicopter?** If your teacher agrees, you could change the number of paperclips or the drop height instead.

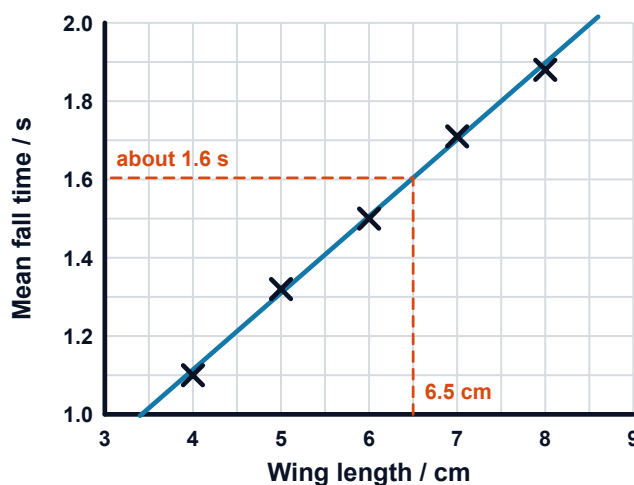
PLAN	THINK ABOUT
Range	From 4 cm to 8 cm: five lengths. Very short wings barely spin; very long wings flop.
Prediction	Longer wings push against more air, so air resistance is larger and the helicopter falls more slowly. A reason turns a guess into a prediction.
Timing	The same person times every drop. Drop from as high as you safely can: a longer fall makes your reaction time a smaller part of each time.



■ READ BETWEEN THE POINTS

A best-fit line lets you predict a value you did not test. Read **up** from the x-axis to the line, then **across** to the y-axis, and leave your ruled lines on the graph.

A prediction is most trustworthy **inside the range** you tested: 6.5 cm sits between results at 6 cm and 7 cm. For 12 cm you would have to assume the pattern carries on. It may not: very long wings bend and stop spinning.



■ EVALUATE: PROBLEM → EFFECT → FIX

PROBLEM	EFFECT	FIX
Reaction time starting and stopping the stopwatch	fall times are scattered (random error); short falls are hit hardest	film the drop and time it from the video, or drop from higher
A draught from a door or window	some drops drift and take longer	close windows and doors; drop away from them

! **Put a number on the problem.** A reaction time is about 0.2 s. On the shortest fall, 1.10 s, that is nearly a fifth of the measurement; on the longest, 1.88 s, about a tenth. So make the error smaller (video) or the measurement bigger (a higher drop). “Be more careful” is not an improvement: name the equipment and the problem it solves.

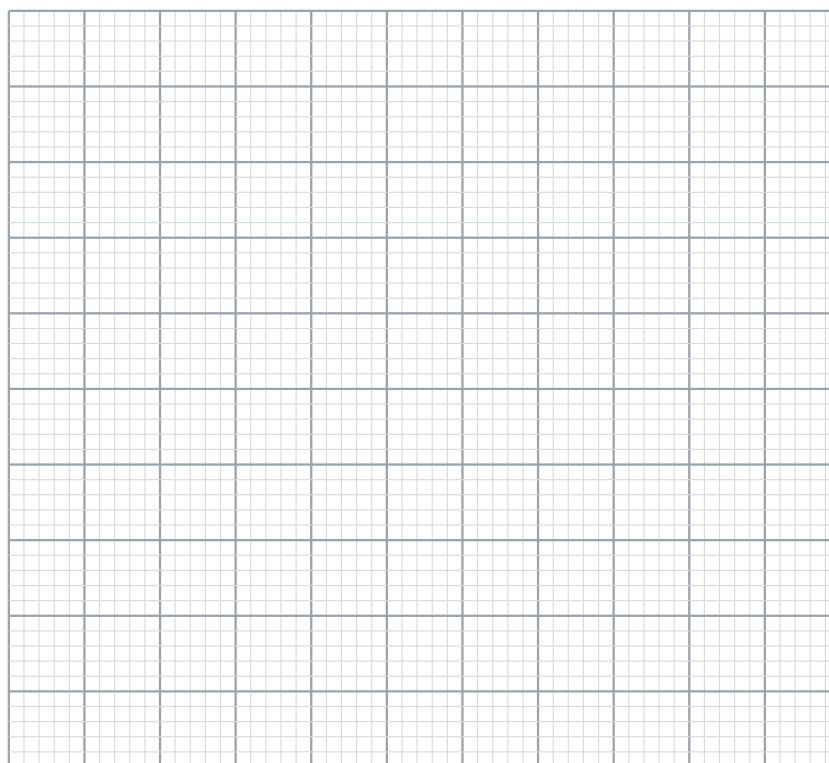


PRACTISE

GRAPH, CONCLUDE, PREDICT

Assessed.

- 1 Graph your results: title, axes, units, scale, accurate crosses, best-fit line, anomalous results noted.



2 Your conclusion.

As the wing length increased, the fall time...	<div> <div>increased</div> <div>decreased</div> <div>stayed the same</div> </div>
Evidence: two values from my results, with units	
Possible anomalous result (or "none")	

3 Make a prediction from your best-fit line for a wing length you did **not** test, inside your range. Show your reading on the graph.

Wing length I did not test	
Fall time read from my line	

4 Mark yourself. Be strict: this is the list your teacher will use.

SUCCESS CRITERIA	NOT YET	DONE
Independent, dependent and control variables all identified	☐	☐
Table designed by me, with units in every heading	☐	☐
Three trials for every value of the independent variable	☐	☐
Means calculated correctly	☐	☐
Correct graph type, with a reason given	☐	☐
Axes labelled, units shown, sensible scale	☐	☐
Best-fit line rather than dot-to-dot	☐	☐
Anomalous results identified, or their absence stated	☐	☐
Conclusion quotes evidence from my own results	☐	☐



My research question	
Independent variable (and unit)	
Dependent variable (and unit)	
Three control variables	
The independent variable is	<div>continuous</div> <div>categoric</div>
My graph will be a	<div>line graph</div> <div>bar chart</div> because
The five values I will test	

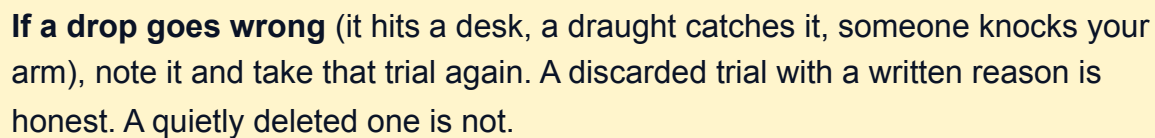
STAY SAFE

- Never climb on chairs, stools or benches to gain height. Use a height you can reach standing on the floor, the same every time.
- Take care with scissors.
- Keep the landing zone clear.



Assessed. Nothing is printed for you
on purpose.

5



6



Get the marks: Compare the size of the error with the size of the measurement.

- 7 A student times paper helicopters falling. Human reaction time is about 0.2 s. Explain why reaction time matters more for a short fall than for a long one. **[2 marks]**

- 8 The student tested wing lengths from 4 cm to 8 cm. Which prediction from the best-fit line is most trustworthy? Tick **one** box. **[1 mark]**

☐ the fall time for 2 cm wings ☐ the fall time for 6.5 cm wings ☐ the fall time for 12 cm wings

- 9 Suggest **one** improvement to the way the fall time is measured, and say how it helps. **[2 marks]**

TAKE IT HOME: EVALUATION PRACTICE

Write about your investigation. You will need all four in the project that starts next lesson.

One strength of my method	
One weakness	
One possible random error	
One improvement I would actually make	

**SUMMARY**

- Plan first: three types of variable, the range of values, and a reason for your prediction.
- Your table: independent variable first, three trials and a mean, units in every heading.
- Predictions from a best-fit line are most trustworthy inside the range tested.
- Evaluate as problem → effect → fix. Name the equipment, never just “be more careful”.

COVER THE PAGE AND ANSWER

1 Name three control variables for the helicopter.

.....

2 Heading for the mean column?

.....

3 A drop hits a chair. What now?

.....

4 Where is a prediction most trustworthy?

.....

I CAN...

plan an investigation on my own

.....



design my own results table

.....



read a prediction from a best-fit line

.....



evaluate a method as problem, effect and fix

.....



YOUR INVESTIGATION

AQA Working scientifically WS 1.6, 2.1, 2.7, 3.8 · Physics and Combined Science

BIG QUESTION Can you produce a result that nobody, including you, can break?

BY THE END YOU CAN

- write a testable question in the form “How does X affect Y?”
- plan a safe, fair investigation and get it approved
- collect repeated measurements and calculate means
- choose and draw the right graph for your own data
- write a conclusion backed by evidence and an honest evaluation

testable question

method

fair test

evaluation

peer review

THE CASE (2015)

Trying to prove themselves wrong. Two LIGO detectors about 3000 km apart picked up the same signal: two black holes colliding a billion light years away. A passing lorry could shake one detector, but not both in the same way at almost the same moment. Even so, the team spent five months attacking their own result before announcing it.

Your job: produce a result you cannot break.



REMEMBER DO NOW

From earlier lessons. No notes!

1

Give the heading for a column of fall times measured in seconds, trial 1.

2

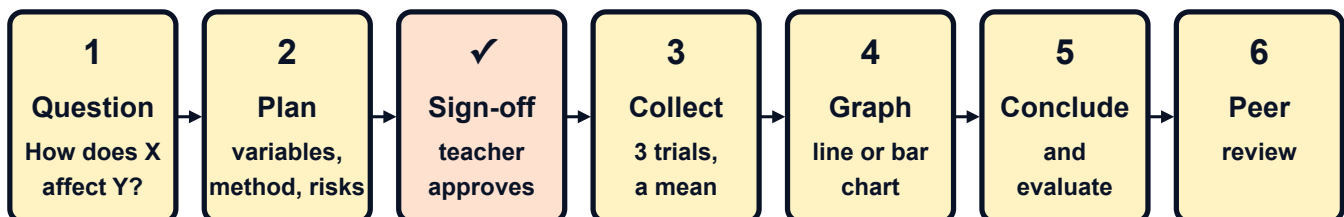
“Human error” earns no marks. Improve: “There was human error with the stopwatch.”

3

A prediction from a best-fit line is most trustworthy _____ (inside / outside) the range of the data.



EXPLAIN THE RULES



- Work in a pair or a three.
- Ask one question: “How does X affect Y?”
- Change **one** independent variable.
- Measure **one** dependent variable.
- Keep at least three control variables the same.
- Test four or five values or categories.
- Take three trials of each, and calculate a mean.
- Choose the correct graph type.
- Write a conclusion **and** an evaluation.
- **No teacher signature, no equipment.**

The reasons behind the numbers. One independent variable, so there is only one possible cause. Three or more controls, because several things could change the result. Four or five values, because fewer cannot show the shape of a pattern. Three trials, so you can spot a reading that is badly out. And the sign-off: a flaw in the plan is free to fix on paper; found afterwards, the results cannot be used.

■ QUESTIONS THAT WORK

RESEARCH QUESTION	INDEPENDENT VARIABLE	GRAPH
How does ramp height affect the distance travelled by a trolley?	ramp height	line
How does wing length affect the fall time of a paper helicopter?	wing length	line
How does surface type affect the distance travelled by a toy car?	surface type	bar
How does material affect the bounce height of a ball?	material	bar
How does the number of elastic bands affect launch distance?	number of bands	line

A CONCLUSION AND EVALUATION THAT WOULD SCORE WELL

“As wing length increased, mean fall time increased: at 4 cm it was 1.10 s and at 8 cm it was 1.88 s. A weakness was timing by hand: reaction time varied, so the times were scattered. I would film the drops and time them from the video.” **How confident?** Compare the change you found with the scatter in your readings: a rise of 0.78 s, with trials agreeing to within 0.05 s, is convincing.



PRACTISE

CHOOSE A QUESTION THAT WILL WORK

- 1 These questions would waste your two lessons. Draw a ring around what is wrong with each one.

“What is the best paper helicopter?”

too vague	too many dependent variables	hard to control
-----------	------------------------------	-----------------

“How does height affect it?”

dependent variable unclear	hard to control	too many dependent variables
----------------------------	-----------------	------------------------------

“How does surface affect speed and distance and time?”

too vague	too many dependent variables	hard to control
-----------	------------------------------	-----------------

“How does throwing force affect distance?”

dependent variable unclear	too many dependent variables	hard to control
----------------------------	------------------------------	-----------------

2 Repair one of them. Write it in the form “How does X affect Y?”



INVESTIGATE

PLAN (LESSON 7)

Stop at the teacher checkpoint.

■ PLANNING GRID

Our research question	
Group members	
Independent variable (and unit)	
Dependent variable (and unit)	
The independent variable is	<div>continuous</div> <div>categoric</div>
Graph we will use, and why	<div>line graph</div> <div>bar chart</div> because
At least three control variables	
Values or categories we will test (4–5)	
Equipment we need	
Safety risks, and how we will reduce them	

■ WRITE YOUR METHOD

- 3 Numbered steps that someone from another class could follow without asking you a single question. Include how many trials you will take and how you will keep the control variables the same.

TEACHER CHECKPOINT



Stop here. Do not collect any data until your teacher has signed this box. In a real lab, no experiment runs without approval.

CHECKED BY YOUR TEACHER



Question is clear and testable

☐

Independent variable is clear

☐

Dependent variable is measurable

☐

Control variables are realistic

☐

Method is safe

☐

Equipment is available

☐

Repeats are included

☐

Graph choice is sensible

☐

Approved by

Date

**RESULTS TABLE**

Write your own headings in the top row, with units. If your independent variable is categorical, the first heading is the category name: "Surface type", "Material".

4

Show one mean calculation in full.

■ LAB NOTES

Write down anything a reader would want to know, as it happens: equipment that misbehaved, a trial you repeated, a control variable that slipped, a surprise. You will not remember it next lesson, and your evaluation comes from here.

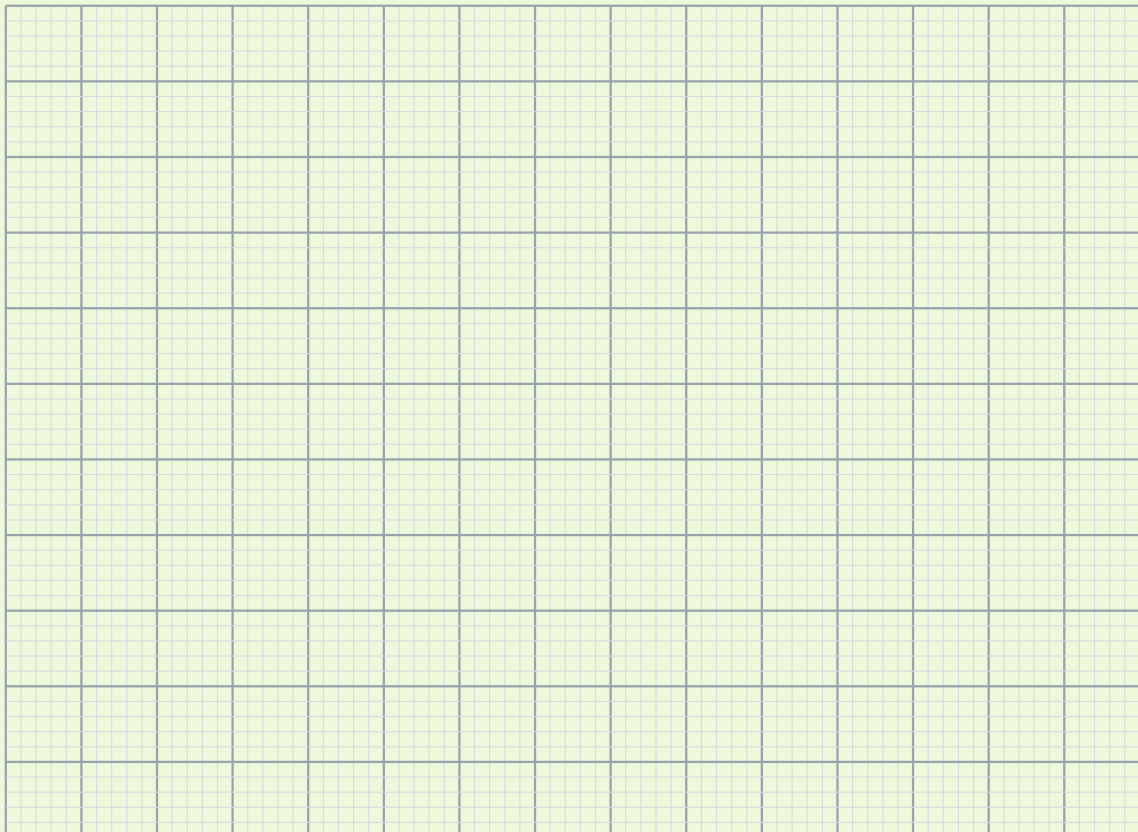
5 Our lab notes:

■ END OF LESSON 7

Our independent variable is	<div>continuous</div> <div>categoric</div>
One control variable we really did keep the same	
One result we may need to check next lesson	



Our independent variable is	<div>continuous</div> <div>categoric</div>
So our graph is a	<div>line graph</div> <div>bar chart</div>
On the x-axis	
On the y-axis	
Largest mean, and the value of each big square on the y-axis	

■ DRAW YOUR GRAPH

Crosses and a best-fit line for a line graph. Equal bars with gaps for a bar chart. Title, labels and units either way.

**CONCLUDE AND EVALUATE
(LESSON 8)**Assessed. This is where the marks
hide.

9

Interrogate your own results.

The pattern: the dependent variable...	<div>increases</div> <div>decreases</div> <div>stays about the same</div>
The pattern is	<div>strong and clear</div> <div>weak and scattered</div> because
Possible anomalous results (or “none”)	
The one number a doubter would find hardest to argue with	

10

Conclusion. Use the frame that matches your graph.

Line graph: As ... increased, ...	
Bar chart: The highest (or lowest) ... was ...	
I know this because (two values with units)	
This suggests that...	

- 11 Evaluation. Name the actual thing, never just “human error”.

One strength of our method	
One weakness of our method	
One possible random error	
One possible systematic error	
An improvement that fixes a weakness	

- 12 How confident are you in your conclusion, and what would make you more confident?



PRACTISE

PEER REVIEW (LESSON 8)

Their job is to find the weakness you missed.

FEATURE	✓
Question uses “How does X affect Y?”	☐
All three types of variable named	☐
Results table has units in the headings	☐
Three trials, means calculated	☐
Right graph for the independent variable	☐
Labels, units, scale, accurate crosses or bars	☐
Best fit line drawn; anomalous results dealt with	☐
Conclusion quotes numbers	☐
Evaluation names an improvement	☐

Reviewed by	
The strongest part of this investigation	
The question I would ask this group	

- 13 **CHALLENGE** Compare your results with another group who investigated something similar. Do you agree? If not, what could explain the difference?

- 14 **CHALLENGE** Is your relationship a straight line or a curve? Is it directly proportional?
☐ yes ☐ no How can you tell?



AQA-STYLE

EXAM CORNER

Write in full sentences. Show every step of a calculation.

Get the marks: Think about what you can and cannot see with only a few points.

- 6 A group investigates how the mass of a ball affects how far it rolls. They test only two masses. Explain why this is not enough. **[2 marks]**

- 7 Two groups in different schools do the same investigation with their own equipment and get similar results. Complete the sentence. **[1 mark]**

The results are ☐ repeatable ☐ reproducible ☐ anomalous

- 8 Suggest why a teacher checks the plan before any equipment is used. **[1 mark]**

TAKE IT HOME: INDIVIDUAL REFLECTION

Answer on your own, not as a group: your teacher wants your view.

What did your group investigate, and what did your graph show?	
What did you personally contribute?	
The hardest part of the unit, and what you would tell next year's Year 9	
The first objection a stranger would raise to your conclusion	



REVIEW LATER

REVISE IT

Use this box after the lesson and before tests.

SUMMARY

- A testable question: "How does X affect Y?", with one independent and one dependent variable.
- Plan, then teacher sign-off, before any equipment.
- Four or five values, three trials each, a mean; record as you go.
- Conclude with numbers; evaluate with a strength, a weakness, named errors and a matching fix.

COVER THE PAGE AND ANSWER

1 What form should a research question take?

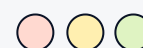
2 Why test four or five values?

3 Repeatable or reproducible: another school gets the same results?

4 What must happen before you collect data?

I CAN...

write a testable research question



plan a fair, safe investigation



collect, record and process my own data



draw the right graph and defend my conclusion



KEY WORDS

Learn the meaning and the spelling. In exams, precise words earn marks: say “random error”, never “human error”.

Accurate [L1]: Close to the true value

Precise [L1]: Repeat readings are close to each other: little spread about the mean

Trial [L1]: One repeat of a measurement

Mean [L1]: The total of the trials divided by the number of trials

Uncertainty [L1]: The interval within which the true value can be expected to lie. From repeats:
 $(\text{largest} - \text{smallest}) \div 2$

Range [L1]: The maximum and minimum values of the independent or dependent variables, stated “from ... to ...”

Resolution [L1]: The smallest change a measuring instrument can detect

Random error [L1]: Unpredictable spread between repeats. Repeats and a mean reduce it

Systematic error [L1]: An error that shifts every reading by the same amount in the same direction. Repeats do not fix it

Zero error [L1]: An instrument reads a value when it should read zero: a systematic error

Repeatable [L1]: The same person, method and equipment give similar results again

Reproducible [L1]: Another person, or different equipment or method, gives similar results

Independent variable [L2]: The one thing you change

Dependent variable [L2]: The thing you measure

Control variable [L2]: Something you keep the same so it cannot affect the result

Fair test [L2]: Only the independent variable changes; all the control variables are kept the same

Continuous data [L2]: Numbers that can take any value on a scale, such as length, time or mass

Categoric data [L2]: Names or groups, such as material, colour or brand

Line graph [L2]: The graph to use when the independent variable is continuous

Bar chart [L2]: The graph to use when the independent variable is categoric

Scale [L4]: The numbers along an axis, going up in equal steps

Best-fit line [L5]: One straight or curved line showing the overall trend, with points balanced on either side

Anomalous result [L5]: A result that does not fit the pattern of the others

Positive correlation [L5]: As one variable increases, the other increases too

Directly proportional [L5]: Double one, and the other doubles: a straight line through the origin

Conclusion [L5]: What the results show overall, with numbers as evidence

Prediction [L6]: A statement of what you expect to happen, with a reason

Evaluation [L6]: A judgement of how good the method and results were, with improvements

Peer review [L7-8]: Checking someone else's work to find its weaknesses before it is shared

■ PHRASES THAT PICK UP MARKS

INSTEAD OF WRITING...	WRITE...
"It was human error."	"Reaction time when starting the stopwatch caused random error."
"The results were good."	"The repeats were close together, so the data is precise."
"It's a bar chart."	"A bar chart was used because material type is categoric."
"Keep it a fair test."	"Use the same trolley and the same start line each time."
"We did it three times."	"Three trials were taken at each value so that a mean could be calculated."
"It went up."	"As the ramp height increased, the mean distance increased from 20 cm to 80 cm."
"One result was weird."	"The value at 20 cm is a possible anomalous result: it is far above the trend."
"Be more careful."	"Film the drops and time them from the video, so reaction time does not matter."

PROGRESS TRACKER

Colour one circle for each statement: **red** = not yet, **amber** = getting there, **green** = I can do this without help. Revisit your reds first.

I CAN...	R / A / G
06: Solo flight	
plan an investigation on my own	  
design my own results table	  
read a prediction from a best-fit line	  
evaluate a method as problem, effect and fix	  
07–08: Your investigation	
write a testable research question	  
plan a fair, safe investigation	  
collect, record and process my own data	  
draw the right graph and defend my conclusion	  



One habit worth building. When something in your results looks wrong, the useful question is never “can I ignore that?” It is “why did that happen?”

THE WHOLE UNIT IN ONE SENTENCE

Measure it more than once, be honest about the doubt, show the pattern clearly, and let the evidence decide.

QUICK ANSWERS

Answers to the “Do now” and “Cover the page” questions, so you can check yourself when revising. Answers to the longer questions are in your teacher's answer edition.

LESSON 6: SOLO FLIGHT

DO NOW

1. kept, circled and reported (and left out of the best-fit line)
2. balanced above and below it
3. As the ramp height increased, the distance increased, from 20 cm at 5 cm to 80 cm at 25 cm.

COVER THE PAGE

1. Drop height, type of paper, number of paperclips.
2. Mean fall time / s
3. Note the reason, then repeat that drop.
4. Inside the range of the data.

LESSONS 7–8: YOUR INVESTIGATION

DO NOW

1. Fall time 1 / s (or Trial 1 / s)
2. e.g. Reaction time starting and stopping the stopwatch varied, so the times were scattered (random error).
3. inside

COVER THE PAGE

1. How does X affect Y?
2. Fewer cannot show the shape of a pattern.
3. Reproducible.
4. The teacher signs off the plan.

THE PHYSICIST'S TOOLKIT

Everything you need for the whole unit, on one page. Fold the corner: you will come back to it.

THE THREE VARIABLES

Independent the one thing you change

Dependent the thing you measure

Control everything you keep the same

Ask: "How does *independent* affect *dependent*?"

TWO KINDS OF DATA

Continuous any value on a scale: length, time, mass → **line graph**

Categoric names or groups: material, colour → **bar chart**

Test: is there a value in between?

THE TWO CALCULATIONS

mean = total of the trials ÷ number of trials

uncertainty = (largest – smallest) ÷ 2

Write the result as mean ± uncertainty, e.g. 1.22 s ± 0.03 s.

PRECISE OR ACCURATE?

Precise repeats close to each other

Accurate close to the true value

Resolution the smallest change an instrument can detect

You can be precise and still wrong.

THE TWO ERRORS

Random scatters repeats both ways. **Repeat and take a mean.**

Systematic shifts every reading the same way. **Find the cause; repeats do not help.**

CHOOSING A SCALE

Largest value ÷ number of big squares, then round up to 1, 2, 5, 10, 20 or 50 per big square. Equal steps. Use most of the grid.

ANOMALOUS RESULTS

Spot it (far from the trend) → **check** the recording, maths and method → **repeat** if you can. Mistake found: correct it. No cause: keep it, circle it, report it, and leave it out of the best-fit line. Never delete it silently.

CONCLUSION AND EVALUATION

Conclude: "As X increased, Y increased", with two values and units. Straight or curved?

Evaluate: a strength, a weakness, a named error, and an improvement that fixes it. Never just "human error".

GRAPH CHECKLIST

- Title: what against what
- Independent variable on the x-axis
- Both axes labelled, with units: "Ramp height / cm"
- Scale in equal steps that fills the grid
- Means plotted as small, accurate crosses
- One best-fit line: never dot-to-dot
- Bar chart: equal bars, equal gaps, axis from 0
- Anomalous results circled, or "none"

THE RULE THAT DECIDES YOUR GRAPH

Continuous independent variable → **line graph**. **Categoric independent variable** → **bar chart**.

It depends on what you *changed*, not on what you measured.