

WORK LIKE A PHYSICIST

PART 1 OF 3

LESSONS 1–2: CAN THIS DATA BE TRUSTED? · WHAT ARE YOU ACTUALLY CHANGING?

2

LESSONS

1

PRACTICAL

20

KEY WORDS

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

RICHARD FEYNMAN, PHYSICIST

ANSWER EDITION FOR TEACHERS AND SELF-MARKING



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 (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
01	Can this data be trusted? Precision and accuracy, random and systematic error, uncertainty, resolution	Measure one thing three times
02	What are you actually changing? Independent, dependent and control variables; continuous and categoric data; choosing a graph	Class demo: which surface slows the car most?

This booklet is Part 1 of 3: Lessons 1–2. The **Physicist’s toolkit** on the last page has every rule, calculation and checklist you need.

CAN THIS DATA BE TRUSTED?

AQA Working scientifically WS 2.6, 3.4, 3.7 · Physics and Combined Science

BIG QUESTION Thousands of repeat measurements agreed perfectly, and the result was still wrong. How can that happen?

BY THE END YOU CAN

- tell the difference between precise and accurate
- describe random and systematic errors, and say why repeats only help with one of them
- calculate a mean and an uncertainty from repeat readings
- say what the resolution of an instrument is

precise

accurate

random error

systematic error

uncertainty

resolution

THE CASE (2011)

The loose cable that broke physics.

Physicists in Italy timed neutrinos travelling 730 km from Switzerland. They seemed to arrive about 60 nanoseconds before light could. Thousands of repeats agreed. Months later the team found a fibre-optic cable that was not properly connected. It shifted every reading by the same amount, so repeating could never reveal it, and the result was withdrawn.

Consistent does not mean correct.



REMEMBER

WHAT DO YOU ALREADY THINK?

No wrong answers: this is your starting point.

1

You time a toy car rolling down a ramp three times and get three different times. Give one reason why.

Any sensible reason, e.g.
your reaction time when
starting and stopping the
stopwatch is different
each time, or the car is
released slightly
differently.

2

Calculate the mean of 4 cm, 5 cm and 6 cm.

$$(4 + 5 + 6) \div 3 = 15 \div 3 = 5$$

cm

3

Which ruler can measure more finely?

the one marked in millimetres

(the one marked in centimetres / the one marked in millimetres)

The one marked in millimetres.



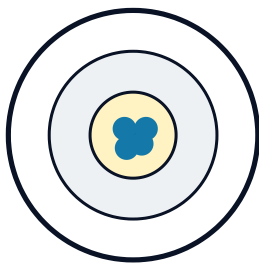
EXPLAIN

CAN YOU TRUST A MEASUREMENT?

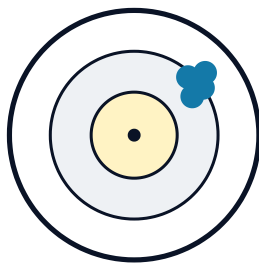
Every measurement has some doubt in it. Measure the same thing three times and you rarely get the same number three times. A physicist asks: **how far can I trust this result?**

PRECISE AND ACCURATE ARE DIFFERENT WORDS

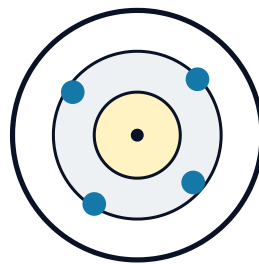
WORD	MEANING	HOW YOU CAN TELL
Precise	repeat readings are close to each other	look at the spread of the readings
Accurate	a reading is close to the true value	compare with the true value, e.g. weigh a known 100 g mass



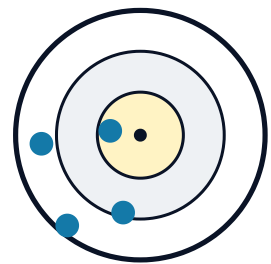
Precise and accurate



Precise, but not accurate



Accurate on average, not precise



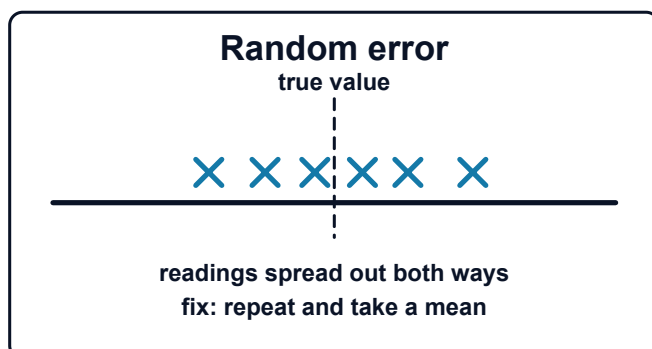
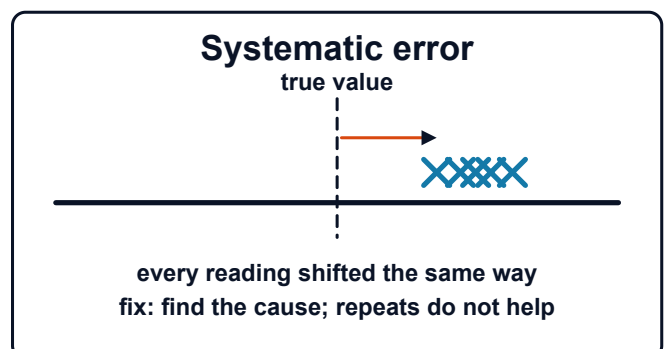
Neither precise nor accurate

Centre = the true value. Blue dots = repeat readings.



You can be perfectly precise and completely wrong. A tight group of readings looks trustworthy, so nobody checks it. That is why precise-but-wrong is the dangerous one.

TWO KINDS OF ERROR

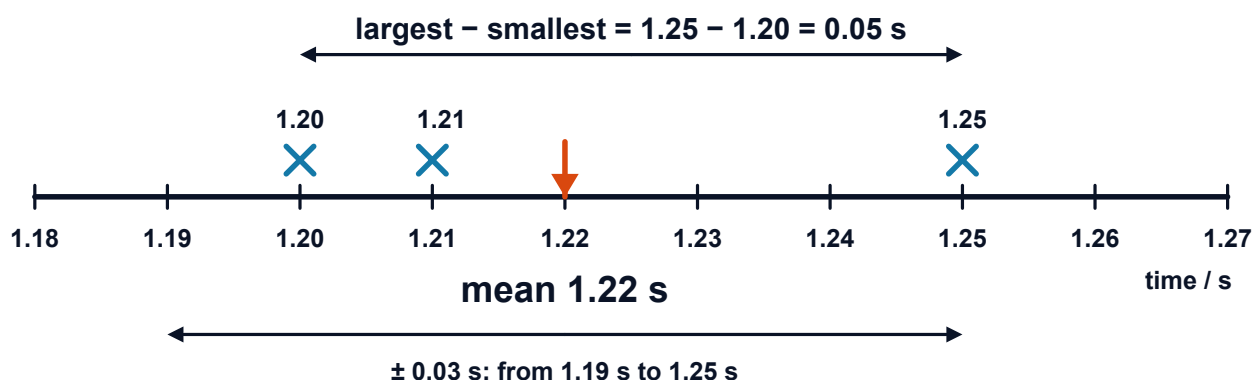


ERROR	WHAT IT DOES	EXAMPLE	WHAT TO DO
Random	spreads readings out unpredictably: some too high, some too low	reaction time with a stopwatch; judging a bounce height by eye	repeat and take a mean; use better equipment, such as light gates
Systematic	shifts every reading by the same amount, in the same direction	a balance that reads 0.2 g with nothing on it (a zero error); measuring from the end of a ruler, not the zero mark	find the cause: check the zero, check against a known value. Repeats do not help

HOW TO TELL WHICH KIND YOU HAVE

Ask: would this make the reading wrong by the same amount, in the same direction, every time? **Yes**: systematic. **Up one time and down the next**: random. A known systematic error can be corrected: if the balance reads 0.2 g with nothing on it, subtract 0.2 g from every reading.

■ UNCERTAINTY: PUT A NUMBER ON THE DOUBT



WORKED EXAMPLE

Three readings: 1.20 s, 1.25 s, 1.21 s. Find the mean and the uncertainty.

	$(1.20 + 1.25 + 1.21) \div 3 =$
MEAN	$3.66 \div 3 = 1.22 \text{ s}$

LARGEST - SMALLEST	$1.25 - 1.20 = 0.05 \text{ s}$
--------------------	--------------------------------

UNCERTAINTY	$0.05 \div 2 = 0.025 \text{ s}$, about 0.03 s
-------------	--

RESULT	$1.22 \text{ s} \pm 0.03 \text{ s}$
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YOUR TURN

Three readings: 4.6 cm, 5.0 cm, 4.8 cm. Find the mean and the uncertainty.

	$(4.6 + 5.0 + 4.8) \div 3 = 14.4$
MEAN	$\div 3 = 4.8 \text{ cm}$

LARGEST - SMALLEST	$5.0 - 4.6 = 0.4 \text{ cm}$
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UNCERTAINTY	$0.4 \div 2 = 0.2 \text{ cm}$
-------------	-------------------------------

RESULT	$4.8 \text{ cm} \pm 0.2 \text{ cm}$
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! **uncertainty** = (largest – smallest) ÷ 2. Why divide by 2? Largest – smallest is the whole width of the spread. The mean sits near the middle, so the readings reach about half that width above it and half below. Read “1.22 s ± 0.03 s” as “about 1.22 s, give or take 0.03 s”. The **range** of these readings is from 1.20 s to 1.25 s: a range is stated “from ... to ...”, never as one number.

■ RESOLUTION: WHAT CAN THE INSTRUMENT SEE?

The **resolution** of an instrument is the smallest change it can detect. A ruler marked in millimetres has a resolution of 1 mm. A stopwatch that reads to 0.01 s has a resolution of 0.01 s.

Match the instrument to the job: 1 mm is tiny next to the length of a desk, but it is half the thickness of a coin.

! **Trap.** Better resolution gives you more decimal places. It does *not* remove a systematic error: a balance with a zero error gives a precise wrong answer to two decimal places.

A: marked every 1 cm



Reading: about 5 cm

resolution 1 cm

B: marked every 1 mm



Reading: 4.7 cm

resolution 1 mm

Repeatable: you do it again with the same method and equipment and get similar results.

Reproducible: another person, or different equipment, gets similar results. Reproducible is the stronger test.



- 1 Three students timed the same toy car rolling down the same ramp.

Set	Trial 1 / s	Trial 2 / s	Trial 3 / s	Mean / s
A	1.20	1.23	1.19	1.21
B	1.05	1.47	1.12	1.21
C	0.90	0.93	0.89	0.91

a Sets A and B have the same mean. The more precise set is A B Explain how you can tell.

A: its readings are close together (1.19 s to 1.23 s); B's are spread from 1.05 s to 1.47 s.

b The true time is about 1.21 s. Set C is precise but accurate not accurate Suggest what could shift every reading in set C by the same amount.

A systematic error, e.g. the stopwatch was stopped too early every time, or the car was started from a different point each time by the same amount.

c What is the point of taking three readings instead of one?

You can see how much the readings vary, spot an odd one, and calculate a mean, which reduces the effect of random error.

- 2 A balance is used to weigh a mass of exactly 50.0 g three times. Draw **one** line from each set of readings to the description that fits.

50.1 g, 49.9 g, 50.0 g	precise but not accurate
52.4 g, 52.5 g, 52.4 g	neither precise nor accurate
47.0 g, 53.1 g, 49.8 g	precise and accurate
44.2 g, 46.9 g, 41.7 g	accurate on average, not precise

3 The neutrino readings in *The case* were

precise and accurate

precise but not accurate

accurate but not precise

Explain

your choice.

The readings agreed closely (precise), but all were wrong by the same amount because of the loose cable: a systematic error, so not accurate.

4 **SUPPORTED** Complete the table. All the readings are in cm. Then answer the questions below it.

Set	Trial 1	Trial 2	Trial 3	Mean	Largest – smallest	Uncertainty
A	12.0	12.4	12.1	12.2	0.4	0.2
B	8.4	9.1	8.6	8.7	0.7	0.35 (0.4)
C	24.9	25.1	25.1	25.0	0.2	0.1
D	3.20	3.65	3.25	3.37	0.45	0.23

a Show your working for the mean of one set.

e.g. A: $(12.0 + 12.4 + 12.1) \div 3 = 36.5 \div 3 = 12.17$, about 12.2 cm

b The most precise set is A B C D The set with the largest uncertainty is

A B C D

c One reading in set D may be a mistake. Which one? What would you do before using the mean?

3.65 cm: it is far from 3.20 and 3.25. Check how it was recorded and repeat that measurement before trusting the mean.

5 Is each problem a random or a systematic error? Draw a ring around one word in each row.

Reaction time: the stopwatch is started sometimes early, sometimes late.

random

systematic

The ruler is read from its very end, not from the zero mark.

random

systematic

A balance reads 0.2 g with nothing on it.

random

systematic

The height of a fast bounce is judged by eye.

random

systematic

A draught from an open window comes and goes.

random

systematic

A scale is always read from above, at the same angle.

random

systematic

- 6 Explain why taking more repeats cannot remove a systematic error.

A systematic error shifts every reading by the same amount in the same direction, so the mean of many repeats is shifted by that amount too. Random errors go both ways, so they partly cancel in a mean.

- 7 Complete the table.

Instrument	Resolution	Could it show a change of 0.5 mm?
Ruler marked every 1 cm	1 cm / 1 mm / 0.1 mm 1 cm	yes / no no
Ruler marked every 1 mm	1 cm / 1 mm / 0.1 mm 1 mm	yes / no no
Digital calipers reading to 0.1 mm	1 cm / 1 mm / 0.1 mm 0.1 mm	yes / no yes

A stopwatch reads to 0.01 s. Its resolution is 0.01 s 0.1 s 1 s

- 8 Explain what is wrong with what Sam says.

Sam

My digital balance shows two decimal places, so my results must be accurate.

More decimal places means a finer resolution, not accuracy. A balance with a zero error gives precise but wrong readings; check it with a known mass.

- 9 **CHALLENGE** Data detective. For each claim, write what you would need to know before believing it, and the error you suspect.

The claim	What I would need to know first	Error I suspect
"Our reaction times improved after training." The two tests were timed by different people.	Was the timing done the same way? How big is the change compared with the spread of repeats?	random / systematic systematic
"The room is exactly 6.000 m long." Measured once, with the tape held slightly slack.	Was the tape tight and straight? Can a tape really read to 1 mm (6.000 m)?	random / systematic systematic
"This spring stretches 4.0 cm for each 100 g." One reading was taken for each mass.	How much do repeat readings vary? One reading cannot show or reduce random error.	random / systematic random

Checkpoint. Complete the sentences.

Choose answers from the box. Each word may be used once, more than once or not at all.

precise accurate random systematic resolution

A set of results that are close together is precise.

A result that is close to the true value is accurate.

Repeats reduce the effect of random errors, but not systematic errors.

The smallest change an instrument can detect is its resolution.



MEASURE ONE THING THREE TIMES

Your teacher gives you one task: a dropped-ruler reaction test, a toy car on a ramp, the bounce of a ball, or one object measured with different rulers.

- 1 Agree exactly what you will measure, and from where to where.
- 2 Take three readings. Write each one down as soon as you take it.
- 3 Calculate the mean and the uncertainty.

What I measured (with unit)	Trial 1	Trial 2	Trial 3	Mean	Uncertainty
catch distance / cm (sample)	14.0	17.5	15.5	15.7	1.8

Instrument I used	e.g. 30 cm ruler
Its resolution	e.g. 1 mm

- 11 Name one random error that affected you. How do you know it was random?

e.g. reaction time catching the ruler: the readings went up and down (14.0, 17.5, 15.5 cm) with no pattern.

- 12 Name one possible systematic error. How would you look for it?

e.g. the zero of the ruler was not level with the fingers each time. Check the zero, or swap the person or equipment and see whether the whole set shifts.

- 13 One thing I would do differently to make my readings more repeatable:

e.g. the same person drops the ruler each time from the same starting position.



Get the marks: Show the sum before you divide. Give the answer to the same number of decimal places as the readings.

- 14 A student times a pendulum swinging 10 times. The readings are 15.2 s, 15.6 s and 15.3 s. Calculate the mean time. [2 marks]

$$(15.2 + 15.6 + 15.3) \div 3 = 46.1 \div 3 \text{ (1)}$$

$$= 15.4 \text{ s (1)}$$

- 15 Calculate the uncertainty in the mean. Use uncertainty = (largest – smallest) ÷ 2 [2 marks]

$$(15.6 - 15.2) \div 2 \text{ (1)}$$

$$= 0.2 \text{ s (1)}$$

- 16 The student always starts the stopwatch late, by about the same amount. [1 mark]
What type of error is this? Tick **one** box.

☐ random error

☒ systematic error

☐ anomalous result

- 17 Explain why repeating the measurement would not reduce this error. [1 mark]

Every reading is shifted by the same amount in the same direction, so the mean is shifted too (1).

TAKE IT HOME

- 18 Find a claim with a number in it: an advert, a headline or a sports statistic. Write it down, then write one question you would have to ask before you believed it. Bring it to Lesson 2.

Open. A good question asks what is missing: how many people or trials, how it was measured, or what it was compared with.



SUMMARY

- **Precise:** repeat readings close together. **Accurate:** close to the true value.
- **Random error** spreads readings both ways; repeats and a mean reduce it.
- **Systematic error** shifts every reading the same way; repeats do not help.
- $\text{uncertainty} = (\text{largest} - \text{smallest}) \div 2$. Write the result as $\text{mean} \pm \text{uncertainty}$.
- **Resolution:** the smallest change an instrument can detect.

COVER THE PAGE AND ANSWER

1 What does precise mean?
.....

2 What does accurate mean?
.....

3 How do you calculate the uncertainty from repeats?
.....

4 Which kind of error do repeats reduce?
.....

5 A balance reads 0.2 g with nothing on it. What kind of error?
.....

6 What is the resolution of a ruler with mm marks?
.....

I CAN...

tell precision from accuracy



calculate a mean and an uncertainty from repeats



tell random from systematic error and say how to deal with each



state the resolution of an instrument



WHAT ARE YOU ACTUALLY CHANGING?

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

BIG QUESTION An advert says a drink makes you smarter. What would you need to know before you believed it?

BY THE END YOU CAN

- identify the independent, dependent and control variables in any investigation
- decide whether data is continuous or categoric
- choose a line graph or a bar chart, and give the reason

independent variable

dependent variable

control variable

continuous

categoric

fair test

THE CASE

The study that proved nothing. An invented example. A drinks company says students who drank its product scored higher in a maths test. But the drinkers sat the test in the morning and the others after lunch, in a different room. Two things changed at once, so the result cannot tell you which one made the difference.

Change one thing. Measure one thing. Keep everything else the same.



REMEMBER

DO NOW

From earlier lessons. No notes!

1

Precise means repeat readings are close to each other (close to each other / close to the true value).

close to each other

2

Repeats and a mean reduce the effect of random (random / systematic) errors.

random

3

Calculate the uncertainty for 3.2 s, 3.6 s and 3.4 s.

$$(3.6 - 3.2) \div 2 = 0.2 \text{ s}$$



EXPLAIN

TAKE THE QUESTION APART

Every investigation answers one question: **How does X affect Y?** X is what you change. Y is what you measure.

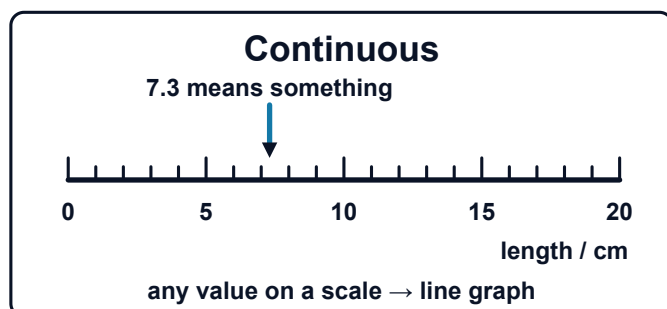


KEEP THE SAME
 control variables
 e.g. same trolley, same start line, same floor, released with no push

VARIABLE	MEANING	EXAMPLE: THE RAMP
Independent	the one thing you change on purpose	ramp height
Dependent	the thing you measure	distance the trolley travels
Control	everything you keep the same , so it cannot affect the result	same trolley, same start line, same floor, no push

! **Change only one thing at a time.** Test a longer pendulum with a heavier bob, and the swing takes longer: was it the length or the mass? You cannot say. “Keep it a fair test” earns nothing on its own: name the variable and how you keep it the same, such as “use the same bob each time”.

■ TWO KINDS OF DATA



Categoric

sponge

cardboard

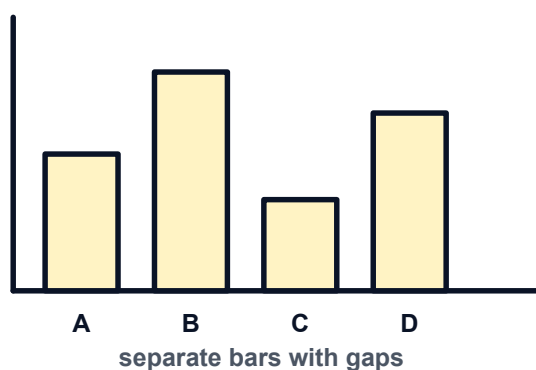
cloth

nothing halfway between sponge and cardboard
names or groups → bar chart

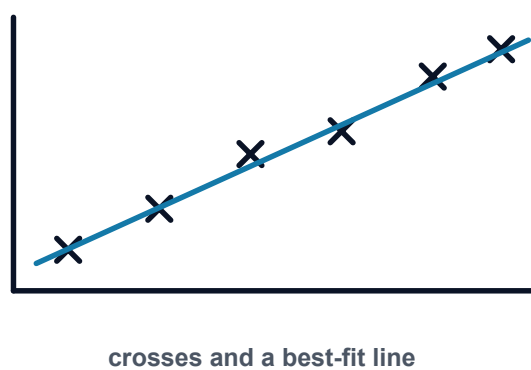
Test: is there a value in between? Between 10 cm and 20 cm there is 15 cm, and it means something: length is **continuous**. There is nothing halfway between sponge and cardboard: material is **categoric**. The same thing can be recorded either way: “hot, warm, cold” is categoric, but “60 °C, 40 °C, 20 °C” is continuous and tells you much more. When you can, measure.

■ WHICH GRAPH?

Categoric → bar chart



Continuous → line graph



THE RULE THAT DECIDES YOUR GRAPH

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

A line says something about the values between your points, which only makes sense if in-between values exist. Separate bars show separate things.

! **The mistake almost everyone makes:** “My results are numbers, so it’s a line graph.” In “Which surface gives the most friction?” you measure a distance in centimetres, but surface type is what you changed, and surfaces are categories. So it is a bar chart. Look only at the independent variable.



- 1 Fill in all three columns. Take care with the controls: they are the column people rush.

Investigation question	I change (independent)	I measure (dependent)	I keep the same (two controls)
How does ramp height affect the speed of a trolley?	ramp height	speed of the trolley	same trolley; same release point
Which material is the best thermal insulator?	insulating material	temperature drop in a set time	same starting temperature; same volume of water
How does the number of elastic bands affect launch distance?	number of elastic bands	launch distance	same projectile; same pull-back
Which drink contains the most sugar?	type of drink	mass of sugar	same volume of drink; same test method

Pick one of the four. If you did not keep your controls the same, what would go wrong with your conclusion?

e.g. ramp height: if the trolley were released from a different point each time, a change in speed could be caused by that, not by the height, so you could not say what caused it.

- 2 Is each variable continuous or categoric? Draw a ring around one word in each row.

The mass of a ball continuous categoric

The colour of a car continuous categoric

The time a ball takes to fall continuous categoric

The type of metal in a wire continuous categoric

The temperature of the water continuous categoric

3

Sort the investigations. Both columns are needed for full credit.

Investigation	Graph	The independent variable is...
How does temperature affect dissolving time?	line / bar line	continuous / categoric temperature: continuous
Which surface gives the most friction?	line / bar bar	continuous / categoric surface: categoric
How does mass affect the stretch of a spring?	line / bar line	continuous / categoric mass: continuous
Which paper towel absorbs the most water?	line / bar bar	continuous / categoric brand: categoric
How does pendulum length affect the time of a swing?	line / bar line	continuous / categoric length: continuous
Which material is the best sound absorber?	line / bar bar	continuous / categoric material: categoric

4

CHALLENGE Fix the broken plan. A student writes: *“I will test whether expensive tennis balls bounce better. I’ll drop an expensive ball from the window and a cheap one from my hand, and see which bounces higher.”*

a Name two things wrong with this plan.

Any two: two things change (the ball and the drop height); “better” is vague: measure the bounce height in cm; only one drop of each, so no repeats; the release is different.

b Rewrite it as a question in the form “How does X affect Y?”

How does the type of tennis ball affect its bounce height when it is dropped from 1.0 m?

c Your question needs a **bar chart** **line graph** because the independent variable is

continuous

categoric

5 Checkpoint. Complete the sentences.

Choose answers from the box. Each word may be used once, more than once or not at all.

change measure keep the same continuous categoric

The independent variable is the thing I change.

The dependent variable is the thing I measure.

Control variables are the things I keep the same.

Use a line graph when the independent variable is continuous.

Use a bar chart when the independent variable is categoric.

6 **EXPLAIN** Explain to someone who missed the lesson why the choice of graph depends on the independent variable and not on the dependent one.

The independent variable goes along the x-axis, so it decides whether the x-axis is a number scale (line graph) or a row of separate labels (bar chart). The dependent variable is nearly always a number, so it cannot tell the two cases apart.



INVESTIGATE

DEMO: WHICH SURFACE SLOWS THE CAR MOST?

Your teacher rolls the same car down the same ramp onto different surfaces: bench, carpet, rubber mat, sandpaper.

Independent variable	type of surface
Dependent variable (with unit)	distance the car travels / cm
Graph type	line graph bar chart

7 List three control variables. Put a star by the one that would be hardest to keep the same.

Same car; same ramp height; same release point, with no push*. The release is hardest: it is easy to give a small push or start from a slightly different spot.



Get the marks: The independent variable is the one the student chooses to change.

- 8 A student investigates how the length of a wire affects its resistance. [1 mark]
Complete the sentence.

The independent variable is

the length of the wire

the resistance

the temperature

- 9 Give **one** control variable for this investigation. [1 mark]

Any one: the thickness of the wire; the material of the wire; the temperature (1).

- 10 Complete the sentence. [1 mark]

The results should be shown on a bar chart line graph because the length of the wire is categoric continuous

Both needed (1).

- 11 Which investigation should be shown on a bar chart? Tick **one** box. [1 mark]

☐

how the height of a drop affects the time a ball takes to fall

☒

how the type of shoe affects grip

☐

how temperature affects how fast sugar dissolves

☐

how mass affects the stretch of a spring

TAKE IT HOME

- 12 Write five investigation questions of your own in the form "How does X affect Y?": at least two that need a bar chart and two that need a line graph. For each, name the independent variable and say whether it is continuous or categoric.

Open. Check that each question changes one thing and measures one thing, and that the independent variable is correctly labelled continuous or categoric.



SUMMARY

- **Independent:** the one thing you change.
Dependent: what you measure. **Control:** what you keep the same.
- Change only one thing, or you cannot tell what caused the result.
- **Continuous:** any value on a scale. **Categoric:** names or groups.
- Continuous independent variable → line graph.
Categoric → bar chart.

COVER THE PAGE AND ANSWER

1 What is the dependent variable?

.....

3 Is surface type continuous or categoric?

.....

2 Why must control variables be kept the same?

.....

4 Which variable decides the type of graph?

.....

I CAN...

identify the independent, dependent and control variables



say whether data is continuous or categoric



choose a line graph or a bar chart and give the reason



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:
(largest – smallest) ÷ 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

■ 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.”

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
01: Can this data be trusted?	
tell precision from accuracy	  
calculate a mean and an uncertainty from repeats	  
tell random from systematic error and say how to deal with each	  
state the resolution of an instrument	  
02: What are you actually changing?	
identify the independent, dependent and control variables	  
say whether data is continuous or categoric	  
choose a line graph or a bar chart and give the reason	  



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 1: CAN THIS DATA BE TRUSTED?

DO NOW

1. Any sensible reason, e.g. your reaction time when starting and stopping the stopwatch is different each time, or the car is released slightly differently.
2. $(4 + 5 + 6) \div 3 = 15 \div 3 = 5$ cm
3. The one marked in millimetres.

COVER THE PAGE

1. Repeat readings are close to each other.
2. Close to the true value.
3. $(\text{largest} - \text{smallest}) \div 2$
4. Random error.
5. Systematic (a zero error).
6. 1 mm

LESSON 2: WHAT ARE YOU ACTUALLY CHANGING?

DO NOW

1. close to each other
2. random
3. $(3.6 - 3.2) \div 2 = 0.2$ s

COVER THE PAGE

1. The variable that is measured.
2. If two things change, you cannot tell which one caused the result.
3. Categorical.
4. The independent variable.

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.