Physics 2019 v1.3

IA2 high-level annotated sample response

November 2022

Student experiment (20%)

This sample of student work has been published by the QCAA to assist and support teachers to match evidence in student responses to the characteristics described in the instrument-specific marking guide (ISMG).

The following sample is an unedited authentic student response produced with permission. Any identifying features have been redacted from the response. It may contain errors and/or omissions that do not affect its overall match to the characteristics indicated.

Assessment objectives

2. apply understanding of gravity and motion, or electromagnetism to modify experimental methodologies and process primary data
3. analyse experimental evidence about gravity and motion, or electromagnetism
4. interpret experimental evidence about gravity and motion, or electromagnetism
5. investigate phenomena associated with gravity and motion, or electromagnetism, through an experiment
6. evaluate experimental processes and conclusions about gravity and motion, or electromagnetism
7. communicate understandings and experimental findings, arguments and conclusions about gravity and motion, or electromagnetism

Note: Objective 1 is not assessed in this instrument.

Instrument-specific marking guide (ISMG)

Criterion: Research and planning

Assessment objectives

2. apply understanding of gravity and motion, or electromagnetism to modify experimental methodologies and process primary data
5. investigate phenomena associated with gravity and motion, or electromagnetism, through an experiment

The student work has the following characteristics:	Marks
• informed application of understanding of gravity and motion, or electromagnetism to modify experimental methodologies demonstrated by – a considered rationale for the experiment – justified modifications to the methodology • effective and efficient investigation of phenomena associated with gravity and motion, or electromagnetism demonstrated by – a specific and relevant research question – a methodology that enables the collection of sufficient, relevant data – considered management of risks and ethical or environmental issues	5–6
• adequate application of understanding of gravity and motion, or electromagnetism to modify experimental methodologies demonstrated by – a reasonable rationale for the experiment – feasible modifications to the methodology • effective investigation of phenomena associated with gravity and motion, or electromagnetism demonstrated by – a relevant research question – a methodology that enables the collection of relevant data – management of risks and ethical or environmental issues	3–4
• rudimentary application of understanding of gravity and motion, or electromagnetism to modify experimental methodologies demonstrated by – a vague or irrelevant rationale for the experiment – inappropriate modifications to the methodology • ineffective investigation of phenomena associated with gravity and motion, or electromagnetism demonstrated by – an inappropriate research question – a methodology that causes the collection of insufficient and relevant data – inadequate management of risks and ethical or environmental issues	1–2
• does not satisfy any of the descriptors above.	0

Criterion: Analysis of evidence

Assessment objectives

2. apply understanding of gravity and motion, or electromagnetism to modify experimental methodologies and process primary data
3. analyse experimental evidence about gravity and motion, or electromagnetism
5. investigate phenomena associated with gravity and motion, or electromagnetism through an experiment

The student work has the following characteristics:	Marks
• appropriate application of algorithms, visual and graphical representations of data about gravity and motion, or electromagnetism demonstrated by correct and relevant processing of data • systematic and effective analysis of experimental evidence about gravity and motion, or electromagnetism demonstrated by – thorough identification of relevant trends, patterns or relationships – thorough and appropriate identification of the uncertainty and limitations of evidence • effective and efficient investigation of phenomenon associated with gravity and motion, or electromagnetism demonstrated by the collection of sufficient and relevant raw data	5–6
• adequate application of algorithms, visual and graphical representations of data about gravity and motion, or electromagnetism demonstrated by basic processing of data • effective analysis of experimental evidence about gravity and motion, or electromagnetism demonstrated by – identification of obvious trends, patterns or relationships – basic identification of the uncertainty and limitations of evidence • effective investigation of phenomenon associated with gravity and motion, or electromagnetism demonstrated by the collection of relevant raw data	3–4
• rudimentary application of algorithms, visual and graphical representations of data about gravity and motion, or electromagnetism demonstrated by incorrect or irrelevant processing of data • ineffective analysis of experimental evidence about gravity and motion, or electromagnetism demonstrated by – identification of incorrect or irrelevant trends, patterns or relationships – incorrect or insufficient identification of the uncertainty and limitations of evidence • ineffective investigation of phenomenon associated with gravity and motion, or electromagnetism demonstrated by the collection of insufficient and irrelevant raw data	1–2
• does not satisfy any of the descriptors above.	0

Criterion: Interpretation and evaluation

Assessment objectives

4. interpret experimental evidence about gravity and motion, or electromagnetism
6. evaluate experimental processes and conclusions about gravity and motion, or electromagnetism

The student work has the following characteristics:	Marks
• insightful interpretation of experimental evidence about gravity and motion, or electromagnetism demonstrated by justified conclusion/s linked to the research question • critical evaluation of experimental processes about gravity and motion, or electromagnetism demonstrated by – justified discussion of the reliability and validity of the experimental process – suggested improvements and extensions to the experiment that are logically derived from the analysis of evidence	5–6
• adequate interpretation of experimental evidence about gravity and motion, or electromagnetism demonstrated by reasonable conclusion/s linked to the research question • basic evaluation of experimental processes about gravity and motion, or electromagnetism demonstrated by – reasonable description of the reliability and validity of the experimental process – suggested improvements and extensions to the experiment that are related to the analysis of evidence	3–4
• invalid interpretation of experimental evidence about gravity and motion, or electromagnetism demonstrated by inappropriate or irrelevant conclusion/s • superficial evaluation of experimental processes about gravity and motion, or electromagnetism demonstrated by – cursory or simplistic statements about the reliability and validity of the experimental process – ineffective or irrelevant suggestions	1–2
• does not satisfy any of the descriptors above.	0

Criterion: Communication

Assessment objectives

7. communicate understandings and experimental findings, arguments and conclusions about gravity and motion, or electromagnetism

The student work has the following characteristics:	Marks
• effective communication of understandings and experimental findings, arguments and conclusions about gravity and motion, or electromagnetism demonstrated by – fluent and concise use of scientific language and representations – appropriate use of genre conventions – acknowledgment of sources of information through appropriate use of referencing conventions	2
• effective communication of understandings and experimental findings, arguments and conclusions about gravity and motion, or electromagnetism demonstrated by – competent use of scientific language and representations – use of basic genre conventions – use of basic referencing conventions	1
• does not satisfy any of the descriptors above.	0

Context

See IA2 sample assessment instrument: Student experiment (20%) (available on the QCAA Portal).

You have completed the following practicals in class:

- Conduct an experiment to determine the horizontal distance travelled by an object projected at various angles from the horizontal (mandatory practical).
- Conduct an experiment to investigate the force acting on a conductor in a magnetic field (mandatory practical).
- Conduct an experiment to investigate the strength of a magnet at various distances (mandatory practical).

Task

Modify (i.e. refine, extend or redirect) an experiment in order to address your own related hypothesis or question.

You may use a practical performed in class, a related simulation or another practical related to Unit 3 (as negotiated with your teacher) as the basis for your methodology and research question.

Sample response

Criterion	Marks allocated	Provisional marks
Research and planning Assessment objectives 2, 5	6	6
Analysis of evidence Assessment objectives 2, 3, 5	6	6
Interpretation and evaluation Assessment objectives 4, 6	6	6
Communication Assessment objective 7	2	2
Total	**20**	**20**

The annotations show the match to the instrument-specific marking guide (ISMG) performance-level descriptors.

Projectile Motion of a Spherical Object Student Experiment

Research Question

What is the relationship between the angle of projection of a spherical projectile and its time of flight, when the mass of the projectile, its initial velocity, and its vertical displacement are constant?

Research and planning [5–6]

a specific and relevant research question

The research question is clearly defined to allow the collection of sufficient and relevant data. The research question is connected to the rationale and the topics covered in the unit.

Rationale

The purpose of the original student experiment was to investigate the relationship between the projection angle of a spherical projectile and its range. The following theoretical relationship was expected ("Projectiles Launched at Angle Review", n.d.)

$$R = \frac{u^2 \sin 2\theta}{g}$$

The angle of projection was the independent variable, carbon paper with plain paper underneath was laid on desks so the range was measured between the mark left by the projectile and the launcher. The spring loader of the launcher had a constant tension, so the initial velocity was constant ("Projectiles Launched at Angle Review", n.d.) However, this experiment allowed moderate random error as the paper shifted easily, so range measurements were randomly inaccurate.

Research and planning [5–6]

justified modifications to the methodology

The response gives sound reasons for how the modifications to the methodology will refine, extend or redirect the original experiment, and includes strategies for achieving these modifications.

Consequently, the experiment was redirected and refined. Whilst the angle was kept as the independent variable, the dependent variable became time. This allowed the relationship between projection angle and time to be investigated, and error as a result of the carbon paper method was eliminated. The experiment was refined by recording the projectiles' trajectories on a phone, converting the videos to 240 frames per second (fps), using a phone to time the trajectories shown by the videos, and then dividing this measurement by eight to determine what the time would be in real life (as this is 30 fps). As initial velocity was a variable in the expected relationship, a photogate was used to measure this. The use of a photogate allowed the measurements to be precise and accurate, thereby increasing the usefulness of the results in comparison to the original experiment. A single ball bearing was used so mass was constant, and the ball landed on a desk the height of the launcher, so vertical displacement was 0 m (allowing a far simpler expected relationship to be used). The angle was measured from $10°$ to $80°$ so the ball was projected at an angle and safely.

Research and planning [5-6]

a considered rationale for the experiment

The rationale explicitly communicates the reasons for the modifications to the methodology.

It was expected that the initial speed would be approximately constant (this is specified in the research question) as the spring loader of the launcher was kept at a constant tension, meaning that the magnitude of the projection force was constant. The projection angle had an effect only on the direction of the initial velocity, not its magnitude.

Research and planning [5–6]

a considered rationale for the experiment

The rationale explicitly communicates the reasons for modifying the original experiment.

Laws of linear motion were used to express the relationship between projection angle and time of flight, because they considered the necessary elements, however this did not consider horizontal acceleration (deceleration due to air resistance). It was assumed that this was negligible because the distance travelled by the projectile was too small and the projectile only had small radius, so the measuring instruments would not register to air resistance to a significant extent because they were not that precise ("Air and fluid resistance" | Khan Academy, n.d.) Additionally, experiments were conducted in a small classroom rather than outside so wind was minimal.

To determine the expected relationship:

$$s_y = \frac{1}{2}gt^2 + u_y t$$

If $s_y = 0\,m$ and $u_y = u\sin\theta$:

$$0 = \frac{1}{2}gt^2 + u\sin\theta\, t$$

Factorise out t and use the null factor theorem:

$$0 = \frac{1}{2}gt + u\sin\theta \text{ OR } t = 0$$

$$t = \frac{2u\sin\theta}{g}$$

So $s_y = 0\,m$ at $t = 0$ and $t = \frac{2u\sin\theta}{g}$. Hence time of flight is:

$$t = \frac{2u\sin\theta}{g}$$

It was expected that the relationship between projection angle and time of flight could be expressed by this equation ("Projectiles Launched at Angle Review", n.d). Therefore:

$$t \propto \sin\theta$$

The constant of proportionality is $\frac{2u}{g}$.

The initial experiment supported the expected relationship, so maximum range was at $45°$. The expected relationship for the modified experiment predicts that time increases as angle increases, meaning that despite the maximum range at $45°$ the maximum distance travelled (and hence maximum height) is at $90°$. As angle increases, more of the initial velocity is in the vertical component and less in the horizontal component, so its height and time of flight increases ("Projectiles Launched at Angle Review", n.d). This can be seen from the expected relationship as $u\sin\theta = u_y$ so $t = \frac{2u_y}{g}$.

Subsequently, the purpose of the student experiment was to investigate the relationship between the projection angle of a spherical projectile and its time of flight, when the mass of the projectile, its initial velocity, and its vertical displacement are constant.

Research and planning [5–6]

considered management of risks and ethical or environmental issues

The response shows careful and deliberate identification and planning to handle risks and ethical or environmental issues in the experiment.

Management of Risks

The primary risk was being hit by a projectile, either while in the air or after bouncing off the table it landed on. To manage this, students wore safety glasses and stood behind the launcher. Additionally $90°$ was not a projection angle used as the projectile would land directly at the launcher, endangering the person who launched it.

Analysis of evidence

collection of sufficient and relevant raw data

The raw data is adequate, even after the outliers are removed, for forming a conclusion and has direct bearing upon the research question.

Results

Table 1: Effect of projection angle of time of flight

Angle of projection ±? (°)	Time ± 0.01 (s)					Mean time (s)	Absolute Uncertainty of Mean Time (s) $(\pm x)$	Percentage Uncertainty of the Mean Time (%)
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5			
10	0.215	0.14875	0.18875	0.175	0.1275	0.16	0.030625	19.14
20	0.275	0.26375	0.2725	0.27375	0.26625	0.27025	0.0056	2.08
30	0.36875	0.36625	0.36875	0.3925	0.3725	0.37375	0.0131	3.51
40	0.46625	0.46375	0.46	0.46	0.475	0.465	0.0075	1.61
50	0.535	0.5275	0.53	0.525	0.53	0.5295	0.005	0.94
60	0.5025	0.5925	0.57625	0.5825	0.56625	0.564	0.01	1.74
70	0.535	0.62375	0.63625	0.61875	0.6375	0.61025	0.0094	1.49
80	0.6375	0.64625	0.64625	0.65	0.64125	0.64425	0.0063	0.97

Table 2: Effect of projection angle on initial velocity

Angle of projection ±? (°)	Initial velocity ± 0.01 (m/s)					Mean initial velocity (s)
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	
10	3.41	3.36	3.55	3.40	3.63	3.4704
20	3.86	3.58	3.46	3.31	3.60	3.562
30	4.29	4.32	4.41	3.73	4.41	4.232
40	3.04	5.03	4.41	6.35	5.86	3.725
45	3.68	3.34	4.24	3.66	3.53	3.69
50	4.97	4.45	4.41	4.39	4.18	4.48
60	3.59	4.22	4.76	4.08	4.34	4.198
70	3.50	4.80	3.86	4.19	4.47	4.164
80	3.38	3.28	3.65	3.31	3.38	3.4
Mean initial velocity ± 0.01 (m/s)	3.88					

Analysis of evidence [5–6]

correct and relevant processing of data

Raw data is manipulated accurately, providing evidence that responds to the research question.

Sample Calculations

Mean time at $\theta = 10°$

$$\frac{\sum_{i=1}^{n} x}{n}$$
$$= \frac{0.14875 + 0.18875 + 0.175 + 0.1275}{4}$$
$$= 0.16\ \text{s}$$

Absolute uncertainty of mean time at $\theta = 10°$

$$\delta = \pm\frac{(x_{max} - x_{min})}{2}$$
$$= \pm\frac{(0.18875 - 0.1275)}{2}$$
$$= \pm 0.030625\ \text{s}$$

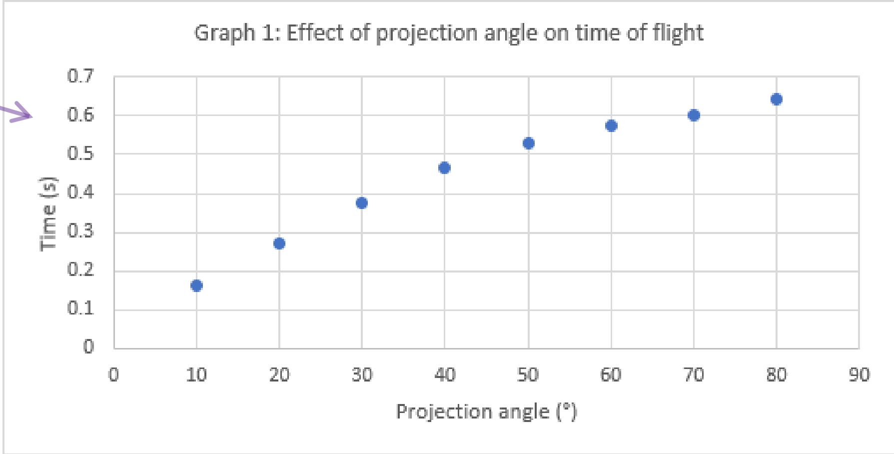
Percentage uncertainty of mean time at $\theta = 10°$

$$\%\delta = \frac{0.030625}{0.16} \times 100$$
$$\approx 19.14\%$$

Communication [2]

appropriate use of genre conventions

The response presents data following scientific conventions of graph construction.



Outliers (highlighted green) were removed from tables 1 and 2 as they were over 20 – 80% different to the other measurements in the row. Although the velocity value in Table 2, $40°$, Trial 1 was an outlier for that angle, it was similar to the measurements for other angles and hence was not removed. This allowed the accuracy of the results to be increased.
Table 2 shows that initial velocity was constant as expected. Although some angles appear to produce initial velocities consistently higher or lower than the mean velocity (such as $80°$), this is not significant as these values are similar to other measurements for different angles.

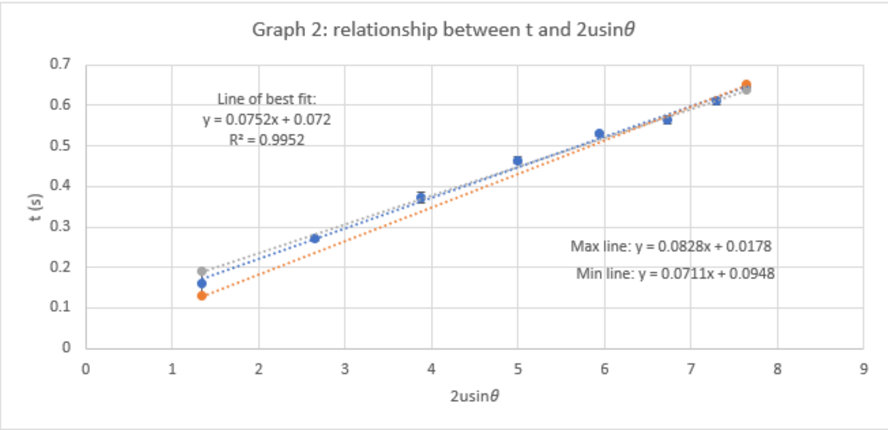
Analysis of evidence [5–6]

thorough identification of relevant trends, patterns or relationships

The response identifies trends, patterns or relationships that are applicable to the research question.

Analysis of Evidence

The relationship shown by graph 1 looks like the first quarter period of a sine curve (only approximately considering the angle was measured from $10°$ to $80°$), as it increases steadily and then flattens as it approaches $90°$, or it could be half a parabola. To determine if the data follows the expected relationship of a sine curve, t vs $2u \sin\theta$ was graphed as the expected theoretical relationship $t = \frac{2u \sin\theta}{g}$ can be rearranged so $g = \frac{2u \sin\theta}{t}$. Hence the reciprocal of the gradient is the observed acceleration due to gravity. Mean u was used as data and theory shows that u is not affected by θ. Additionally, it can be inferred from graph 1 that time would be greatest at $90°$, as $80°$ and $100°$ give the same angle from the horizontal. This also supports the expected relationship.



Analysis of evidence [5–6]

thorough and appropriate identification of the uncertainty and limitations of evidence

The response quantifies the uncertainty of the evidence using numerical calculations associated with the processed data . This allows decisions to be made about the confidence with which the evidence can be applied to the research question.

Sample Calculations

X-axis $(2u\sin\theta)$ for $\theta = 10°$

$$2u\sin\theta$$
$$= 2 \times 3.88 \sin 10$$
$$= 1.348$$

Uncertainty of gradient:

$$\delta = \left|\frac{(m_{max} - m_{min})}{2}\right|$$
$$= \left|\frac{(0.0828 - 0.0711)}{2}\right|$$
$$= 0.00585$$

Percentage uncertainty of gradient:

$$\%\delta = \frac{0.00585}{0.0752}$$
$$= 7.78\%$$

As $\frac{1}{gradient}$ was the observed value for g, the uncertainty of observed g is the reciprocal of (0.0752 $\pm 7.78\%$).

Alternatively:

Uncertainty of $\frac{1}{gradient}$:

$$\delta = \left|\frac{(m_{max} - m_{min})}{2}\right|$$
$$= \left|\frac{\left(\frac{1}{0.0711} - \frac{1}{0.0828}\right)}{2}\right|$$
$$= 0.99337$$

Percentage uncertainty of $\frac{1}{gradient}$:

$$\%\delta = \frac{0.99337}{\left(\frac{1}{0.0752}\right)}$$
$$= 7.5\%$$

The observed g value is $\frac{1}{0.0752} = 13.298\ ms^{-2}$.

Communication [2]

acknowledgment of sources of information through appropriate use of referencing conventions

The use of in-text referencing for the purpose of a scientific report.

The percentage error was determined by comparing the observed and expected g ("Gravity | Geoscience Australia", n.d.)

$$\%\ error = \left|\frac{v_{observed} - v_{expected}}{v_{expected}} \times 100\right|$$
$$= \left|\frac{13.298 - 9.8}{9.8} \times 100\right|$$
$$\approx 36\%$$

This error is greater than the percentage uncertainty of the gradient of 8%, suggesting significant error in the data not related to measurement uncertainty. This is likely to be systematic as the y-intercept is not 0 (a y-

	intercept of 0 suggests no systematic error) and R^2 value of 0.9952. This could be due to systematic measurement errors in time. Graph 2 also shows slight random error as R^2 is 0.9952, and the first four data points appear more consistent than the last four. This is likely because the timing method relied on human reaction.
Communication [2] fluent and concise use of scientific language and representations The response refers to data to accurately interpret the observed trends, patterns and relationships.	## Interpretation of Evidence The purpose of this experiment was to investigate the relationship between the projection angle of a spherical projectile and its time of flight. The evidence shows that when the projection angle increased from 10° to 80°, time of flight increased from 0.16 s to 0.644 s. Graph 1 shows that as angle increases, time increases, and suggests some sinusoidal or parabolic relationship consistent with the expected relationship.
Analysis of evidence [5–6] thorough and appropriate identification of the uncertainty and limitations of evidence The response examines the uncertainty to determine if the evidence that will be used to draw a conclusion to the research question is reliable and valid.	Although graph 2 linearises, suggesting a sinusoidal relationship like the expected one, the percentage error of the observed g value is 36%, suggesting significant error or that the expected relationship was not appropriate. The y-intercept of graph 2 is not 0 and R^2 is 0.9952, suggesting that the primary cause of the percentage error was systematic error (if R^2 were less this error would be more likely to be random.) Overall, the data suggests that either there was significant systematic error and moderate random error, or that $t = \frac{2u\sin\theta}{g}$ is not the most appropriate relationship because there were significant and unknown factors affecting the results.
Interpretation and evaluation [5–6] justified discussion of the reliability and validity of the experimental process The response uses sound reasoning and evidence from the identification of uncertainties and limitations to support the consideration of the reliability and validity of the experimental process.	## Evaluation The reliability and hence precision of the results was acceptable. Although the maximum percentage uncertainty for time was 19%, this is likely due to random error from the timing method or if the launcher slipped in some way. The percentage uncertainty for time other than this was between 3.5% and 0.94%, which is acceptable. The data was consistent as R^2 from graph 2 is 0.9952. The method for timing allowed moderate random error, evident in primarily the last four data points for graph 2 when compared to the first four, also decreasing the reliability. This suggests that the precision of the measurements was acceptable, but the accuracy of the measurements was low (as shown by the percentage error of 36%) due to significant systematic error.
Interpretation and evaluation [5–6] justified conclusion/s linked to the research question The response uses an accepted value to draw a conclusion about the accuracy of the experimental results.	The data was not valid as the observed g value has a 36% percentage error and the expected value did not fall within the uncertainty of this value ($13.298 \pm 7.5\%$ is $14.3\ ms^{-2}$ to $12.3 ms^{-2}$). The y-intercept of the line of best fit suggests that the error and hence invalidity is from systematic error. It is possible that the expected relationship was not appropriate because it did not consider some unknown factors. This

justified discussion of the reliability and validity of the experimental process The response uses evidence from the identification of uncertainties and limitations to support the consideration of the reliability and validity of the experimental process. The response identifies significant random and systematic errors.	is not likely to be air resistance because the distance travelled by the projectile and the radius of the projectile was small, and this would slow the projectile, increasing time of fall. Observed g is 36% greater than expected, so the times recorded were smaller than in reality rather than greater. Additionally it was observed that the vertical displacement was in fact not 0 but negative, however this would increase the distance and hence the times, and this displacement was not significant enough to have such a large effect. So although this was a source of systematic error it is not the primary one. Systematic error could be due to the phones and videoing software used to calculate times—the videos may not have been slowed down to the necessary 240 fps or may have recorded the videos with too many fps, hence decreasing the times from what they were in reality. Alternatively, this error could be the result of an unknown source. Furthermore, the projectile may not have passed through the centre of the photogate, consequently recording initial velocity incorrectly. This would affect the y-intercept (already affected by the gradient), so it is unknown if this source of systematic error was present.
Interpretation and evaluation [5–6] **suggested improvements and extensions to the experiment which are logically derived from the analysis of evidence** The response uses clear, sound reasoning to arrive at improvements and extensions that would improve the reliability and validity of the experimental process by reducing the impact of the identified random and systematic errors.	Therefore, the experimental process was not appropriate as it allowed significant systematic error, resulting in invalid evidence. **Suggested Improvements and Extensions** The experiment could be improved by using more accurate measuring instruments for time and initial velocity, such as motion software as opposed to smartphones, as this would reduce systematic error. This would also reduce the random error present from human reaction time. This would improve the validity of the results and allow other factors affecting the relationship (such as air resistance and vertical displacement) to be investigated more thoroughly. Additionally more trials could be conducted to improve precision, considering that the percentage uncertainty of one of the mean times was 19%. The experiment could be extended by investigating the relationship between maximum height and angle of projection. It was expected and observed that maximum height increased as angle increased, so this could be investigated, again with software to minimise error. Additionally as initial velocity was constant for this experiment, the relationship between initial velocity and either range or time of flight could be investigated.
Interpretation and evaluation [5–6] **justified conclusion/s linked to the research question** The conclusion is related to the research question and is explicitly supported using the evidence gathered during the experiment.	**Conclusion** The evidence supports the expected relationship between projection angle and time of flight to an extent. The reliability of the results was moderate however they were not valid, as the percentage error was 36% and expected value for g did not fall in the uncertainty for the gradient. Graph 1 suggests some sinusoidal or parabolic relationship, supporting the expected sinusoidal relationship that as projection angle increases, time increases. Systematic

	error is shown by Graph 2, suggesting that the time or initial velocity was measured incorrectly consistently due to issues with the smartphones used, the photogate, or an unknown source. Hence, the improvements and extensions outlined previously are recommended.
Communication [2] **acknowledgment of sources of information through appropriate use of referencing conventions** The sources of information are acknowledged using a referencing style that is suitable for the purpose of the scientific report.	# References *Projectiles Launched at Angle Review*. Khan Academy. Retrieved on 26 April 2021 from: https://www.khanacademy.org/science/high-school-physics/two-dimensional-motion-2/projectiles-launched-at-an-angle-2/a/projectiles-launched-at-angles Gravity | Geoscience Australia. Retrieved 26 April 2021, from https://www.ga.gov.au/scientific-topics/disciplines/geophysics/gravity Air and fluid resistance (article) | Forces | Khan Academy. Retrieved 29 April 2021, from https://www.khanacademy.org/computing/computer-programming/programming-natural-simulations/programming-forces/a/air-anFd-fluid-resistance