Physics 2019 v1.2

IA2 high-level annotated sample response

August 2018

Student experiment (20%)

This sample has been compiled 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).

Assessment objectives

This assessment instrument is used to determine student achievement in the following 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 irrelevant 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 phenomena 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 uncertainty and limitations of evidence • effective investigation of phenomena 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 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 uncertainty and limitations of evidence • ineffective investigation of phenomena 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 relevant 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 objective

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
• adequate 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

Task

Context
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	Result
Research and planning Assessment objectives 2, 5	6	5
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**	**19**

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

Key: Research and planning | Analysis of evidence | Interpretation and evaluation | Communication

Note: Colour shadings show the characteristics evident in the response for each criterion.

Annotations	Response
Research and planning [5–6] **a specific and relevant research question** The response explicitly states the relationship in question and connects the relationship to the original experiment.	# Factors affecting the projectile motion of a sphere ## Research Question What is the relationship between the cross-sectional area of a spherical projectile and its horizontal displacement (range) when launched horizontally from a constant height above the ground, with a constant initial velocity?
a considered rationale for the experiment The response carefully communicates the purpose and reasons for the experiment. **Communication [2]** **acknowledgment of sources of information through appropriate use of referencing conventions** The use of in-text referencing fits the purpose of a scientific report.	## Rationale The purpose of conducting this experiment was to determine how the radius of a spherical projectile affects the projectile's range. An experiment was conducted in class that measured the horizontal distance travelled by an object projected at various angles from the horizontal. It was expected that the data should reflect the theoretical relationship of: $$s_x = \frac{v^2 \sin 2\theta}{g},$$ where s_x is the range (m), v is the initial velocity (m/s), θ is the angle and g is the acceleration due to gravity (Fitzpatrick, 2011). This theoretical relationship was not supported by the data because the range was always less than what was theoretically predicted. One of the major errors identified during this experiment was that air resistance or drag F_D was not considered. Initial research revealed that when a

Research and planning [5–6]	
a considered rationale for the experiment The response carefully communicates the purpose and reasons for the experiment.	projectile is fired, a drag force opposes the object's motion. This force is represented by the equation: $$F_D = C_D \times \rho \times \frac{v^2}{2} \times A$$ where C_D is the drag coefficient, ρ is the density of air, v is the object's velocity and A is the cross-sectional area (Benson, 2015). C_D can be determined by the shape of the falling object. The value of 0.42 can be substituted into C_D, as one side of the ball interacting with air, it can be considered to be a hemi-sphere shape when in flight (Bengtson, 2010). It is assumed that at a temperature of 20℃, ρ is 1.2041 kg/m^3 (Helmenstine, 2015). Objects with a larger surface area experience greater force due to drag, resulting in a shorter range for the projectile. Assuming the force of drag is the only force acting on the horizontal velocity, it is assumed that the force due to drag ($F_D = C_D \times \rho \times \frac{v^2}{2} \times A$) is responsible for the deceleration of the ball in the horizontal direction. This suggests that $F_D = ma_x = C_D \times \rho \times \frac{v^2}{2} \times A$. Rearranging this equation gives: $$a_x = C_D \times \rho \times \frac{v_x^2}{2m} \times A$$ (It is assumed that the deceleration due to air resistance is constant. However, it is known that the v_x term is not constant due to the fact that it is the instantaneous horizontal velocity of the projectile at any given time. This quantity is decreasing due to the deceleration a_x and thus, the assumption is not fully correct. It may however serve as an appropriate approximation to let $v_x = u_x$.) It is known that $v_x^2 = 2a_x s_x + u_x^2$ and, assuming the final velocity (v_x) is close to zero, it can be rearranged to make s_x the subject. $$s_x = -\frac{u_x^2}{2a_x}$$ This assumption that v_x is close to zero is suitable because the ball is projected so high off the ground that when it lands, almost all of its motion is in the y-direction. Substituting $a_x = C_D \times \rho \times \frac{v_x^2}{2m} \times A$ into the equation above gives: $$s_x = \frac{mu_x^2}{C_D \rho v_x^2 A}$$ Note: the negative sign is cancelled because a_x is acting in the opposite direction to the motion of the projectile. If $C_{D,}\ \rho, m, u_x\ and\ v_x$ are kept constant, then: $$s_x \propto \frac{1}{A}$$ with a proportionality, constant of $\frac{m}{C_D \rho}$.

Research and planning [5–6] **a considered rationale for the experiment** The response carefully communicates the purpose and reasons for the experiment.	As such, this experiment modifies the original experiment by redirecting it towards determining the relationship between the cross-sectional area of a spherical projectile and its horizontal displacement (range).
	Method
	Original Method
Research and planning [3–4] **feasible modifications to the methodology** The modifications can be achieved. However, the response does not justify how the modifications will refine, extend or redirect the original experiment.	The original method measured the horizontal distance travelled by an object projected at various angles from the horizontal. **Modifications:** • The angle was kept constant at zero degrees. • Hollow plastic balls of different radii were used. • Mass was added to the inside of the hollow ball using sand to give the ball a mass of 1.5 (± 0.05) $\times 10^{-3}$ Kg. • 7 different surface areas were tested. • Each surface area was trialled 5 times.
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 Risk:** The most significant risk identified is the potential for injury caused by the moving projectile. This was managed by ensuring that each experimenter wore safety glasses and was not standing in the firing area.

Research and planning [5–6]

a methodology that enables the collection of sufficient, relevant data

The methodology shows careful and deliberate thought. It enables collection of adequate data so an informed conclusion to the research question can be drawn.

Analysis of evidence [5–6]

collection of sufficient and relevant raw data

Even when the outliers are removed, there is enough data to find a relationship. The data can be used to respond to the research question.

Results

Table 1: Effect of ball's radius on range of a projectile (anomalies highlighted in red were ignored for the average)

Radius r (m) ($\pm 0.0001m$)	Area (m^2) ($\pm 4\%$)	Range s_x (m) ($\pm 0.01m$)							
		Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	**Mean**	**Absolute uncertainty of the mean (m) ($\pm x$)**	**Percentage uncertainty of the mean (%)**
0.005	0.00008	11.11	13.10	10.12	11.20	10.50	10.73	0.54	5
0.010	0.00031	6.32	9.12	6.11	6.52	5.90	6.21	0.31	5
0.015	0.00071	3.98	3.91	3.81	2.83	3.80	3.88	0.09	2.3
0.020	0.00126	2.12	2.03	2.34	4.28	2.51	2.25	0.24	10
0.025	0.00196	1.45	1.41	1.43	1.51	1.43	1.45	0.05	3.4
0.030	0.00283	1.10	1.20	1.03	2.73	1.50	1.21	0.24	20
0.035	0.00385	0.71	0.74	0.81	0.67	0.45	0.73	0.07	10

The values highlighted in red are identified as outliers because they are between 20-80% larger or smaller than the other 4 measurements. During the experiment, it was noticed that some wind gusts effected the flight of the projectiles. Time prevented the repetition of these effected trials. These values were excluded from the calculation of averages and not included in the graphs.

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

Cross-sectional area of the 0.005m projectile: $$A = \pi r^2$$ $$A = \pi(0.005)^2$$ $$A = 0.000078$$ With significant figures taken into account: $A = 0.00008$ m^2
Average range for the 0.00008m^2 projectile: $$\bar{x} = \frac{\sum_{i=1}^{n} x}{n}$$ $$= \frac{11.11+10.12+11.20+10.50}{4} = 10.73\ m$$
Absolute uncertainty of the mean for the 0.00008m^2 projectile: $$\pm \frac{x_{max} - x_{min}}{2}$$ $$\pm \frac{11.20 - 10.12}{2} = \pm 0.54\ m$$
Percentage uncertainty of the mean for the 0.00008m^2 projectile: $$\frac{0.54}{10.73} \times 100 = 5\%$$

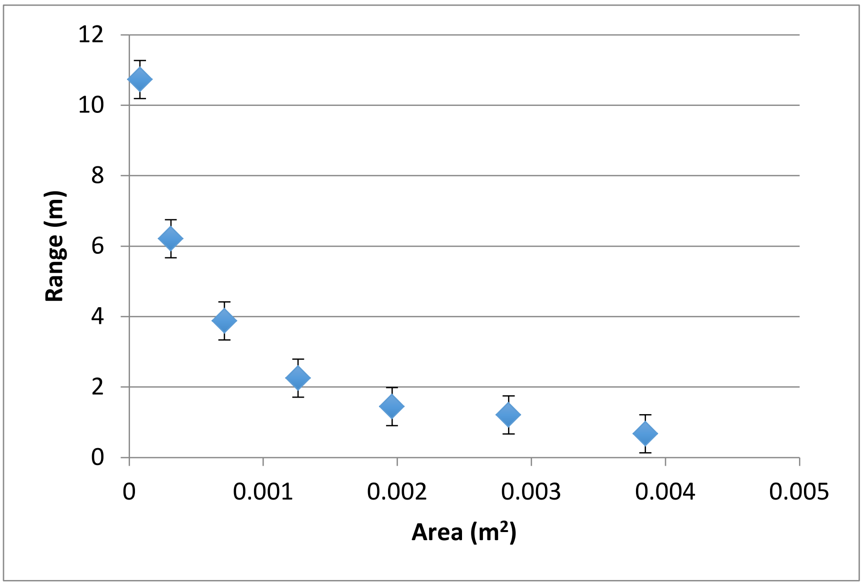
The absolute uncertainty of the mean was used for the error bars on the graph.

Communication [2]

appropriate use of genre conventions

The response follows scientific conventions of the construction of graphs.

Graph 1: Effect of ball's cross-sectional area (m^2) on range (m) of a projectile



fluent and concise use of scientific language and representations

The response is easily understood, avoids unnecessary repetition and meets the required length.

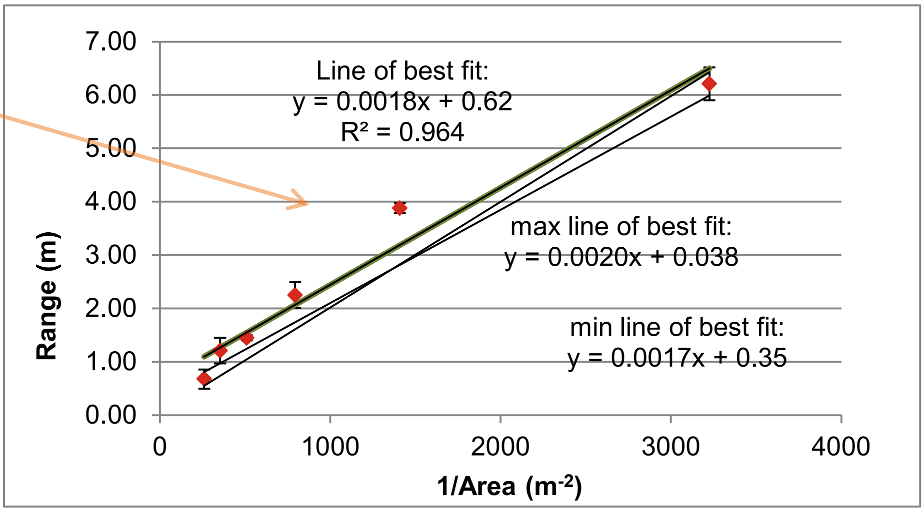
appropriate use of genre conventions

The response follows scientific conventions of the construction of graphs.

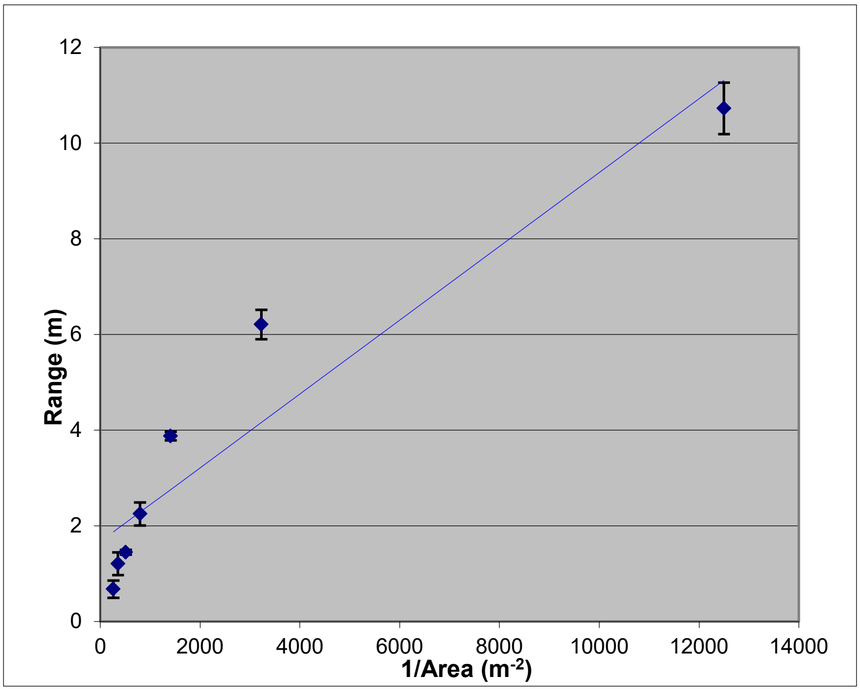
Analysis of evidence

The plot of the raw data suggests that the relationship between range and cross-sectional area is:

$s_x \propto \frac{1}{A}$, $s_x \propto \frac{1}{A^2}$, $s_x = e^{-A}$ or some other logarithmic relationship. Theory suggests that relationship is $s_x \propto \frac{1}{A}$. To determine if this relationship is correct, a graph of range (m) vs 1/Area (m^{-2}) was plotted.

Analysis of evidence [5–6]	
thorough identification of relevant trends, patterns or relationships The identification of relationships is not superficial or partial. The relationships are applicable to the research question.	Graph 2: The relationship between 1/cross sectional area (m^{-2}) and range (m) of a projectile. 
thorough and appropriate identification of the uncertainty and limitations of evidence The uncertainty of the evidence has been quantified so that a decision can be made about the application of the evidence to the research question.	**Sample calculations** Uncertainty of the gradient = $\left\lvert\frac{m_{max}-m_{min}}{2}\right\rvert$ Uncertainty of the gradient = $\left\lvert\frac{0.002-0.0017}{2}\right\rvert$ Uncertainty of the gradient = 0.00015 Percentage uncertainty of the gradient = $\frac{0.00015}{0.0018} \times 100$ Percentage uncertainty of the gradient = 8% The first data point (radius of 0.005 m) was excluded from Graph 3 because it did not fit with the line of best fit and was tentatively identified as an anomaly. This graph is consistent, within absolute uncertainty of the measurements, with the relationship established in the rationale: $$s_x \propto \frac{1}{A}$$ In order to confirm this, the gradient of a $s_x\ vs\ \frac{1}{A}$ graph should be equal to $\frac{m}{C_D \rho}$. For a spherical projectile with mass 1.5 × 10^{-3} kg this is equal to 0.00297 m^3. However experimentally the gradient of the graph was 0.0018 m^3 ± 8%, leading to a percentage error of: $$Percentage\ Error\ (\%) = \left\lvert\frac{0.0018 - 0.00297}{0.00297}\right\rvert \times 100$$ $$Percentage\ Error\ (\%) = 39\%$$ This is greater than the percentage uncertainty of the gradient (8%), suggesting the data does not support the suggested relationship. With this in mind, 0.005m radius projectile may not be an anomaly and may give further insight as to the relationship between s_x and A. Whilst the measurement uncertainty is small, the absolute uncertainty of the mean suggests a total of 8% uncertainty of the proportionality constant between s_x and A. When compared to the expected theoretical value, the percentage error is 39%. This suggests uncertainty about the evidence is more than measurement uncertainty of the data.

Analysis of evidence [5–6] **thorough and appropriate identification of the uncertainty and limitations of evidence** The response identifies the limitations of the evidence. This allows decisions to be made about the application of the evidence to the research question.	The findings and comparison with theoretical expectations must only be considered within the parameters of the experiment, and the associated limitations of the evidence, namely: 1. the assumption that a_x is constant 2. the assumption that $v_x^2 = u_x^2$ (to avoid ODE's) Note: this assumption is referring to the velocity used to calculate the force due to drag; $F_D = C_D \times \rho \times \frac{v^2}{2} \times A$, not the velocity used to rearrange the formula $v_x^2 = 2a_x s_x + u_x^2$ into $s_x = -\frac{u_x^2}{2a_x}$ whilst it is not expected that a greater domain (cross sectional area of projectiles) will produce results different from those suggested by the data gathered, any conclusion made must be confined to the domain used in this experiment.
Interpretation and evaluation [5–6] **justified conclusion/s linked to the research question** The response uses sound reasons and evidence to support a conclusion that directly responds to the research question.	**Interpretation of evidence** The aim of this investigation was to examine how changing the cross-sectional area of the ball affects the vertical velocity. The results showed that as the cross-sectional area is increased from 0.00031 m^2 to 0.00071 m^2, the horizontal displacement, or range, decreased from 6.21 m to 3.88 m. So, when the area doubles, the range approximately halves. Graph 2 showed, within the uncertainty of the measurements, an inversely proportional relationship between the cross-sectional area of the projectile and horizontal displacement. However, the gradient of the graph, 0.0018 has a percentage error of 39%, suggesting that the following relationship quoted in the rationale is not correct. $s_x \propto \frac{1}{A}$ Looking at the original graph, a mathematical relationship other than a 1/x relationship may be more appropriate. This suggests that there are other factors affecting the range of a projectile in addition to air resistance, or that the initial assumptions were not correct. This is made all the more evident if the first data point, which was left off Graph 2 as an anomaly, is included in the graph. It has been included in Graph 3, which does not suggest an inversely proportional relationship.

Communication [2] **appropriate use of genre conventions** The response presents data following scientific conventions of graph construction.	Graph 3: The relationship between 1/cross sectional area (m^{-2}) and range (m) of a projectile, with the first data point included.  This suggests that the relationship between the range and the cross-sectional area is either $s_x \propto \frac{1}{A}$ and is influenced by other factors that were assumed to be constant or controlled, or it is a different relationship all together.
Interpretation and evaluation [5–6] **justified discussion of the reliability and validity of the experimental process** The evaluation of the experiment is consistent with the uncertainties and limitations identified in the analysis of the evidence. The response explicitly justifies the evaluation of the experiment using these uncertainties and limitations.	**Evaluation of experimental process** The measurements were relatively precise. The maximum measurement uncertainty in the area was 4% and the maximum measurement uncertainty in the range was 1.5%. However, in the maximum measurement uncertainty of the mean there is a much greater error of 20% for the 0.03m radius projectile. This suggests the precision of each individual measurement was high but that the method itself had significant random errors that caused the data to not be reliable. This resulted in an overall percentage error of 39%. The main source of error was the wind factor. The experiment was conducted outside and it was almost impossible to control the environmental factors. The most significant of these was the wind, which added a force that was not accounted for in the initial theory. The mass of the projectile was light, which resulted in the range being significantly reduced when the force was towards the launcher and significantly increased when the force was away from the launcher. The method attempted to mitigate these affects by repeating the experiment five times and ignoring any obvious outliers. It was assumed that the mass of the projectile was constant and whilst it was initially, during flight the sand sometimes leaked out of the ball, reducing the mass and, because of the $s_x \propto \frac{m}{C_D \rho v_x^2 A}$ relationship, increasing the horizontal displacement. It was also assumed that the mass was evenly distributed in the projectile but due to the method of adding/subtracting the mass to the inside it was not possible to ensure

	uniformity, which would have resulted in a change in rotational inertia and therefore a change to the acceleration on the projectile. This phenomenon is called the Magnus effect (Encyclopedia Britannica, 2015). Another factor to mention was that it was assumed that the drag coefficient was 0.42 due to literature findings, however the ball may not have always been a perfect spherical shape. This could have resulted in pressure changes and other factors that would have either reduced or increased the horizontal displacement. It was assumed that the density of air was always 1.2041kg/m^3 as substantiated by scientific literature, however testing was done over a range of days, with varying weather conditions. Increased humidity results in increased air density that would increase the force of drag as more air particles would be colliding with the parachute. The y-intercept of the graph 2 should go through the origin as there are no other factors in the relationship, but it does not. This suggests there are systematic errors in the method. The systematic error may have been that the launcher was not set exactly as 0 degrees, or it moved when the projectile was launched. $s_x = \frac{v^2 \sin 2\theta}{g}$ However, this relationship suggests that any change in the angle would decrease the horizontal displacement by decreasing the magnitude of the horizontal velocity. This should result in a y-intercept of negative, whereas graph 2 has a positive y-intercept. It is likely then that the systematic error was related to a horizontal velocity greater than that planned. As such, the initial velocity of the launcher must be greater than first measured.
Interpretation and evaluation [5–6]	The assumption that a_x was constant was not appropriate. Whilst this is not immediately evident, a_x depends on v_x which is effected by a_x. Because v_x is not constant it is clear that $s_x \propto \frac{1}{v_x^2 A}$ is more appropriate theoretical relationship.
suggested improvements and extensions to the experiment that are logically derived from the analysis of evidence The suggested improvement addresses the uncertainty identified in the analysis. The suggested extensions address identified limitations and provide further insight into the behaviour or phenomena observed during the experiment.	**Suggestions for improvements and extensions** The experimental process could be improved by: • collecting more data and conducting repeated trials to ensure the data is more reliable and accurate. This is especially important around the first data point of 0.005 m, to determine if this is an anomaly or represents a pattern or trend • reducing the number of environmental factors, such as wind and humidity, that affected the trajectory of the projectile, by conducting the experiment indoors. The humidity and temperature should be controlled using air conditioning • replacing the use of sand to regulate the mass with blue-tack or liquids of different densities. This would ensure the mass is uniformly distributed • using a bullet shaped projectile to reduce the Magnus effect. The experiment could be extended by • investigating the effect of mass on the range of a projectile and further investigating the possible exponential or logarithmic relationship between the range and the surface area, as indicated by the data collected in this experiment • investigating the impact of the Magnus effect on horizontal displacement by projecting objects varying in shape (such as a sphere, bullet shape,

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.

Communication [2]

acknowledgment of sources of information through appropriate use of referencing conventions

The use of a referencing system fits the purpose of a scientific report.

Appendixes provide background information and context only. They are not considered when making judgments about the quality of the response.

cube and tear-drop pendant shape) of constant mass, at a constant velocity and angle.

- repeating the experiment but with a better theoretical understanding of the effect of a non-constant a_x.

Conclusion

It is evident that the data suggests that the range and cross-sectional area are related, however, the exact mathematical nature of this relationship is unknown. Whilst the precision of the measurements was acceptable, the percentage error of 39% means that it is not possible to justify this relationship with the data collected. Theoretically, the projectile's instantaneous velocity would decrease, causing a decrease in the drag force experienced by the projectile. Therefore, further investigations as outlined previously are recommended.

Word Count: 1920

Reference List

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Appendix

Maximum percentage measurement uncertainty in the range occurs for the 0.030m radius projectile during trial 4:

$$\frac{0.01}{0.67} \times 100\,\% = 1.5\%$$