Physics 2007

Sample assessment instrument and indicative response

Extended experimental investigation: Inclined plane

This sample is intended to inform the design of assessment instruments in the senior phase of learning. It highlights the qualities of student work and the match to the syllabus standards.

Criteria assessed

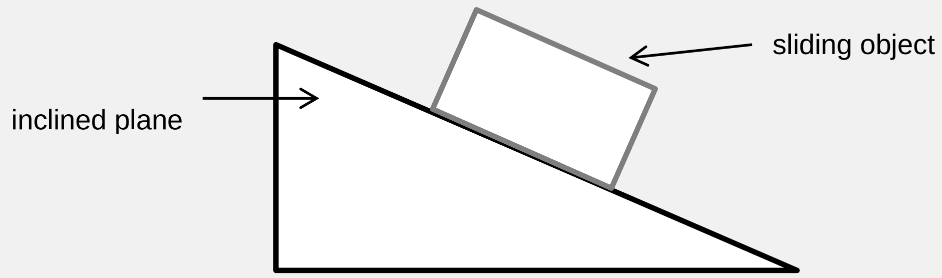
- Knowledge and conceptual understanding
- Investigative processes
- Evaluating and concluding

Assessment instrument

The response presented in this sample is in response to an assessment task.

Background:

The inclined plane is a classic physics experiment; versions of it can be found in almost any physics or mechanics textbook. It provides opportunities to explore a whole range of physics concepts including resolution and addition of vectors, equilibrium, normal force, Newton's second law and friction. Practical applications include water slides, skiing and the cambering of corners.



Groups: 3–4 students (assigned by your teacher)

Time: 4 weeks

What to do:

1. Perform background research to find a standard inclined plane experiment from a physics textbook or website.
2. Perform the standard experiment.
3. Refine the experiment to either improve its level of accuracy/precision or redesign it to investigate a different variable. Consult with your teacher before proceeding.
4. Perform the new experiment.
5. If time permits, further refine or redesign the experiment and perform it.
6. Write a report (Discussion/Conclusion no more than 1000 words) on your findings.

Queensland Government
Queensland Studies Authority
www.qsa.qld.edu.au
Queensland Studies Authority

Instrument-specific criteria and standards

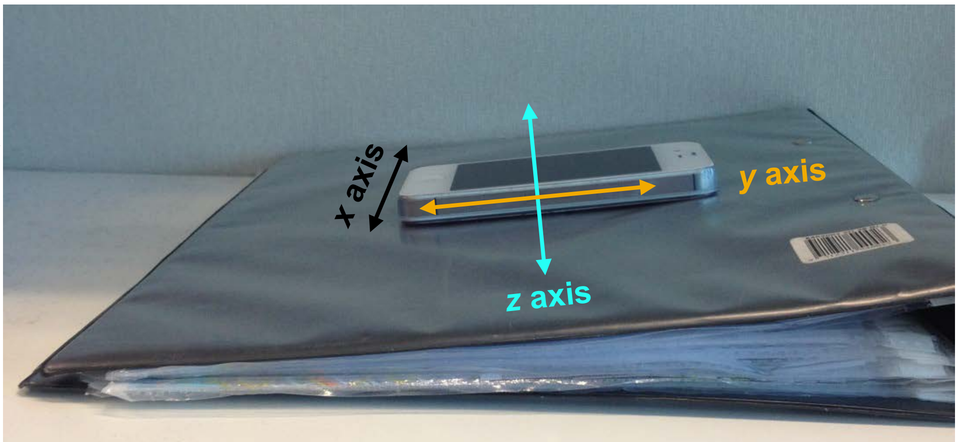
Student responses have been matched to instrument-specific criteria and standards; those which best describe the student work in this sample are shown below. For more information about the syllabus dimensions and standards descriptors, see www.qsa.qld.edu.au/1964.html#assessment.

	Standard A
Knowledge and conceptual understanding	The student work has the following characteristics: • comparison and explanation of complex force and motion concepts, processes and phenomena • linking and application of algorithms, concepts and theories to find solutions in complex and challenging force and motion situations
Investigative processes	The student work has the following characteristics: • formulation of a justified significant question which informs effective and efficient design, refinement and management of investigation • assessment of risk, safe selection and adaptation of equipment, and appropriate application of technology to gather, record and process valid force and motion data • systematic analysis of primary and secondary force and motion data to identify relationships between patterns, trends, errors and anomalies
Evaluating and concluding	The student work has the following characteristics: • analysis and evaluation of complex scientific interrelationships • exploration of scenarios and possible outcomes with justification of conclusions/recommendations • discriminating selection, use and presentation of scientific data and ideas to make meaning accessible to intended audiences through innovative use of range of formats.

Note: Colour highlights have been used in the table to emphasise the qualities that discriminate between the standards.

Indicative response — Standard A

The annotations show the match to the instrument-specific standards.

The student response demonstrates:	Using a smart phone to measure acceleration down an inclined plane
formulation of justified significant question which informs effective and efficient design, refinement and management of investigations	***Aim:*** To determine if the accelerometers in a smart phone can be used to measure the coefficients of static and sliding friction between the phone and an inclined plane.
discriminating selection, use and presentation of scientific data and ideas to make meaning accessible to intended audiences through innovative use of diagram	***Method:*** **Figure 1: Experimental apparatus** 
safe selection and adaptation of equipment, and appropriate application of technology to gather, record and process valid data	Notes on data collection: • Accelerometer values which were read as negative values in the *y* and *z* directions were recorded as positive values for ease of processing. Negative values indicated direction (i.e. down slope or vertically down). • Although the accelerometer presented acceleration values to 6 decimal places, random variations in readings meant that measured values could only be confidently read to two decimal places. • Accelerometer readings were measured in multiples of ***g***, i.e. gravitational acceleration: ***g*** = 9.8 m/s2. *The process of refinement of the investigation was observed by the teacher and documented by the student in a journal which has not been included.*

The student response demonstrates:	
discriminating selection, use and presentation of scientific data and ideas to make meaning accessible to intended audiences through innovative use of tables →	**_Results:_**
linking and application of algorithms, concepts and theories to find solutions in complex and challenging force and motion situations →	

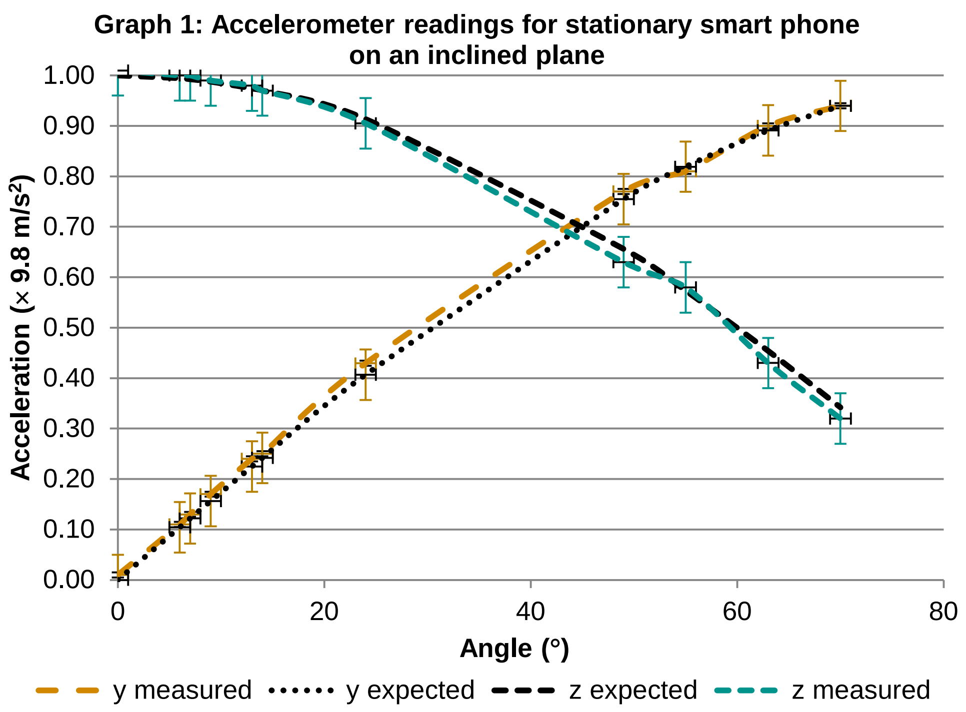
Table 1: Accelerometer readings at various angles of inclination

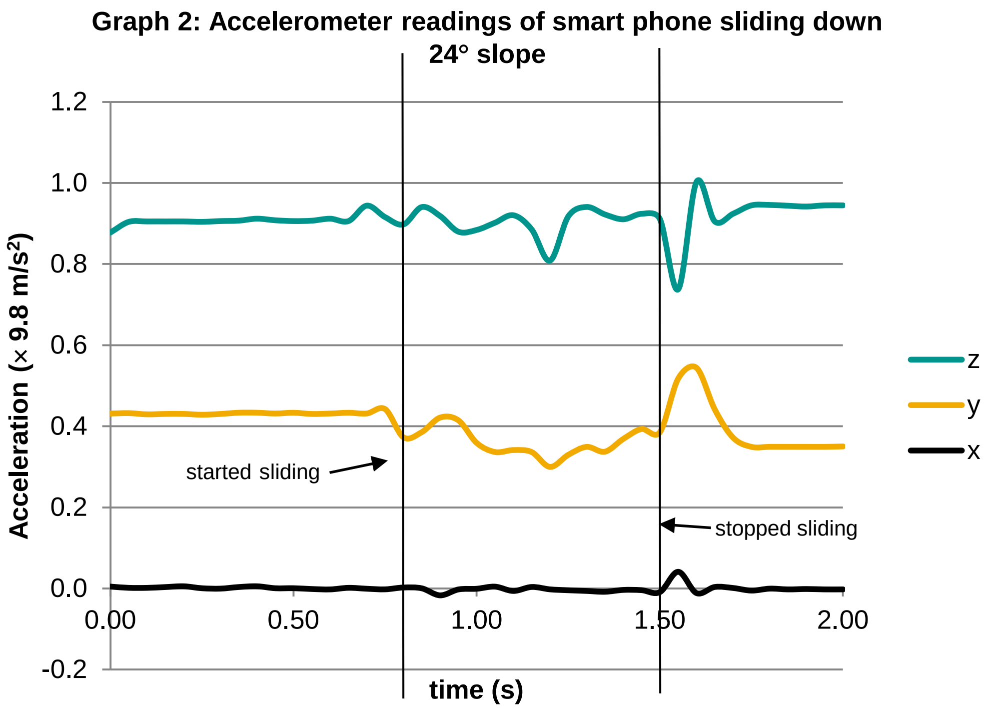
Angle of inclination (°) (± 1)	Accelerometer reading (× 9.8 m/s^2)								Relative error
	Measured				Expected				
	x (± 0.005)	y (± 0.005)	z (± 0.005)	total (± 0.02)	x	y	z	total	
0	0.00	0.01	1.01	1.01	0	0.00	1.00	1	1%
6	0.02	0.11	1.00	1.01	0	0.10	0.99	1	1%
7	0.00	0.13	1.00	1.01	0	0.12	0.99	1	1%
9	0.00	0.17	0.99	1.00	0	0.16	0.99	1	0%
13	0.00	0.24	0.98	1.01	0	0.22	0.97	1	1%
14	0.01	0.25	0.97	1.00	0	0.24	0.97	1	0%
24	0.00	0.43	0.91	1.00	0	0.41	0.91	1	0%
49	0.01	0.77	0.63	0.99	0	0.75	0.66	1	1%
55	0.01	0.81	0.58	1.00	0	0.82	0.57	1	0%
63	0.01	0.90	0.43	1.00	0	0.89	0.45	1	0%
70	0.02	0.94	0.32	0.99	0	0.94	0.34	1	1%
formula				*=SQRT(C16^2+D16^2+E16^2)*	*0*	*=SIN(A17/180*PI())*	*=COS(A17/180*PI())*	*1*	*=(F17-J17)/J17*

Note: Shaded readings were taken while the smart phone was being held to stop it from sliding.

The student response demonstrates:

discriminating selection, use and presentation of scientific data and ideas to make meaning accessible to intended audiences through innovative use of graphs





Raw data contained in the journal have not been reproduced.

The student response demonstrates:
selection and adaptation of equipment, and appropriate application of technology to record and process valid data

Table 2: Accelerometer readings for smartphone sliding down an incline of 24°

time (s)	*x* acceleration (× 9.8 m/s²)	*y* acceleration (× 9.8 m/s²)	*z* acceleration (× 9.8 m/s²)
0.80	0.00	0.37	0.90
0.85	0.00	0.39	0.94
0.90	-0.02	0.42	0.92
0.95	0.00	0.41	0.88
1.00	0.00	0.36	0.88
1.05	0.00	0.34	0.90
1.10	-0.01	0.34	0.92
1.15	0.00	0.34	0.89
1.20	0.00	0.30	0.81
1.25	0.00	0.33	0.92
1.30	-0.01	0.35	0.94
1.35	-0.01	0.34	0.92
1.40	0.00	0.37	0.91
1.45	0.00	0.39	0.92
1.50	-0.01	0.39	0.91
average:	**0.00**	**0.36**	**0.90**

Discussion:

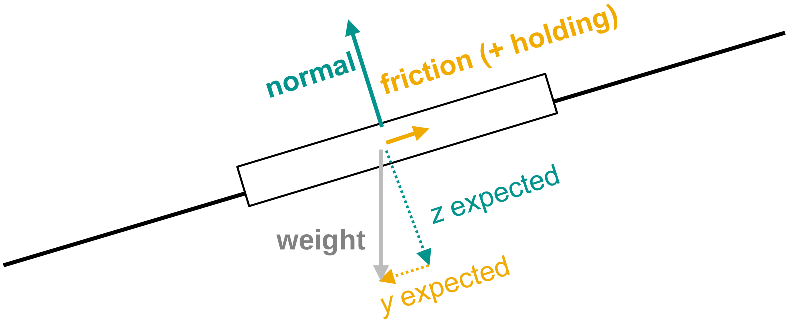
As the angle of inclination of the plane increased, the accelerometer reading increased in the *y* direction and decreased in the *z* direction (see Graph 1). These results matched with expectations within experimental uncertainty.

explanation of complex force and motion concepts, processes and phenomena

A preliminary investigation showed that when the smart phone was allowed to fall, all three accelerometers recorded accelerations of 0. This means that when the smart phone was sitting stationary on the inclined plane, the accelerometer readings could be interpreted as measuring the contact forces acting on the phone. Specifically, these forces were the *friction* parallel to the plane (*y*-axis) and the *normal* force perpendicular to the plane (*z*-axis) (see Figure 2). When friction was insufficient to hold the phone in place, the force parallel to the plane would be a combination of friction and the force applied by the hand of the person holding the phone, called the *holding* force. The expected magnitude of these forces was predicted using vector resolution of the acceleration due to *gravity* (see Table 1).

discriminating selection, use and presentation of scientific data and ideas to make meaning accessible to intended audiences through innovative use of diagrams

Figure 2: Forces acting on smart phone on an inclined plane



The student response demonstrates:	
systematic analysis of primary data to identify relationships between patterns and errors	Table 1 indicates that when the smart phone was stationary on the inclined plane at different angles, the accelerometer readings matched the expected values within experimental uncertainty. The relative error between the vector sum of the three measured accelerations and the expected acceleration due to gravity was very small — around 1%. This was within the uncertainty of 2% calculated for a typical reading (see Appendix). Accelerometer readings in the *x*-direction were negligible as expected. These small readings were probably due to some sideways tilting or bending of the surface.
comparison and explanation of complex force and motion concepts, processes and phenomena	The maximum friction occurred at 14°. At higher angles, the phone slid down the plane, indicating that friction was less than the *y* component of the weight of the smart phone. Using these results, the coefficient of static friction between the smart phone and the inclined plane was calculated as 0.26 (see Appendix). This value is at the lower end of the range of typical coefficients for static friction (Walding et. al.) which are generally between 0.1 and 1.0 depending on the combination of surfaces. Graph 2 illustrates the motion of the phone on the 24° inclined plane. For the first 0.8 s, it was held in place and its accelerometer readings matched the expected values outlined in Table 1. It then slid for approximately 0.7 s. The sudden 'bump' as the phone stopped at the end of the slope is clearly visible as sudden peaks in each data set at the 1.5 s mark. The peak in the *x* axis data set indicates that there must have been some sideways movement of the phone as it came to a stop. Similarly, the sharp peak in the *y* axis data is consistent with a sudden stopping force acting on the phone as it reached the bottom of the plane. Unexpectedly, at this point, the *z* axis graph dips suddenly and then peaks. The dip is probably due to the small gap between the bottom of the inclined plane and the table top. The *z* graph dip probably corresponds to the phone 'falling' off the edge of the plane, while the following peak corresponds to it stopping when it hits the table top.
systematic analysis of primary data to identify relationships between patterns	When the smart phone was sliding down the plane (Graph 2), the accelerometer reading in the *y* direction decreased from 0.43 ***g*** to an average of 0.36 ***g*** (see Table 2). This is consistent with the idea that this reading measured the contact force acting parallel to the plane. When the phone was released, the holding force was removed and so the only force acting on the phone in this direction was the sliding friction. Although the accelerometer reading in the *z* direction varied somewhat randomly while the phone was sliding, on average it remained at about 0.90 ***g***. The force in this direction was not expected to change while the phone was sliding. The variations suggest that the phone may have bounced slightly as it slid. An obvious bounce occurred at the 1.20 s mark, where there are noticeable dips in both the *y* and *z* data sets.
analysis and evaluation of complex scientific interrelationships	The *y* and *z* accelerometer readings during sliding were used to calculate the coefficient of sliding friction (see Appendix) as 0.40. This result was surprising since the sliding friction is expected to be smaller than static friction. It is possible that this value is higher than expected due to the addition of air resistance as the phone slides. However, air resistance is unlikely to be large enough to explain this anomaly because the phone slid relatively slowly. Further investigation is required to confirm this result.
exploration of scenarios and possible outcomes with justification of recommendations	It is likely that if the sliding test was conducted at a lower angle (e.g. 15°), it would show that coefficient of sliding friction was lower than for static friction. Sliding tests should be conducted at a range of angles to determine whether or not static friction remains constant for all angles as expected. Further trials should also be conducted to ensure that 14° is the highest angle of inclination before the phone starts to slide to ensure the accuracy of the measured coefficient of static friction. This experiment could also be repeated with different materials attached to the surfaces of the phone and the inclined plane. This would allow the coefficients of friction for a variety of surface combinations to be measured.

The student response demonstrates:	
exploration of scenarios and possible outcomes with justification of conclusions	***Conclusion:*** Results indicate that the accelerometers in a smart phone accurately reflect the contact forces acting on the phone. The coefficients of static and sliding friction between the phone and the inclined plane were found to be 0.26 and 0.40 respectively. While the value for the static friction fell within the expected range, sliding friction should be lower than static friction. This result requires further investigation.
linking and application of algorithms to find solutions in complex and challenging force and motion situations	***Appendix:*** *Sample calculations:* Uncertainty in total measured acceleration (based on 24° slope): $$\%U = \left(\frac{0.005}{0.43} + \frac{0.005}{0.91}\right) \times 100\% = 2\%$$ $$U = 2\% \times 1.00 = 0.02$$ Coefficient of static friction (based on 14° slope): $$\mu = \frac{F_{friction}}{F_{normal}} = \frac{m \times a_y}{m \times a_z} = \frac{a_y}{a_z} = \frac{0.25 \times 1g}{0.97 \times 1g} = 0.26$$ Coefficient of sliding friction (based on averages from 24° sliding data): $$\mu = \frac{F_{friction}}{F_{normal}} = \frac{m \times a_y}{m \times a_z} = \frac{a_y}{a_z} = \frac{0.36 \times 1g}{0.90 \times 1g} = 0.40$$ ***Bibliography:*** Walding, R, Rapkins, G & Rossiter G 2004, *New Century Senior Physics: Concepts in context*, Oxford University Press, South Melbourne, Australia.