Aims of today's session

- To explain how the laboratory portion of the Science A module works and how it is assessed.
- To provide you with a general overview of performing a scientific investigation.
- To introduce the concept of uncertainty and how to compare results correctly
- To show you where to go for more information and resources for report writing.

Science A

Introduction to Labs and Report Writing

Assessment

- There are **2 laboratory sessions** this semester. During each lab sessions, you will **perform 3 experiments**.
- **Experiments 1 & 2** are assessed via an online quiz (5%)
- **Experiment 3** is assessed via a written report (20%)
- The report is **group assessed (so you only submit one report for your lab group),** whilst the online quiz is individually assessed.

Purpose of a Report

- In order to **write a good scientific** report we first need to understand the **purpose of a report.**

- Why do **scientists write reports**?
- A scientific report is a way for **scientists to share the findings** of an investigation with scientific community.
- A report should **contain enough information** that the **reader can understand** exactly what was done during an investigation and **how the evidence obtained leads to the conclusion(s)** of the report.

Evidence

- All scientific discoveries are **based upon evidence**, in order to claim something as a 'scientific truth' we **must have evidence to back it up.**

- So how do scientists gather this evidence?

- By **performing an investigation** (usually involving an experiment) and **gathering data.**

- So what are **the steps involved** in **performing an investigation**?

Performing an Investigation

- **Question:** We start with a question, why do objects fall towards the ground? Is the earth round?

- **Hypothesis**: We then create a hypothesis – an initial idea or belief of how an aspect of the universe works, which must be further investigated to prove its validity.

Performing an Investigation

- **Choose an Experiment**: We then choose an experiment to test our hypothesis

- **Make Predictions**: We make predictions about what we will observe in the experiment if our hypothesis is correct.

- **Perform the Experiment:** Now we can carry out our experiment

Performing an Investigation

- **Compare Results:** Compare the predicted results with the actual results from the experiment.

- **Draw Conclusions:** Draw conclusions based on evidence from the experiment. Decide if the results **support (prove)** or **refute (disprove)** the **hypothesis**.

Example

- Let’s examine a specific experiment and see how this works in practice.

Hypothesis

- For **each experiment in this module** there is a specific hypothesis we are aiming to test; which is **written on the instructions** for the experiment.

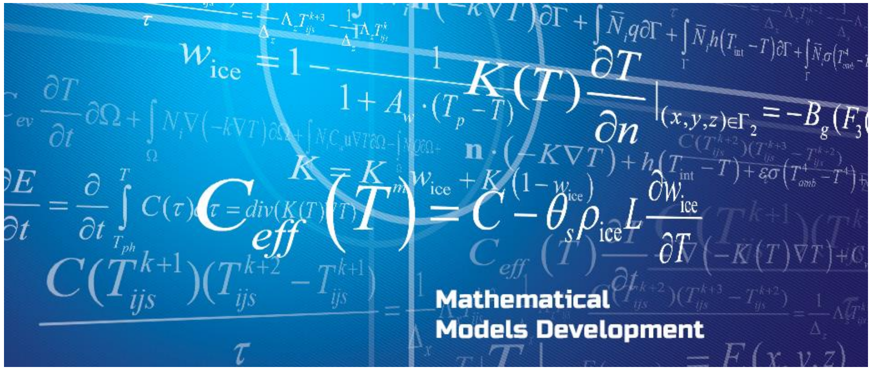
- In the case of this **experiment**;

  “The acceleration of a vehicle can be accurately modelled using Newton’s second law of motion”.

Make predictions

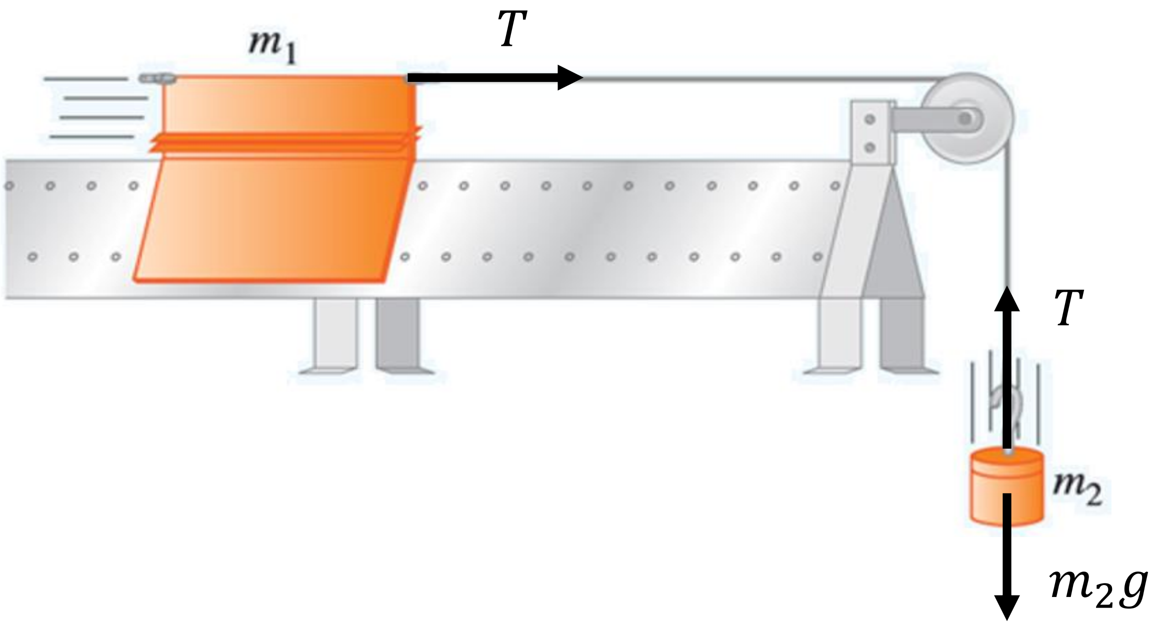
- How do we make **meaningful predictions** about what we will observe in the experiment?

- We need to **create an equation** which links the **control variable** (**independent variable**) with the **measured variable** (**dependent**), this is called a **mathematical model.**



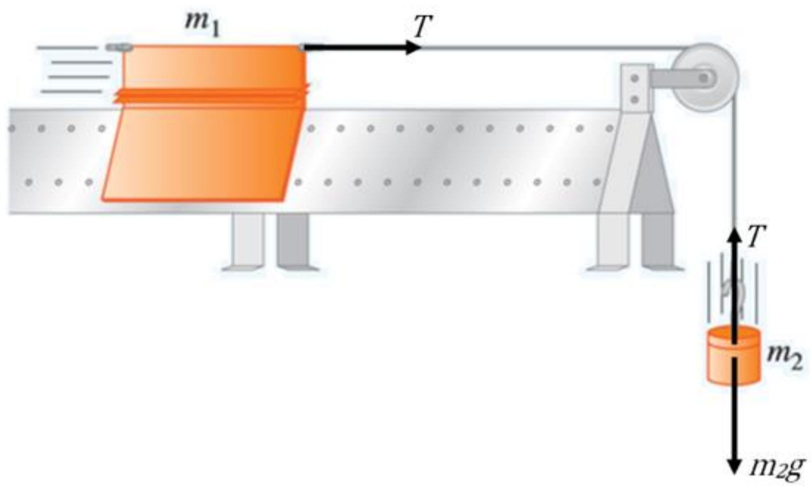
Mathematical model

- Let's start with a simple diagram



- What are the **main forces involved** in this experiment?
  - Weight (mass multiplied by acceleration due to gravity)
  - The force from the string (called tension)
- Let's add these to the diagram.

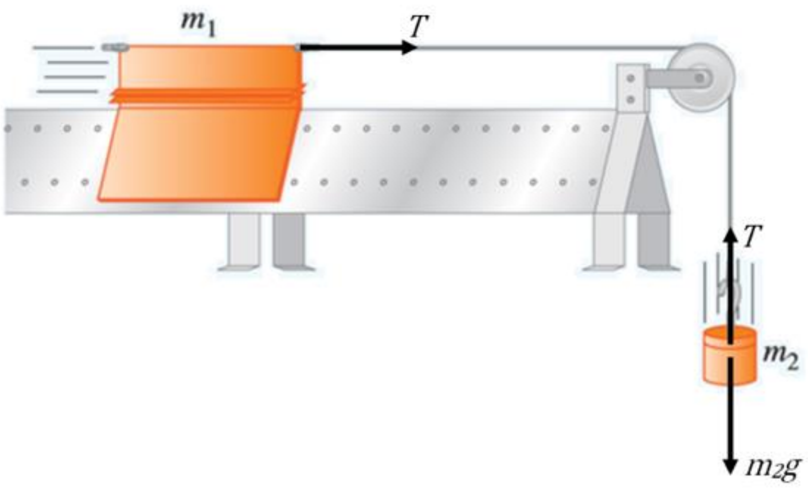
Mathematical model



- Now we can use Newton's second law ($F = ma$) to create our equation **linking the independent variable** (mass 2) with the **dependent variable** (acceleration).

- We can then use this **equation to predict the value of the dependent variable** for different **values of the independent variable.**

Mathematical model



- Using **Newton's second law** on the **vehicle** we find that

$$T = m_1 a$$

- And using **Newton's second law** on the **mass hanger** we find that

$$m_2 g - T = m_2 a$$

- Now we can **replace T** in our **second equation** to obtain

$$m_2 g - m_1 a = m_2 a$$

Mathematical model

- Now we can **replace T** in our **second equation** to obtain

$$m_2 g - m_1 a = m_2 a$$

- Now we can **rearrange the equation** to **make acceleration, a, the subject.**

$$m_2 g = m_2 a + m_1 a$$

$$m_2 g = (m_1 + m_2) a$$

$$a = \frac{m_2 g}{(m_1 + m_2)}$$

- Note what he have just done is known as **deriving the equation.**

Mathematical Model

- A **mathematical model** is simply a tool to **represent the real world** in the form of one or more equations.

- A **mathematical model** is usually a **simplification of the real world**; as it does not include all of the possible factors that can affect the results.

- What factors have we ignored when we made our model?

- **Discuss with the people around you and try to come up with 3 such factors.**

Assumptions

- **Discuss with the people around you and try to come up with 3 such factors.**

- Friction and air resistance have a negligible effect.
- The track is perfectly horizontal.
- The string has no mass and is inextensible.
- The acceleration due to gravity is constant at $9.81\ \mathrm{m} \cdot \mathrm{s}^{-2}$

- We hope that all of our assumptions are close to being true, then our predictions will be accurate!

Assumptions

- We call these factors **modelling assumptions**, as we are **assuming they will have no affect** on the results.

- This is **obviously not true**, but if the **effect they have is small enough** then it is okay to assume they have no affect.

- **When writing a report** the **assumptions are very important** as often if the **results do not match the predictions** it is because **we have a bad assumption**, not because the hypothesis is wrong!

Perform the Experiment

- Now that we can **make our predictions,** we can **perform the experiment** and gather our results.

Table 1: Mass of the vehicle.

m_1 (g)
100

Table 2. Measurements and predicted values.

Measurement no.	m_2 (g)	$\frac{m_2}{m_1 + m_2}$	Measured acceleration $(\mathrm{ms^{-2}})$				Predicted acceleration a_p $(\mathrm{ms^{-2}})$
			a_1	a_2	a_3	a_m	
1	50.1	0.334	3.26	3.28	3.29	3.28	3.27
2	60.1	0.375	3.71	3.67	3.69	3.69	3.68
3	70.1	0.412	4.06	4.06	4.04	4.05	4.04
4	80.1	0.445	4.52	4.49	4.50	4.50	4.36
5	90.1	0.474	4.82	4.81	4.79	4.81	4.65
6	100.1	0.500	5.12	5.13	5.11	5.12	4.91

Perform the Experiment

Table 2. Measurements and predicted values.

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4	80.1	0.445	4.52	4.49	4.50	4.50	4.36
5	90.1	0.474	4.82	4.81	4.79	4.81	4.65
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- You may have noticed that the **measured and predicted values in the table are not the same**, does this mean that the **results do not support the hypothesis**?

- **How do we decide how close the predicted and measured results need to be?**

Uncertainty

- First of all we need to realise that there is no such thing as a perfect measurement, every measurement we make has **uncertainty**.

- The uncertainty in a measurement **represents the range of statistically likely values** that true value of the measurement could take.

$$Measurement = value \pm uncertainty$$

- This plus/minus **uncertainty** tells us **how much bigger or smaller** than the value we have measured our measurement could be.

Uncertainty

- Whenever we **measure something we are approximating the true value** to a certain number of decimal places, there is **always uncertainty since we don’t know the value of the decimal places we can’t measure**!

- For example a measurement of length as $20.8\ \mathrm{cm}$ could actually be $20.8237\ldots$ we **don’t know the value of the additional decimal places** since our **ruler can only measure to 1 decimal place.**

$$l = 20.8 \pm uncertainty\ \mathrm{cm}$$

Uncertainty

- The uncertainty in a measurement is **denoted by the Greek letter delta δ**. For example if we have a measurement of x then the symbol for the **uncertainty in the measurement** is δx.

$$x = value \pm \delta x$$

- For each lab session there is an **uncertainty guide available on Moodle** which gives you all the equations you will need. **For this module you will not be asked to create your own uncertainty equations.**

Uncertainty

Table 3: Mass of the vehicle.

δm_1 (g)
0.29

Table 4. Uncertainties associated with the measured and predicted values.

Measurement no.	δm_2 (g)	$\delta\left(\frac{m_2}{m_1+m_2}\right)$	δa_m $(\mathrm{m}\cdot\mathrm{s}^{-2})$	δa_p $(\mathrm{m}\cdot\mathrm{s}^{-2})$
1	0.29	0.03	0.07	0.01
2	0.29	0.04	0.07	0.01
3	0.29	0.04	0.08	0.01
4	0.29	0.04	0.09	0.01
5	0.29	0.04	0.10	0.01
6	0.29	0.04	0.10	0.01

- So we can use the **formulae provided to calculate the uncertainty** in the **measured** and **predicted values**.

Comparing Results

- For two values to agree they need to have **possible values in common when we consider the uncertainty.**

Value Uncertainty

- **For example**

$$x_m = 20.8 \pm 0.2 \qquad x_p = 20.7 \pm 0.4$$

$$20.6 \leq x_m \leq 21.0 \qquad 20.3 \leq x_p \leq 21.1$$

- The **predicted value**, x_p, agrees with the **measured value**, x_m, since there are values they have in common when we consider the uncertainty.

Comparing Results

- Normally at this point we would also **plot a graph of our results** and **analyse the values** from the graph as **additional sources of evidence.**

- However for this example we will **leave this step out** as producing the graph and analysing it is a significant amount of work.

- There is a **training PPT and exercise available on Moodle in the report writing section** and you should **work your way through it in your own time** to make sure you can do this for your own reports.

Comparing Results

To analyse a set of results we should ask ourselves 4 simple questions.

1) How many of the measured results agreed with the predicted results?
2) Is there an observable pattern to how the measured and predicted results differ?
3) What are most likely sources of any discrepancies between our measured and predicted results?
4) Overall, do the measured results support your hypothesis or not?

Comparing Results

1) How many of the measured results agreed with the predicted results?

Measurement no.	a_m $(\mathrm{m \cdot s^{-2}})$	δa_m $(\mathrm{m \cdot s^{-2}})$	a_p $(\mathrm{m \cdot s^{-2}})$	δa_p $(\mathrm{m \cdot s^{-2}})$	
1	3.28	0.07	3.27	0.01	✓
2	3.69	0.07	3.68	0.01	✓
3	4.05	0.08	4.04	0.01	✓
4	4.50	0.09	4.36	0.01	✗
5	4.81	0.10	4.65	0.01	✗
6	5.12	0.10	4.91	0.01	✗

- So 3 out of 6 of the measured values agree with the predicted values.

Comparing Results

2) Is there an observable pattern to how the measured and predicted results differ?

Measurement no.	a_m $(\mathrm{m \cdot s^{-2}})$	δa_m $(\mathrm{m \cdot s^{-2}})$	a_p $(\mathrm{m \cdot s^{-2}})$	δa_p $(\mathrm{m \cdot s^{-2}})$
1	3.28	0.07	3.27	0.01
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6	5.12	0.10	4.91	0.01

- The results **all agree for small values of mass**, m_2, as m_2 gets **larger our measurements get further away** from the predictions.

Comparing Results

2) Is there an observable pattern to how the measured and predicted results differ?

Measurement no.	a_m $(\mathrm{m \cdot s^{-2}})$	δa_m $(\mathrm{m \cdot s^{-2}})$	a_p $(\mathrm{m \cdot s^{-2}})$	δa_p $(\mathrm{m \cdot s^{-2}})$
1	3.28	0.07	3.27	0.01
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6	5.12	0.10	4.91	0.01

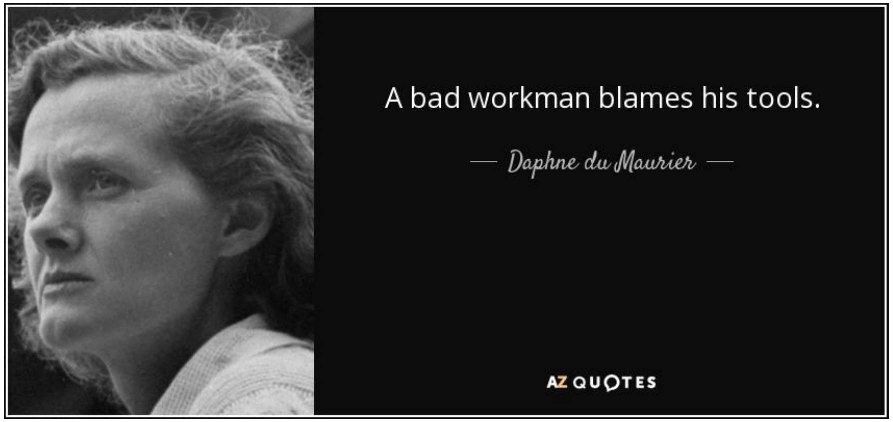
- Also **all of the measured values which disagree are larger** than the predicted value.

Comparing Results

3) What are most likely sources of any discrepancies between our measured and predicted results?

- A **good answer** to this question is to **consider the modelling assumptions**, this demonstrates we are thinking about a **scientific explanation for the results**.

- A **poor answer** to this question is to claim that **results are an error or caused by faulty equipment**



Comparing Results

3) What are most likely sources of any discrepancies between our measured and predicted results?

- There are 3 values that don't match the predictions and **they are all larger than we predicted**. Why that might be the case?

- Lets **review the assumptions** and think about which might have affected the results in this manner.
  - The string has no mass and is inextensible. X
  - Friction and air resistance have a negligible effect. X
  - The track is perfectly horizontal. ✓
  - The acceleration due to gravity is constant at $9.81\ \mathrm{m} \cdot \mathrm{s}^{-2}$ ✓

Discussion

4) **Overall, do the measured results support your hypothesis or not?**

- To support a hypothesis we need the **majority (more than half)** of the **measured values** to **agree** with the **predicted values.**

- Since **only half of the results agree** with the predicted values there is **not enough evidence** to support the hypothesis.

Draw Conclusions

- The conclusion is where we **pull together everything we have talked about when comparing the results** and come to an overall conclusion about the experiment.
- Did the experiment **support your initial hypothesis or not**?
- It is worth mentioning that it **doesn’t matter if the experiment supports the hypothesis or not.** What matters is that you **base your conclusion on the evidence** you have collected.
- If the results **don’t support the hypothesis** but your **conclusion states that they do**, then you will score poorly on a report.

Draw Conclusions

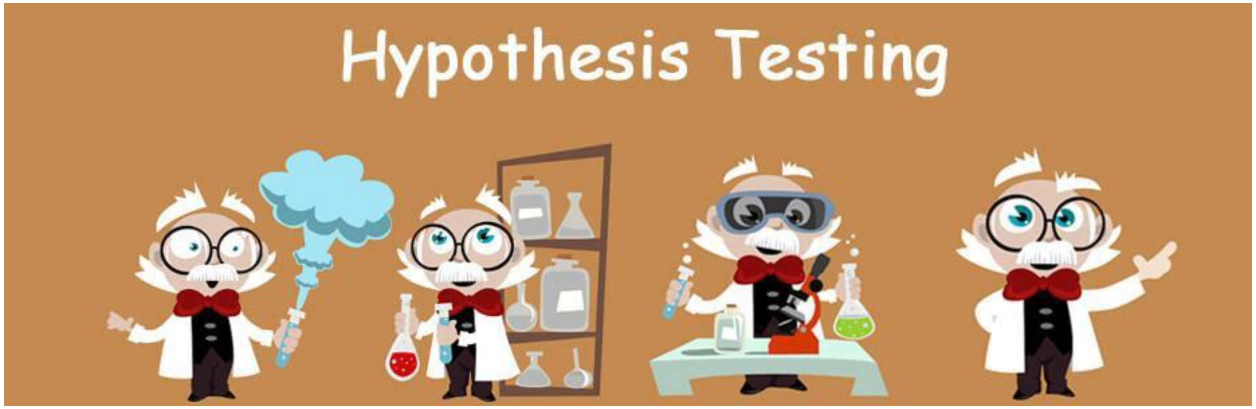
- To write a good conclusion we should ask ourselves 3 simple questions.

1) Based on the results does our experiment demonstrate the validity of the hypothesis or not?
2) Which of the factors we have discussed is the main source of any measured results differing from predicted results?
3) What improved experimental techniques or mathematical models could account for these discrepancies in future investigations?

Conclusion

1) Based on the results does our experiment demonstrate the validity of the hypothesis or not?

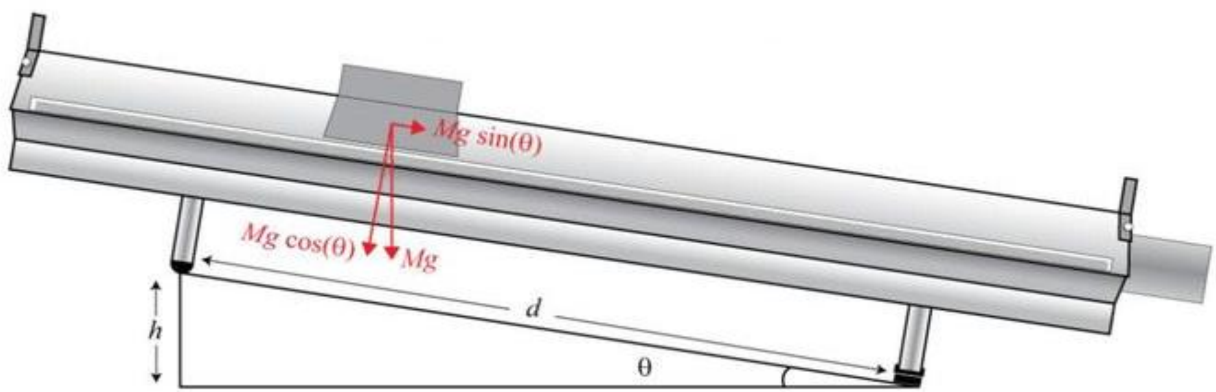
- Half of the results obtained were found to be within the corresponding predicted acceleration value ranges, while for the other half, this was not the case. This evidence was insufficient to support the hypothesis.



Conclusion

2) Which of the factors we have discussed is the main source of any measured results differing from predicted results?

- The main factor which affected the results was most likely to be the apparatus not having been setup perfectly horizontal, this would have caused a component of the vehicles weight to increase the acceleration and would explain why the values that differed were larger than predicted.



Conclusion

3) What improved experimental techniques or mathematical models could account for these discrepancies in future investigations?

This experiment could be further improved by;

- using a spirit level to ensure that the air track was perfectly horizontal
- obtaining an accurate value for the local acceleration due to gravity
- taking in to account the effect of air resistance in the mathematical model.

Writing a Report

- A Scientific Report can be broadly broken down in to the following sections:
  - Abstract
  - Objective & Introduction
  - Apparatus & Procedure
  - Results & Uncertainty analysis
  - Discussion
  - Conclusion

You can find video guides to writing these various sections of the report on the Science A Moodle page in the report writing section. Additionally there are also practice exercises for formatting a report, making graphs and analysing results.