Lesson framework for teacher

A common framework on how to use or develop the STEMforYOUTH materials into the classroom.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 710577

Flow diagram

Ask a question

↓

Do background research

↓

Construct a hypothesis

↓

Plan a fair test experiment (only one variable must be changed at a time)

↓

Do the experiment

↓

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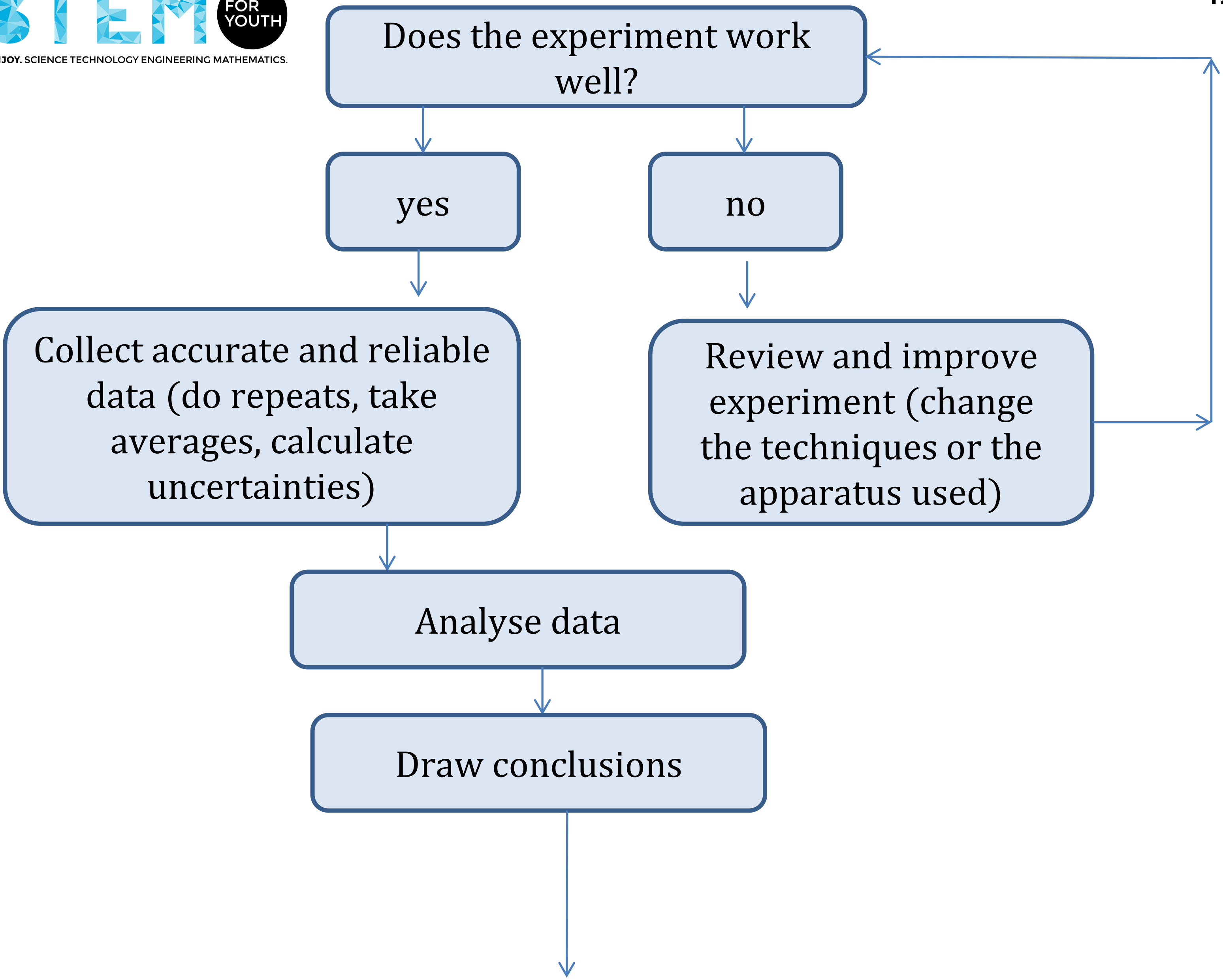

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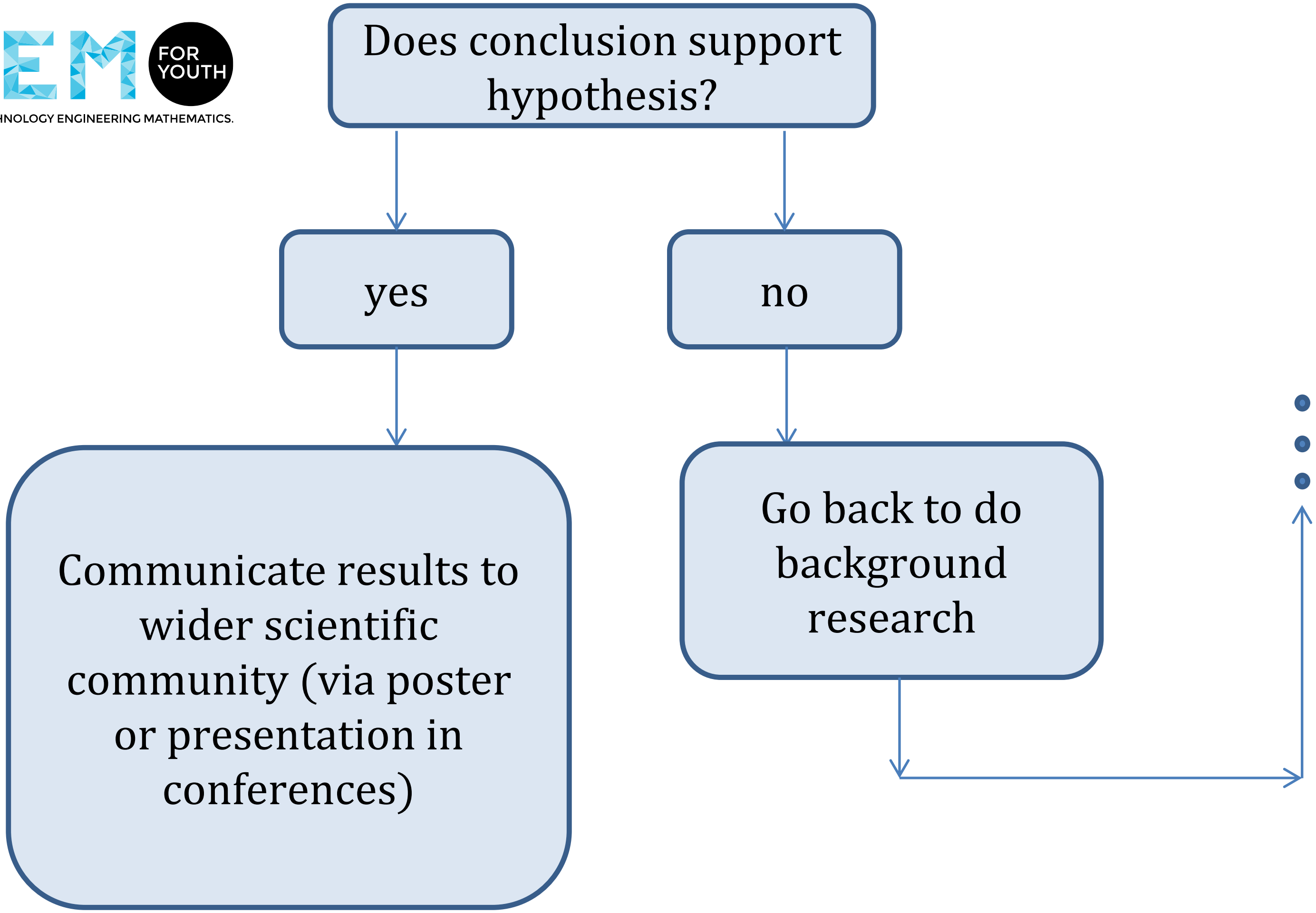

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Introduction

Water Rocketry is an activity that can be used in investigating and teaching various physical concepts such as:

- Inertia-Mass
- Velocity
- Acceleration
- Forces
- Thrust
- Newton's 2nd and 3rd Law
- Mass-Acceleration Relation
- Mass-Height Relation
- Flight Stability
- Aerodynamics
- Collect Data
- Take averages
- Calculate uncertainties
- Plot Data

In the following section we give an example of how water rockets can be used in order to investigate:

1. Mass-Acceleration Relation
2. Mass-Height Relation
3. How to collect accurate and reliable data (do repeats, take averages, calculate uncertainties)
4. How to plot data

In order to conduct the following experiments we will need an accelerometer and an altimeter attached to the rocket.

The analysis will be simplified. We will ignore the drug force and the adiabatic expansion of the gas.

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Ask a Question

- What makes an object move?
- What makes an object accelerate?
- How mass affects an object's acceleration?
- Which force(s) make(s) a rocket fly?
- Which forces act on the rocket?
- How can a rocket be stable during flight?
- What mechanism do rockets use to lift themselves off the ground, resulting in a forward motion?
- Why would you have water (which is quite heavy) in addition to air in your water bottle rocket before liftoff?
- Which is the optimal amount of water that provides the rocket with maximum height?

An appropriate starting question that allows*:
- planning, research, development and review
- span in several subject areas in a creative way, or involve development of new skills or deeper understanding

* http://www.researchinschools.org/

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Background Research

1. What makes an object move?
- A force can change the state of motion and/or the shape of an object.
- Every object continues in its state of rest, or of uniform motion in a straight line, unless it is compelled to change that state by forces impressed upon it (Newton's First Law of Motion).

2. What makes an object accelerate?
- Force causes acceleration.
- The acceleration of an object is directly proportional to the net force acting on the object, is in the direction of the net force, and is inversely proportional to the mass of the object (Newton's Second Law of Motion).

3. Why is acceleration inversely proportional to the mass of the object?
- Because mass is the measure of the inertia or sluggishness that an object exhibits in response to any effort made to start it, stop it, or change its state of motion in any way.

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Background Research

4. Which force(s) make(s) a rocket fly?

- Thrust is the force which moves the rocket through the air, and through space. Thrust is generated by the propulsion system of the rocket through the application of Newton's Third Law of Motion which states that: "Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first" or "For every action there is an equal and opposite re-action".

5. Which forces act on the rocket?

- Weight, Thrust, Drag
- Weight: The force upon an object due to gravity.
- Thrust: a reaction force described quantitatively by Newton's Third Law. When a system expels or accelerates mass in one direction, the accelerated mass will cause a force of equal magnitude but opposite direction on that system.
- Aerodynamic forces: Aerodynamic forces are generated and act on a rocket as it flies through the air. aerodynamic force is broken into two components: the drag force which is opposed to the direction of motion, and the lift force which acts perpendicular to the direction of motion. For lift and drag to be generated, the rocket must be in contact with the air.
- Drag: Drag is the aerodynamic force that opposes an aircraft's motion through the air. Drag is a mechanical force and is generated by the interaction and contact of a solid body with a fluid (liquid or gas).

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Hewitt, P., G., 2006, Conceptual Physics
https://www.grc.nasa.gov/WWW/k-12/airplane/lift1.html
https://www.grc.nasa.gov/WWW/K-12/rocket/rktaero.html
https://www.grc.nasa.gov/WWW/k-12/airplane/drag1.html
https://www.grc.nasa.gov/WWW/k-12/airplane/thrust1.html
https://spaceflightsystems.grc.nasa.gov/education/rocket/rktth1.html
https://spaceflightsystems.grc.nasa.gov/education/rocket/rktbot.html

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Hypotheses

1. If we increase air pressure inside the bottle, keeping mass constant, the rocket will achieve a higher acceleration and will reach higher altitudes.

2. If we increase the rocket’s mass, keeping pressure constant, the rockets acceleration will decrease and the rocket will reach lower altitudes.

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Explain which factor you will change in your experiment and list all the other factors you will keep the same

1st Experiment: Investigation on the effect of increasing net force on acceleration.

- Independent variable: Applied force
- Dependent variable: Acceleration

In the context of the first experiment we will keep the mass of the rocket constant. Every time we run the experiment we will add the same amount of water in the rocket's fuel tank. The parameter which will vary is the air pressure inside the bottle. We will test the dependency of the rocket's acceleration (dependent variable) on the net force (independent variable) acting upon the rocket.

2nd Experiment: Investigation on the effect of increasing mass on height.

- Independent variable: Mass
- Dependent variable: Height

In the context of the second experiment we will keep the air pressure, inside the bottle, constant.

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Write the method of your experiment (what you will do)

1st Experiment: Investigation on the effect of increasing net force on acceleration.

i. Water Volume: $V_{water} = 0.3\ lt$
Water mass: $m_{water} = \rho_{water} * V_{water}$, for $\rho_{water} \cong 1\ kgr/lt \Longrightarrow m_{water} \cong 0.3kg$
Pressure: $20\ psi < P_{gauge} < 80\ psi$ in steps of 10 psi
10 Trials for each step

We add 0.3 kg of water in the bottle. We begin the experiment by using 20 psi of pressure inside the bottle. We conduct the experiment 10 times and each time we measure the acceleration. We incrementally increase the pressure by 10 psi and conduct each experiment ten times. Each time we measure the acceleration. We collect our data in tables.

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Write the method of your experiment (what you will do)

2nd Experiment: Investigation on the effect of increasing mass on height.

Pressure: $P_{gauge} = 80\ psi$
Water mass: $0.2\ kg < V_{water} < 1.0\ kg$

We begin the experiment by using 0.2 kg of water inside the bottle. We pressurize air until the pressure inside the bottle reaches 80 psi. We conduct the experiment 10 times and each time we measure the height that the rocket reaches. By maintaining pressure constant, we incrementally increase the volume of water by 0.1 kg and conduct each experiment ten times. Each time we measure the corresponding height altitude. We collect our data in tables.

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Write any problems you encountered in the experiment and the steps you took to improve these

The measurements of pressure, mass, acceleration and height were not accurate. They exhibited large uncertainties. In order to reduce the errors we can do the following:

- In the first experiment we can increased pressure in steps of 5 psi each time and conducted 20 instead of 10 trials
- In the second experiment we can increase the mass in steps of 0.05 kgr each time and again conducted 20 instead of 10 trials.

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Share the data of your experiment

1st Experiment: Investigation on the effect of increasing pressure on acceleration.

Water mass: $m_{water} \cong 0.3kg$ (constant)

Pressure: $20\ psi < P_{gauge} < 80\ psi$ (increasing in steps of 10 psi)

10 Trials for each step

#	Acceleration 1 (P=20 psi)	Acceleration 2 (P=30 psi)	Acceleration 3 (P=40 psi)	Acceleration 4 (P=50 psi)	Acceleration 5 (P=60 psi)	Acceleration 6 (P=70 psi)	Acceleration 7 (P=80 psi)
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
Mean $\pm$ error							

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Share the data of your experiment

2nd Experiment: Investigation on the effect of increasing mass on height.

Pressure: $P_{gauge} = 80\ psi$ (constant)
Water mass: $0.2\ kg < V_{water} < 1.0\ kg$ (increasing in steps of 0.1 kg)
10 Trials for each step

#	Height 1 (m=0.2 kg)	Height 2 (m=0.3 kg)	Height 3 (m=0.4 kg)	Height 4 (m=0.5 kg)	Height 5 (m=0.5 kg)	Height 6 (m=0.6 kg)	Height 7 (m=0.7 kg)	Height 8 (m=0.8 kg)	Height 9 (m=0.9 kg)	Height 10 (m=1.0 kg)
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
Mean $\pm$ error										

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Share the data of your experiment

Constant Mass (m = 0.3 kg of water)	
Pressure (psi)	Mean Acceleration (m/s^2)
20 ± 1.0	460 ± 30
30 ± 1.5	690 ± 45
40 ± 1.0	945 ± 55
50 ± 2.0	1150 ± 50
60 ± 2.0	1430 ± 40
70 ± 2.0	1650 ± 55
80 ± 2.5	1815 ± 50

Constant Pressure (80 psi)	
Water mass (kg)	Mean Height (m)
0.2 ± 0.02	23 ± 0.2
0.3 ± 0.01	24 ± 0.2
0.4 ± 0.02	25.3 ± 0.1
0.5 ± 0.03	25.5 ± 0.1
0.6 ± 0.02	25.4 ± 0.2
0.7 ± 0.01	25.0 ± 0.1
0.8 ± 0.02	24.4 ± 0.2
0.9 ± 0.03	23.5 ± 0.1
1.0 ± 0.02	22.3 ± 0.2

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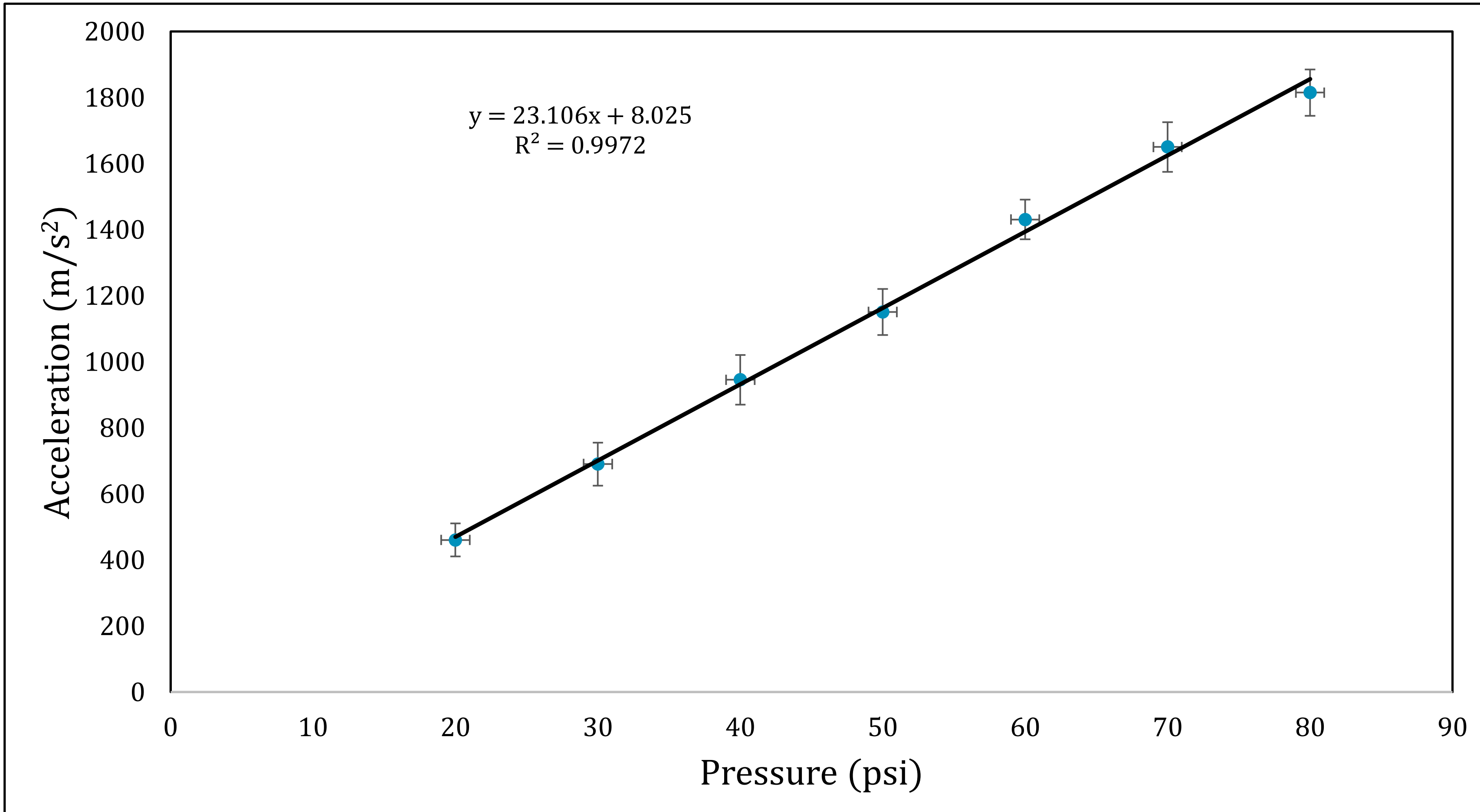
1st Experiment: Investigation on the effect of increasing pressure on acceleration.



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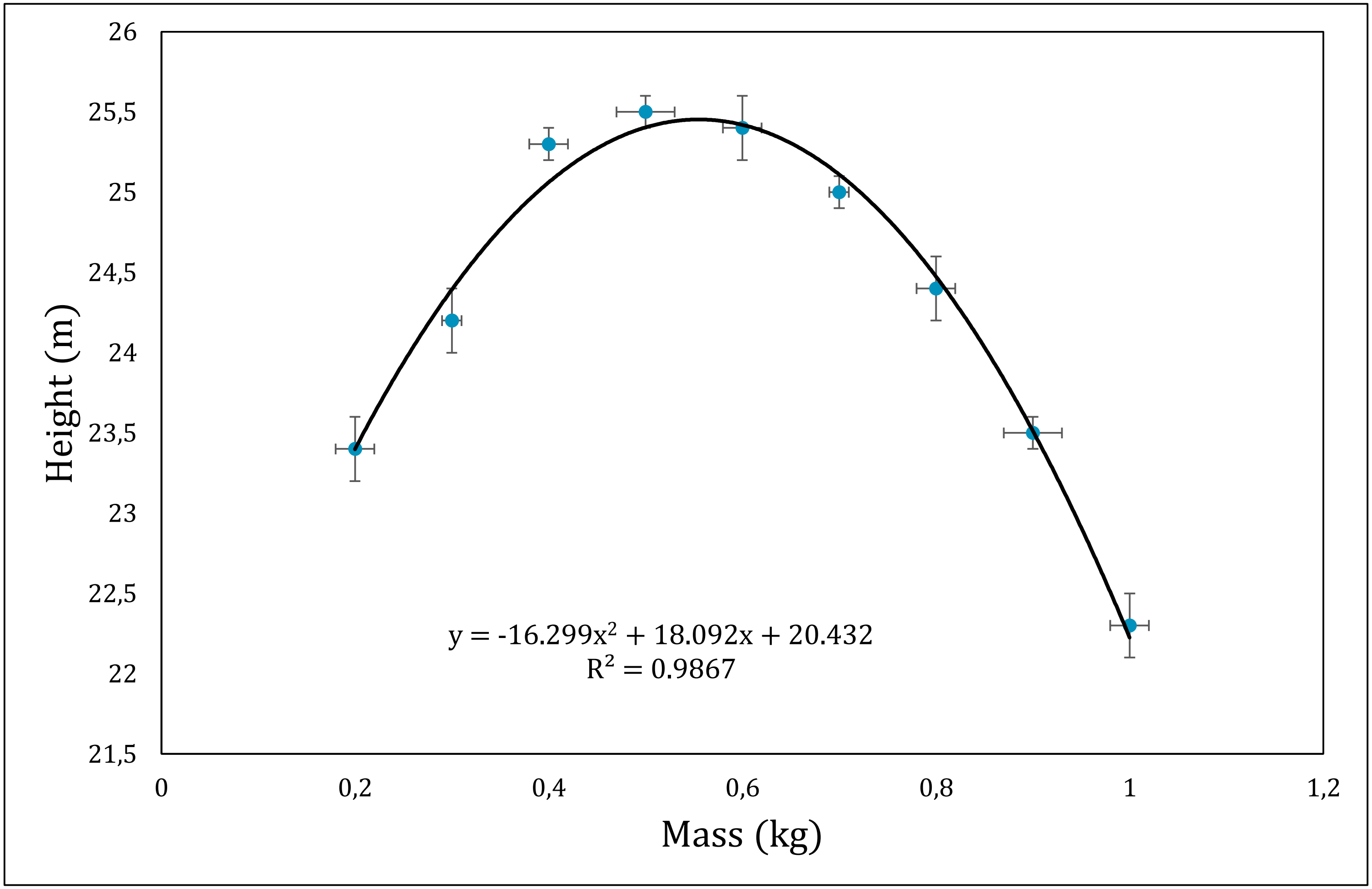
2nd Experiment: Investigation on the effect of increasing mass on height.



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Explain how you analysed your data

1. Collected data in tables
2. Calculated mean values of measured parameters and uncertainties
3. Plotted $Pressure\ vs\ acceleration$ and $m_{water}\ vs\ height$ in excel
4. Performed regression analysis in excel

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Write your conclusions

1. We observed that Pressure (and as a consequence the thrust force) and acceleration are proportional. The higher the pressure force the larger the acceleration.
2. We observed the dependence of height on water's mass.
3. We found the optimal amount of water (~0.5 lt) in the bottle which provides the maximum height to the rocket.

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Compare your conclusion with the hypothesis

The conclusions reached through experimentation confirmed our hypotheses that:

1. If we increase air pressure inside the bottle, keeping mass constant, the rocket will achieve a higher acceleration and will reach higher altitudes.
   Our first hypothesis is confirmed by the experiments.

2. If we increase the rocket's mass, keeping pressure constant, the rocket will reach lower altitudes.
   Our second hypothesis in not confirmed by the experiments. We found that increasing water's mass from 0.2 kg< m <0.5 kg the height increases, it reaches its maximum value for $m \simeq 0.5$ kg and then height decreases as mass increases.

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Write here what future steps you will take in relation to extending your experiment

In order to improve the rocket's performance wee need to conduct more experiments and try to correlate different variables such as:

- $F_{thrust} - time$
- $height - time$
- $velocity - time$
- $acceleration - time$
- *Fins' contribution*
- *Nose cone's contribution*
- *Nozzle's diameter*
- $F_{thrust} - height$

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Some Physics

$$F_{thrust} * \Delta t = \Delta p = \Delta(m v_{water}) = \Delta m * v_{water}$$

$$F_{thrust} = \left(\frac{\Delta m}{\Delta t}\right) * v_{water} \quad (1)$$

Bernoulli's equation

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \quad (2)$$

- $P_1 = P_{gauge} + P_{atm} \quad (3)$
- $P_2 = P_{atm} \quad (4)$
- The hole through which water is leaving is fairly small relative to the overall volume of water. In other words, there's enough of a constriction so that all of the water doesn't go whooshing out instantly. If this is the case, the velocity of the water leaving through the hole is much higher than the velocity of the surface of the water inside the rocket. In fact, that difference is so large that we will assume here that the water's upper surface has zero velocity, so $v_1 = 0 \quad (5)$
- In the case of our water rockets, the height of the water column in the rocket is very small, so it generates very little pressure. Furthermore, the pressure in the rocket is very high, causing the effects of this gravity-generated pressure to be even more negligible. So, let's leave out anything having to do with h_1 *or* $h_2 \quad (6)$.

So (2) becomes: $P_{gauge} = \frac{1}{2}\rho_{water} v_{water}^2$

$$\Leftrightarrow \boldsymbol{v_{water}} = \left(\frac{\boldsymbol{2P_{gauge}}}{\boldsymbol{\rho_{water}}}\right)^{\boldsymbol{1/2}} \quad (\boldsymbol{7})$$

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Bottle's volume: $V = length * area$
Volume of water exiting per sec: $\frac{V}{t} = * \, (meters\ of\ length/t) * area$
However, $meters\ of\ length/t = v_{water}$
So:

$$\Delta V/\Delta t = v_{water} * A$$

Where A is the area of the nozzle in m^2
But $V = m/\rho_{water}$
So

$$\left(\frac{\Delta m}{\Delta t}\right) = \rho_{water} v_{water} A \quad (8)$$

From (1), (8) we get

$$\boldsymbol{F_{thrust} = \rho_{water} * A * v_{water}^2} \quad \mathbf{(9)}$$

From (7), (9) we get

$$\boldsymbol{F_{thrust} = 2P_{gauge}A} \quad \mathbf{(10)}$$

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$$m * a = F_{thrust} - F_{grav} - F_{drag}$$

$$m * a = \frac{\Delta m}{\Delta \mathrm{t}} v_{water} - m * g - \frac{1}{2} C_d * \rho_{air} * A_{bottle} * v^2$$

where:

a: rocket's acceleration
C_d: Drag coefficient (~0.5 for smooth cylinder). Here we accept $C_d \approx 0.98$
ρ_{air}: air density
A_{bottle}: bottle's cross section
v: rocket's velocity

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