The 3, 2, 1 of Newton’s Laws

N5 Physics - Dynamics
Why is this so hard?

Newton’s 3 Laws of Motion aren’t exactly what our experience shows.

Aristotle seemed to have motion cracked. He thought a force was needed to maintain motion— I mean that is what we see in real life. He also thought heavier things fall faster than lighter objects. It took 2000 years before Galileo convinced people he was wrong!
Newton’s 2^{nd} and 1^{st} Laws

Observations:
• Pedal (apply force) gently and your travel slowly.
• Pedal harder and you travel faster.
• Stop pedaling and you slow down and stop.

Conclusions:
• You need to apply a force to keep moving.
• Speed is proportional to the force applied.
Diagnostic assessment

A large lorry collides head-on with a small car. Compare the force on the lorry from the car, with the force on the car from the lorry during the collision. Which force, if either, is larger?
Student A has a mass of 95 kg and student B has a mass of 77 kg. They sit in identical office chairs facing each other. Student A places his feet on the knees of student B. Student A then suddenly pushes outwards with his feet, causing both chairs to move. What can you say about the amount of force each student exerts on the other during the push?
A large lorry breaks down and is pushed back into town by a small car, as shown.

Whilst the car, pushing the lorry, is speeding up, how does the force that the car exerts on the lorry compare with the force that the lorry exerts on the car?

After the car reaches the constant speed, at which the driver wished to push the lorry, how does the force that the car exerts on the lorry compare with the force that the lorry exerts on the car?
Let’s do Newton’s Third Law 1st!
Newton’s Third Law

- For every action there is an equal but opposite reaction. 
or
- If A exerts a force on B, B exerts an equal but opposite force on A.
To identify a ‘reaction’ force to a specific ‘action’ force it is first necessary to identify clearly:

• the **type** of ‘action’ force
• the **object** causing the ‘action’ force
• the **object** on which the ‘action’ force acts, and
• the **direction** in which the ‘action’ force acts.

When identifying Newton Pairs
Newton Pair eg 1

Action:
The hockey stick pushes forward on the ball

Type of force – push
Object causing the ‘action’ force – hockey stick
Object on which the ‘action’ force acts – ball
Direction of force - forwards

Reaction:
The ball pushes backwards on the hockey stick
Newton Pair eg 2

Action:
The gravitational pull of the Earth downwards on the mug
type of force – gravitational pull
object causing the ‘action’ force – the Earth
object on which the ‘action’ force acts – mug
direction of force - downwards

Reaction:
The gravitational pull of the mug upwards on the Earth
Key to Newton Pairs

The fist applies a push on the desk, the desk applies an equal but opposite push on the fist.
Identify the Newton Pairs
More Newton Pairs
Newton’s First Law

- A body will remain at rest or travel at a constant speed in a straight line, unless acted upon by an unbalanced force.

- A body will remain at rest or travel at constant velocity, unless acted upon by an unbalanced force.
Newton’s First Law

Zero unbalanced force does not cause an acceleration:

• object continues with a constant speed in the same direction (constant velocity)
• remains at rest (special case of above)
Newton's First Law of Motion

An object at rest will remain at rest...

Unless acted on by an unbalanced force.

An object in motion will continue with constant speed and direction,...

...Unless acted on by an unbalanced force.
An object will remain at rest or move at constant velocity unless acted on by an unbalanced force.
Newton's first law

The ball is initially stationary. No forces are being applied to it. A force of 1 N can be applied to the ball by clicking once on the up arrow on the left or right side of the screen. Try this and observe the motion of the ball.

Velocity = 0 m / s

When the forces on the ball are balanced, or there are no forces, the ball is either stationary or has a constant velocity.

Normally this is difficult to observe because of friction effects, which may not be obvious. In a frictionless situation, such as outer space, objects will behave like this ball.
Newton’s 2\textsuperscript{nd} Law

You need to understand the difference between speed/velocity and can explain acceleration before tackling Newton’s Second Law. (so let’s review!)

An unbalanced force causes an acceleration:

- a change in the speed (or magnitude of velocity)
- a change in direction (of velocity)
Newton’s Second Law

This is best learned as a formula

\[ \text{Force} = \text{mass} \times \text{acceleration} \]

\[ F = ma \]

Where

Force in newtons, mass in kg and acceleration in m/s²
Let’s Prove Newton’s Second Law

Acceleration and force

Newton's First Law describes the motion of an object when there are no forces acting on an object, or the forces are balanced. The apparatus shown can be used to investigate the motion of a vehicle when an unbalanced force is applied.
Summary of Results

Can you suggest why it might not go through the origin?
Proving Newton’s Second Law Part 2

Acceleration and mass

The apparatus can be used to investigate how the acceleration of the vehicle depends on its mass.

The vehicle is on a linear air track so that there is very little friction. The unbalanced force acting on the vehicle is kept constant. The mass of the vehicle can be varied by clicking on the Increase / Decrease buttons.

When the vehicle is released, an unbalanced force is applied and the acceleration is displayed. Use the apparatus to investigate how the acceleration depends on the mass of the vehicle when the unbalanced force remains constant.
## Summary of Results

A graph shows the relationship between mass (kg) and acceleration (m/s²), as well as the inverse of mass (1/m) and acceleration. The data is presented in a table:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass</td>
<td>acceleration</td>
<td>1/m</td>
</tr>
<tr>
<td>(kg)</td>
<td>(ms⁻²)</td>
<td>(kg⁻¹)</td>
</tr>
<tr>
<td>0.2</td>
<td>1.47</td>
<td>5.0</td>
</tr>
<tr>
<td>0.4</td>
<td>0.73</td>
<td>2.5</td>
</tr>
<tr>
<td>0.6</td>
<td>0.48</td>
<td>1.7</td>
</tr>
</tbody>
</table>

The trend line equation is given as:

\[ y = 0.2968x - 0.0135 \]

The coefficient of determination, \( R² = 1 \), indicates a perfect fit of the data to the line. The text notes that acceleration against 1/m gives a straight line almost through the origin.
Newton’s 2\textsuperscript{nd} Law

Acceleration is proportional to force \textit{and not velocity}.

\[ a \propto F \]

\[ a \propto \frac{1}{m} \]

and hence

\[ a \propto \frac{F}{m} \]

giving

\[ F_{un} = ma \]
Newton’s 2nd and 1st Laws

Newton’s 1st Law is just a special case of the 2nd Law.

When \( F \), the unbalanced force, is zero. When that happens, the acceleration \( a \) must also be zero.

\[
F_{un} = ma
\]

An object of mass 20 kg

\[
0 N = 20 \text{ kg} \times \text{acceleration}
\]

\[
\frac{0}{20} = a = 0
\]

0 acceleration is no change in velocity or constant velocity
Newton’s Laws 3rd Law

Confusion between Newton’s First and Third Laws:

Newton’s First Law

Forces of equal magnitude and opposite direction acting on one object.
- balanced forces

Newton’s Third Law

Forces of equal magnitude and opposite direction acting on two objects.
- action and reaction pair
If the helicopter is **hovering** at constant height, the helicopter main rotor generates a vertical force in opposition to the helicopter’s weight.
Here’s N1L and N3L

Newton Pair: (2 forces on 2 objects)
The blade pulls down the air
The air pulls up the blade

Newton Pair: (2 forces on 2 objects)
The Earth pulls down the helicopter
The helicopter pulls up the Earth
Now your turn: Remember balanced forces happens at constant height and constant velocity only! Newton Pairs all the time!

**Newton Pair: (weight)**
The Earth pulls down the plane
The plane pulls up the Earth

**Newton Pair: (drag)**
The air pushes back the plane
The plane pushes forward the air

**Newton Pair: (Lift)**
The wing pushes down on the air
The air pushes up on the wing

**Newton Pair: (Thrust)**
The engine pushes back the exhaust gases
The exhaust gases pushes forward the engine
Now you try all alone. A motorbike is travelling at constant velocity along a long straight road.
Diagnostic assessment

A large lorry collides head-on with a small car. Compare the force on the lorry from the car, with the force on the car from the lorry during the collision. Which force, if either, is larger?
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Diagnostic Questions

A large lorry breaks down and is pushed back into town by a small car, as shown.

Whilst the car, pushing the lorry, is speeding up, how does the force that the car exerts on the lorry compare with the force that the lorry exerts on the car?

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Reminder: Can you quote all 3 of Newton’s 3 Laws of Motion

Newton’s First Law states:
A body will remain at rest or travel at a constant speed in a straight line, unless acted upon by an unbalanced force.

A body will remain at rest or travel at constant velocity, unless acted upon by an unbalanced force.

Newton’s Second Law we normally write as a formula:

\[ F_{un} = ma \]

Unbalanced Force = mass \times gravitational field strength (Newtons) = (Kilogram) \times (Newtons per kilogram)

Newton’s Third Law states:
For every action there is an equal but opposite reaction.
or
If A exerts a force on B, B exerts an equal but opposite force on A.

After Godfrey Kneller, Public domain, via Wikimedia Commons
“A horse is harnessed to a cart. When the horse tries to pull the cart, the horse exerts a force on the cart. By Newton's third law the cart then exerts an equal and opposite force on the horse. Since the two forces are equal and opposite, they must add to zero, so Newton's second law tells us that the acceleration of the system must be zero. If the cart is at rest, and doesn't accelerate, it must remain at rest, and therefore no matter how hard the horse pulls, it can never move the cart.”

Use your knowledge of physics to comment on this statement.