# Longer Worksheet: Newton’s Laws of Motion And Inertial Frames of Reference

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Before looking at Newton’s first two laws of motion, we need to understand **inertial frames of reference**. An inertial frame of reference is an environment which is not accelerating. The results of Newton’s Laws of Motion are only valid if they are calculated from the point of view of someone in an inertial frame of reference. The following are examples of inertial frames of reference:

* A plane at constant speed in a steady straight line, not in turbulence. This means a person on the inside does not really notice they are moving. Objects around them appear as if they are not moving and if they are dropped or thrown they behave as expected.
* A train or a bus travelling at a constant speed in a straight line on a smooth track/road without any bumps. Again, anyone on the inside of the bus or the train would not feel the motion of the bus or train if they had their eyes closed
* A person standing at rest on a train platform waiting for their train. Anything on the platform is an inertial frame of reference but anyone on a train that is slowing down to stop at the platform or speeding up as they leave the platform is not in an inertial frame of reference.

The best way to tell if a point of view is an inertial frame of reference is to imagine yourself in that situation. If you had your eyes closed, would you be able to feel if you are moving? If the answer is no, you are in an inertial frame of reference and you are not accelerating. In fact, it was Einstein who said you are unable to tell the difference between inertial frames of reference! There is no difference between a moving inertial frame of reference or a stationary one. So, any results of Newton’s Laws of Motion applied in different inertial frames of reference are all still valid.

The following are examples where you cannot apply Newton’s Laws of Motion because these frames of reference are accelerating.

* Passengers on a plane that is experiencing turbulence, taking off or landing. When you’re on a plane in these situations you can feel the plane moving.
* A car turning around a corner. When you’re in the car going around the corner you can feel your body move in the opposite direction to the turn

Even though the Earth is rotating on its axis and orbiting the Sun, this motion is small enough that we can consider someone standing on the Earth as someone in an approximate inertial frame.

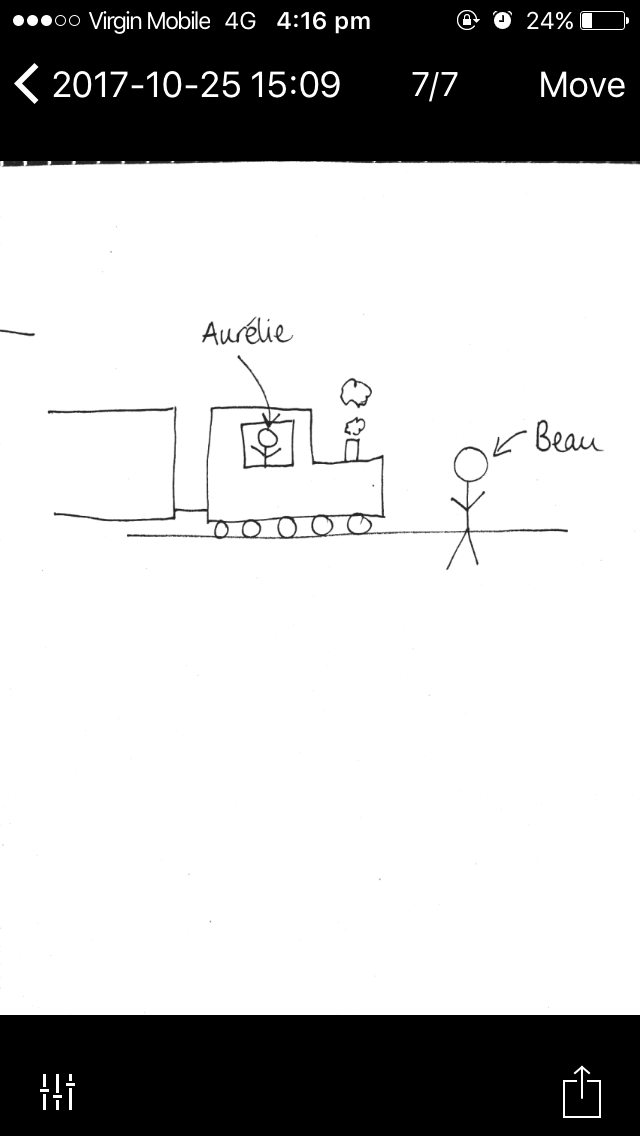
Example 1

Which of the following frames of reference are inertial:

|  |  |
| --- | --- |
| A skateboarder going down a hill getting faster and faster | Non-inertial since the skateboarder is accelerating |
| A train travelling at a constant speed on smooth tracks | Inertial, the train is not accelerating and not experiencing any bumps |
| A person sitting on a bench waiting for their bus | Inertial, the person is stationary (not moving) and so not accelerating |

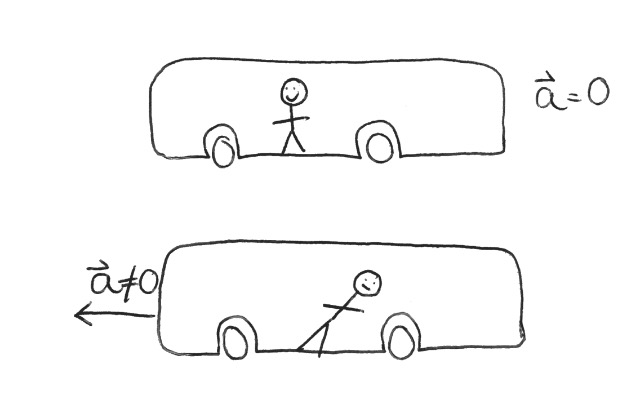
Example 2

Beau is standing on a train platform waiting for their train into the city. While they’re waiting a train travels past at a constant velocity on smooth tracks but does not stop at Beau’s platform. On the train is Aurélie. Using inertial frames of reference, discuss the differences between Beau and Aurélie’s observations.

* Firstly, we draw a diagram of the situation so that we can picture ourselves in each inertial frame of reference.
* The first inertial frame of reference we will consider is Beau’s. Since Beau is standing still on the platform, they are not accelerating and their frame of reference is inertial. As the train travels past the platform, it appears to Beau that Aurélie is moving past at a constant velocity.
* Now, if we consider Aurélie’s frame of reference. Firstly, we need to check it is an inertial frame of reference. Since the train travelling with a constant velocity, on smooth tracks and in a straight line, the train and anyone inside it is in an inertial frame. So Aurélie is also in an inertial frame of reference. As the train travels past the platform, it seems to Aurélie that she is motionless while Beau and the platform and moving with a constant velocity in the opposite direction to the velocity of the train that Beau observed.
* While in one frame of reference Beau appears to be the object that is motionless and Aurélie the object that’s moving compared to the other frame where Aurélie appears motionless and Beau appears to be moving, both observations are valid! They seem to produce contradictory results but as both observations were made in an inertial frame of reference, both are completely valid.

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Newton’s laws of motion physically describe the motions of objects we observe every day. His first law, the law of inertia, states:

**In an inertial frame of reference, if the resultant force acting upon an object is zero, then the object will be at rest or moving with constant velocity**

This means if there is no net force acting on an object, the motion will remain unchanged, all objects resist a change in their motion. For example, a hockey puck gliding along an icy (frictionless) surface will go on forever or until something stops it (like another player or the net of the goal). The motion of astronauts at the ISS is another example. The astronauts are in a permanent state of free fall which means all the forces acting on them are balanced, which means they seem to float around in the station. If an astronaut pushes off from the wall of the ISS they move away with a constant velocity (and would continue to do so) until they hit the opposite wall.

You can feel the effects of Newton’s First Law when travelling on a bus that suddenly brakes. When the bus is travelling forward with constant velocity, if you close your eyes you can’t tell you are moving forward (so we must be in an inertial frame of reference). However, if the bus stops, your body will resist the change in its motion and continue to move in the same direction. As a result, jerk forward and it feels like someone has pushed you forward. The same happens in the opposite direction when the bus suddenly moves forward.

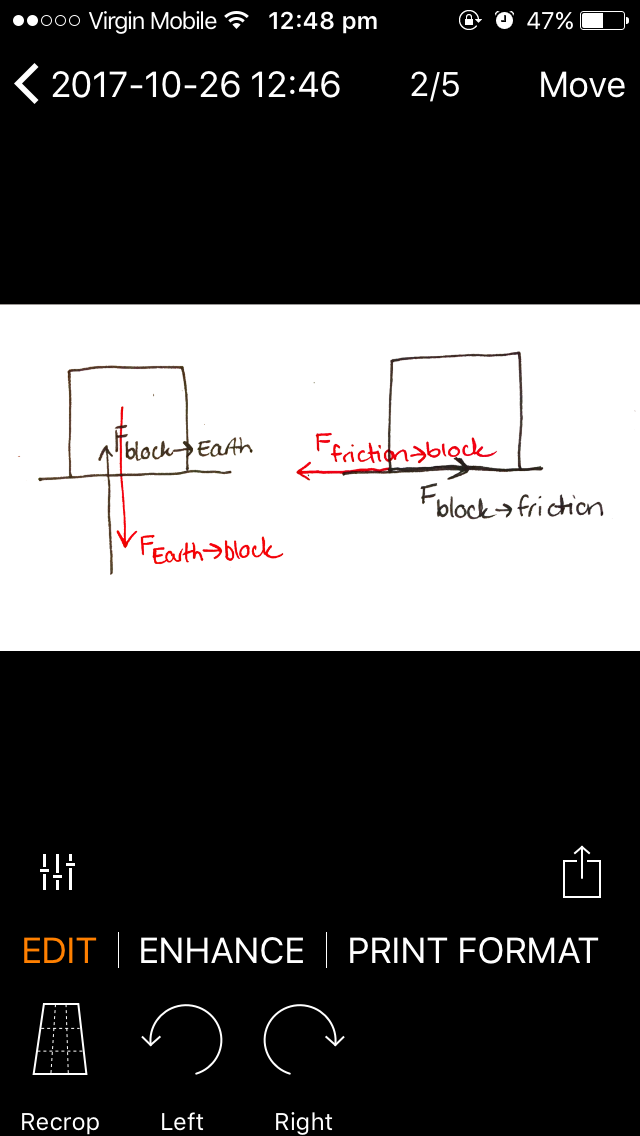
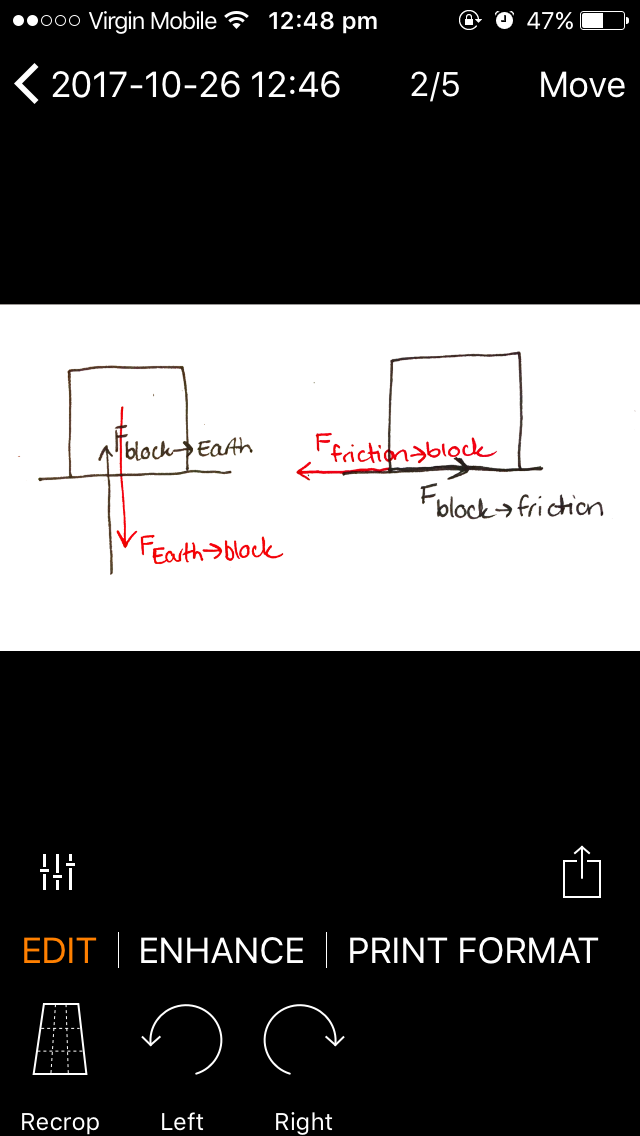
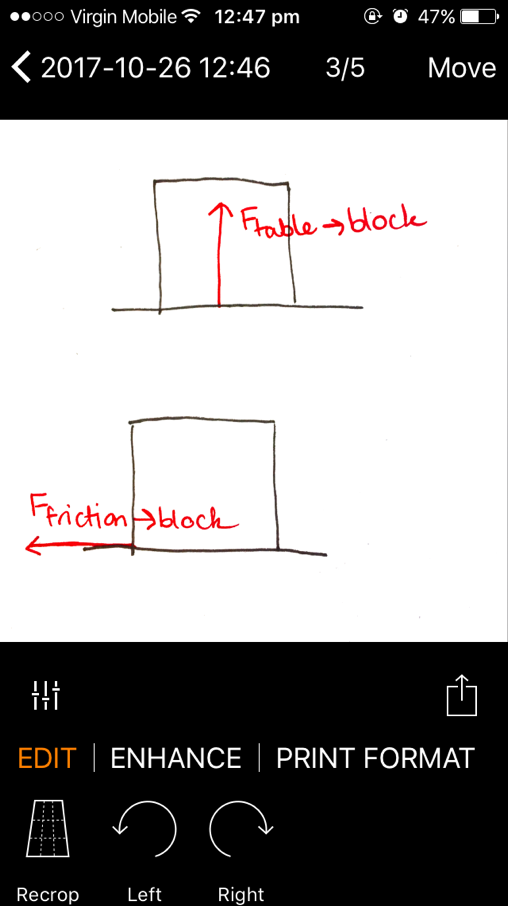
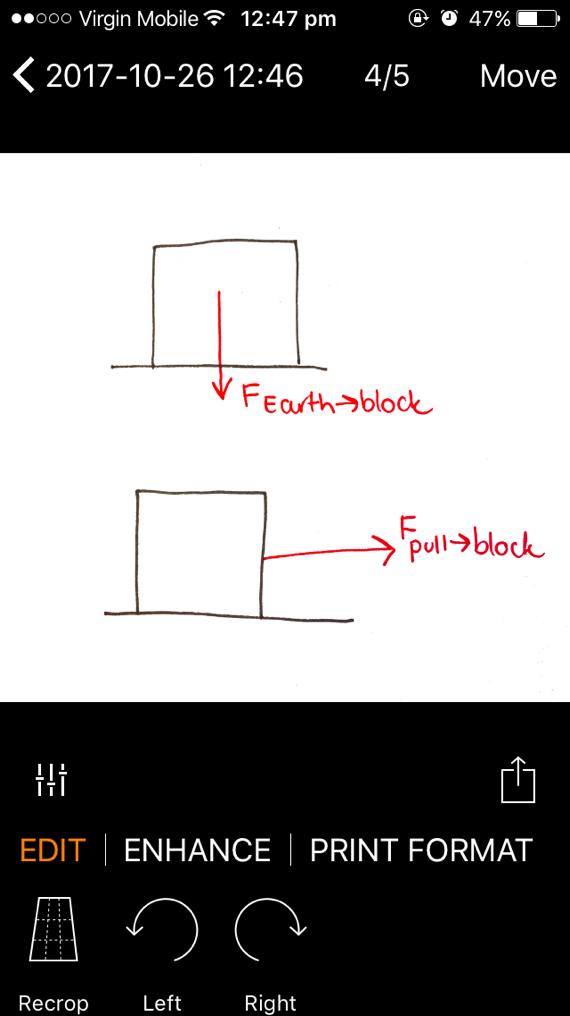
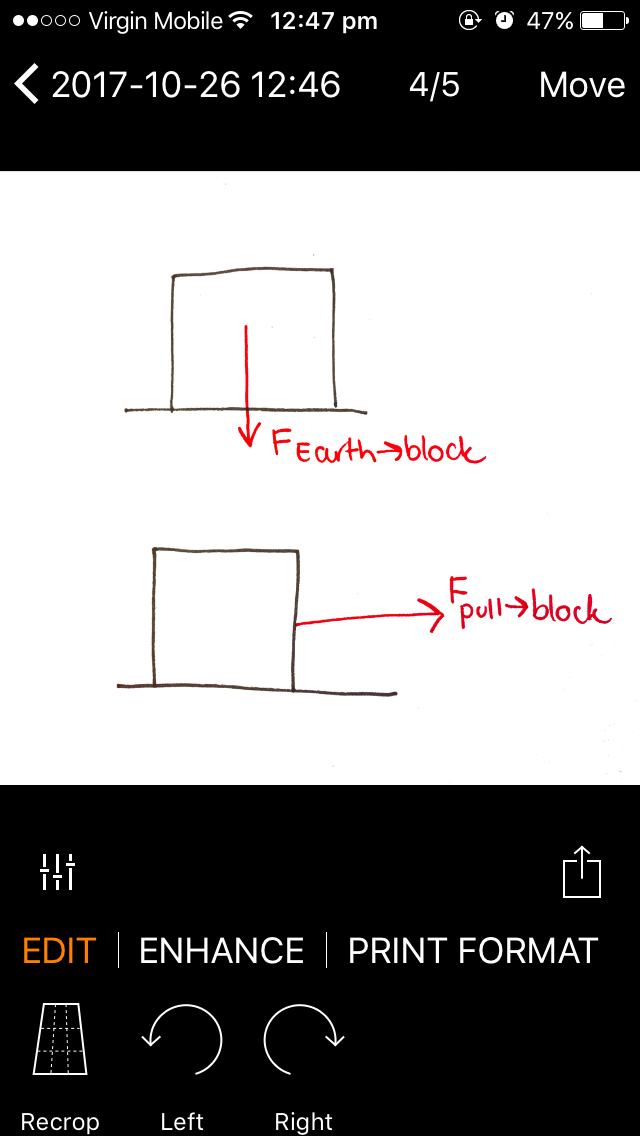
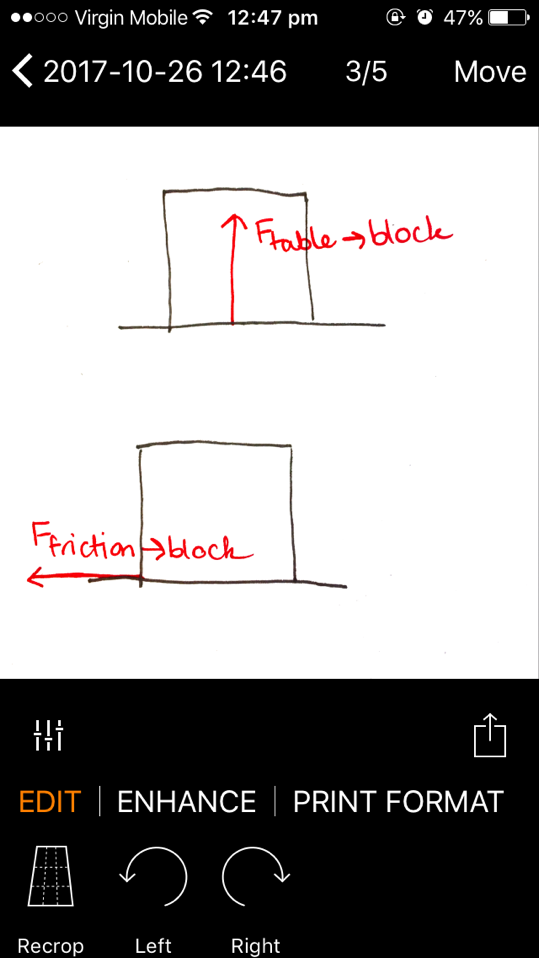
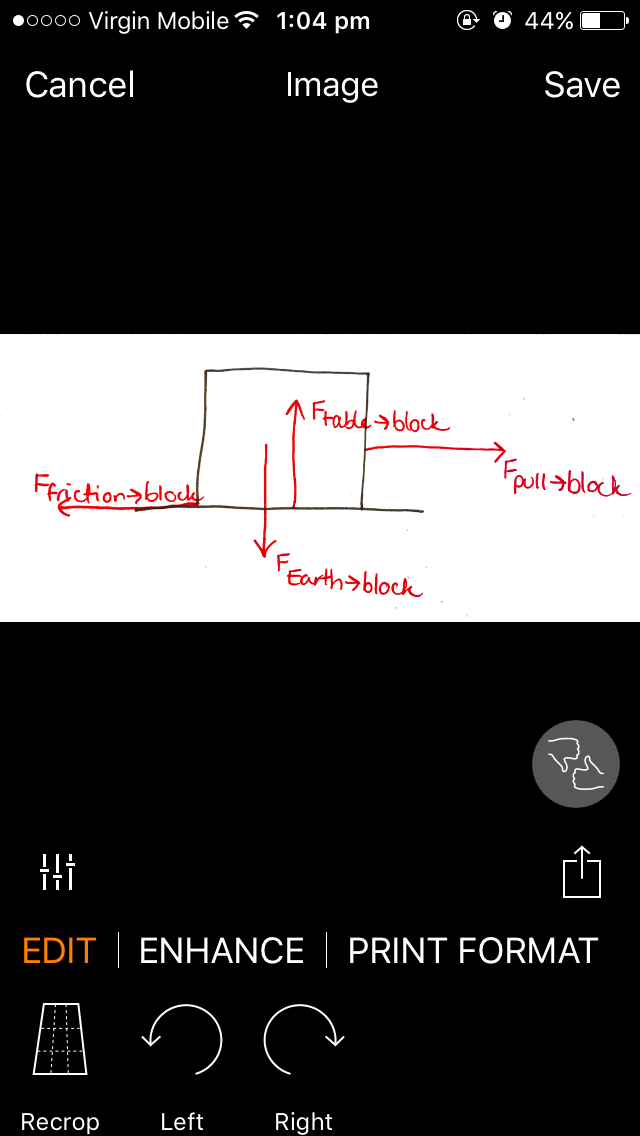
Newton’s Second Law of motion connects the net force acting on an object with the acceleration of the object:

**If there is an unbalanced force acting, there is an acceleration in the direction of the net force**

Where is the net force acting on the object, is the mass of the object at rest and is the acceleration of the object. This means any object that has a non-zero acceleration has a non-zero net force and vice versa and the more massive an object is, the more force is required to accelerate it. For example, throwing a netball requires less force from the player than throwing a brick.

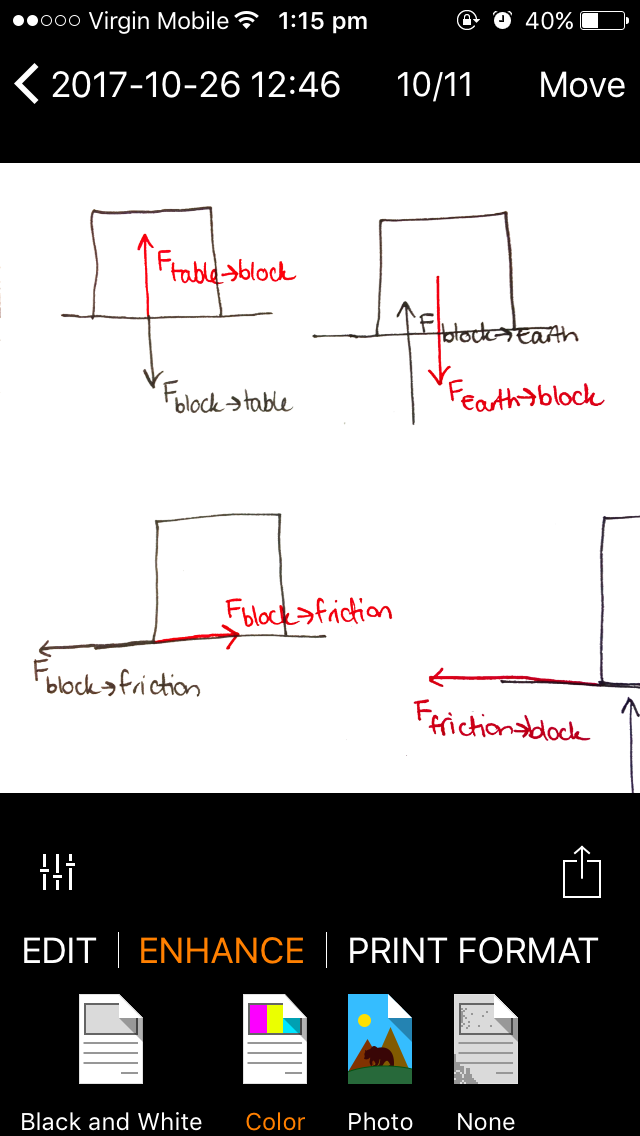
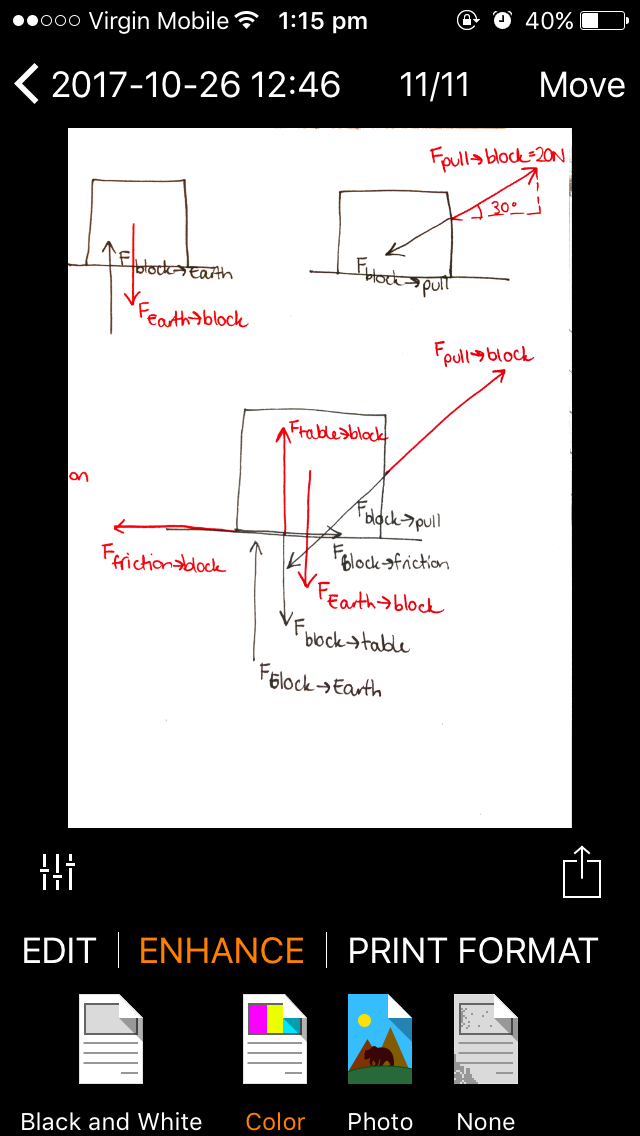
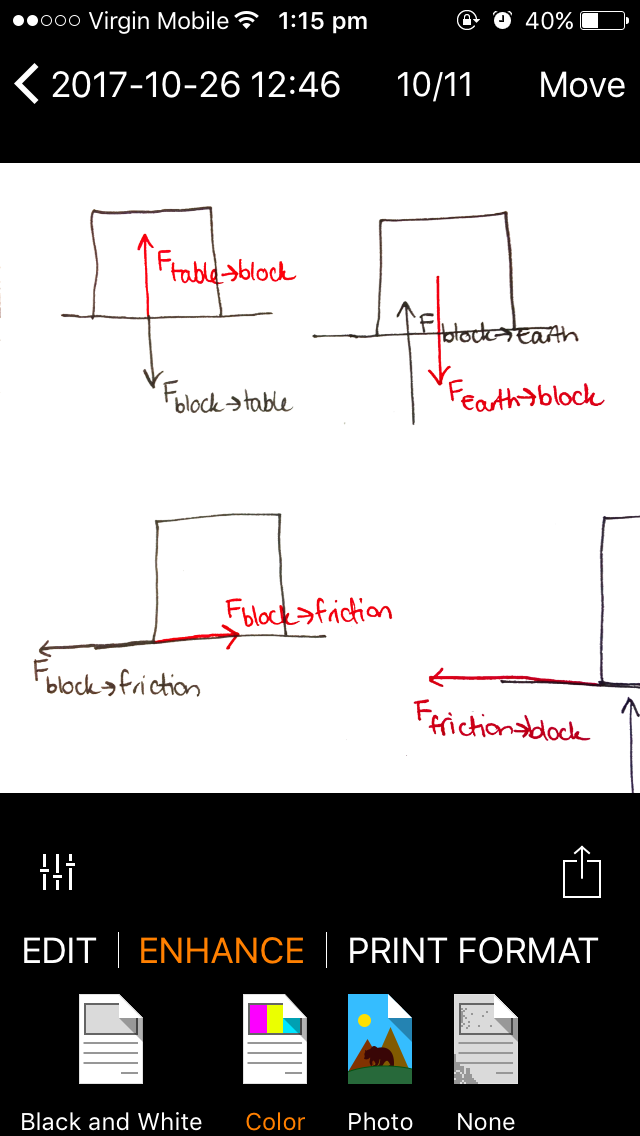
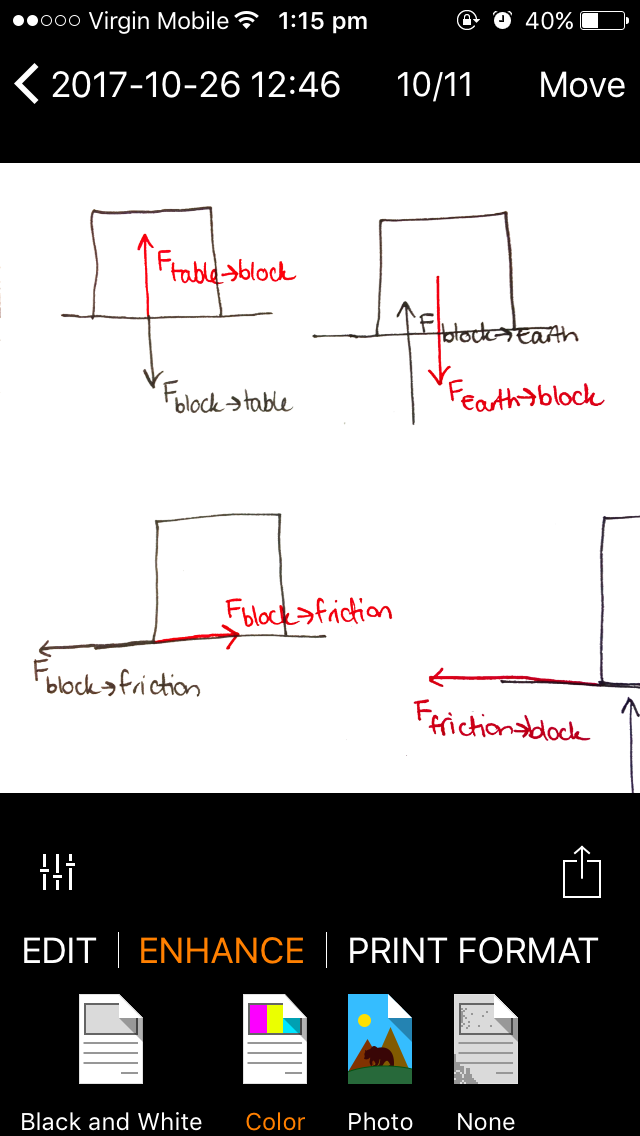
Example 1

A block is being pulled across a table with a horizontal force. The force of the pull is so small the block isn’t moving anywhere, it is still at rest. Draw all the forces acting on the block and qualitatively explain them.

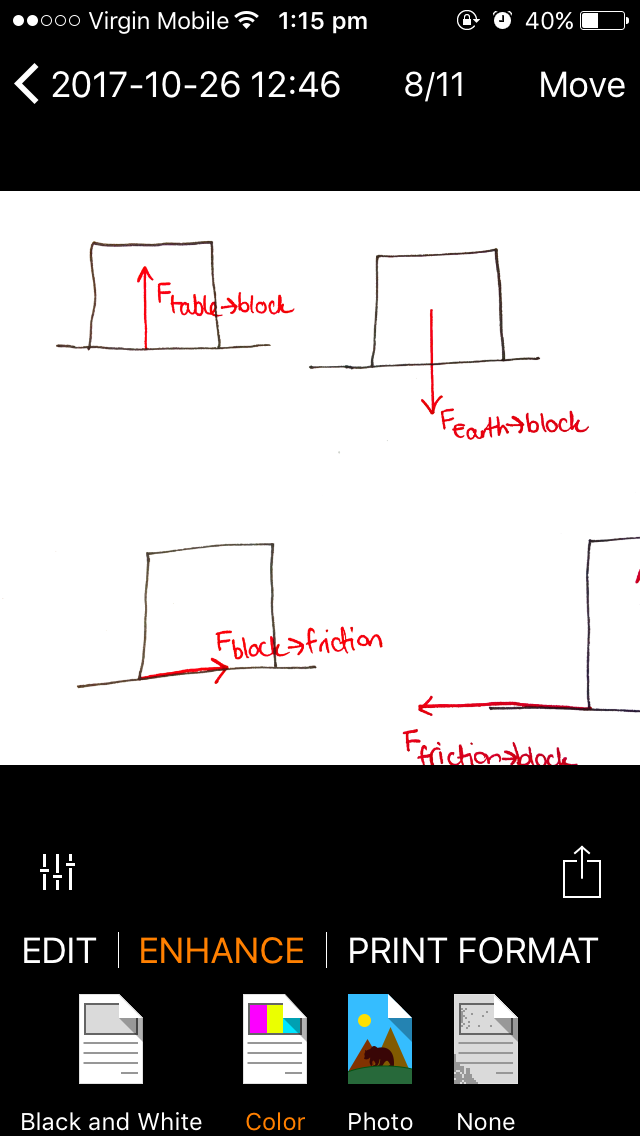
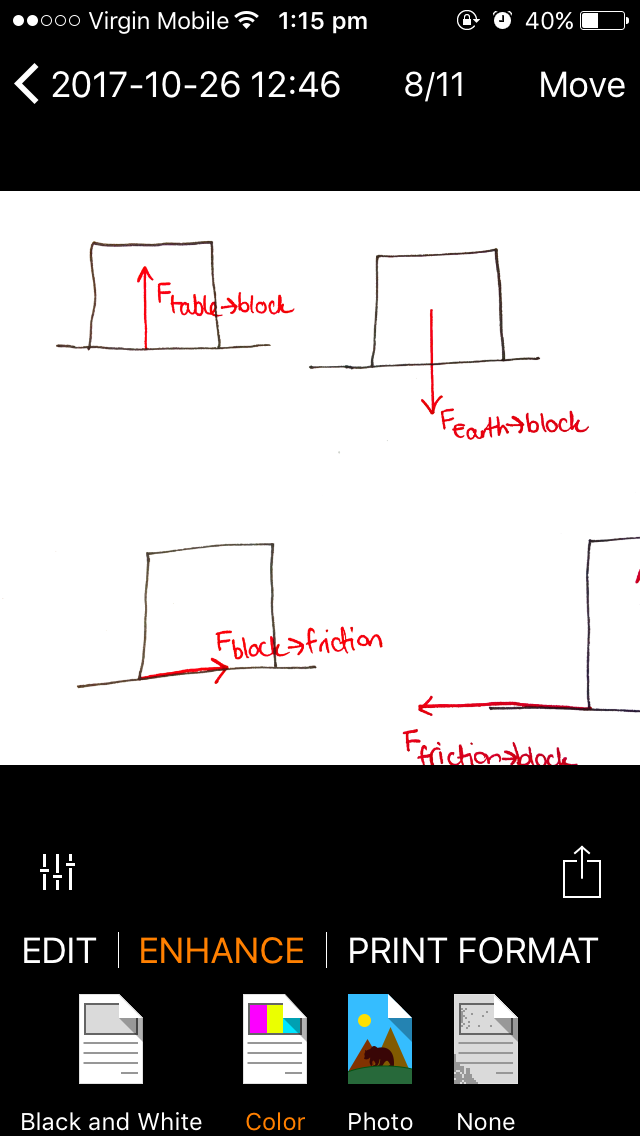
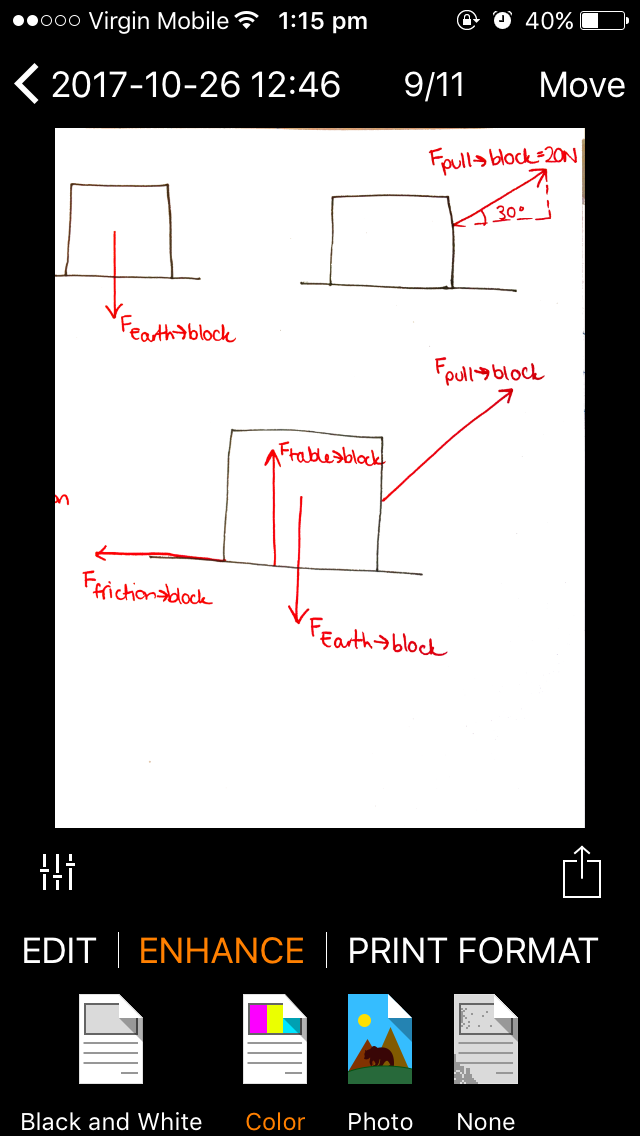
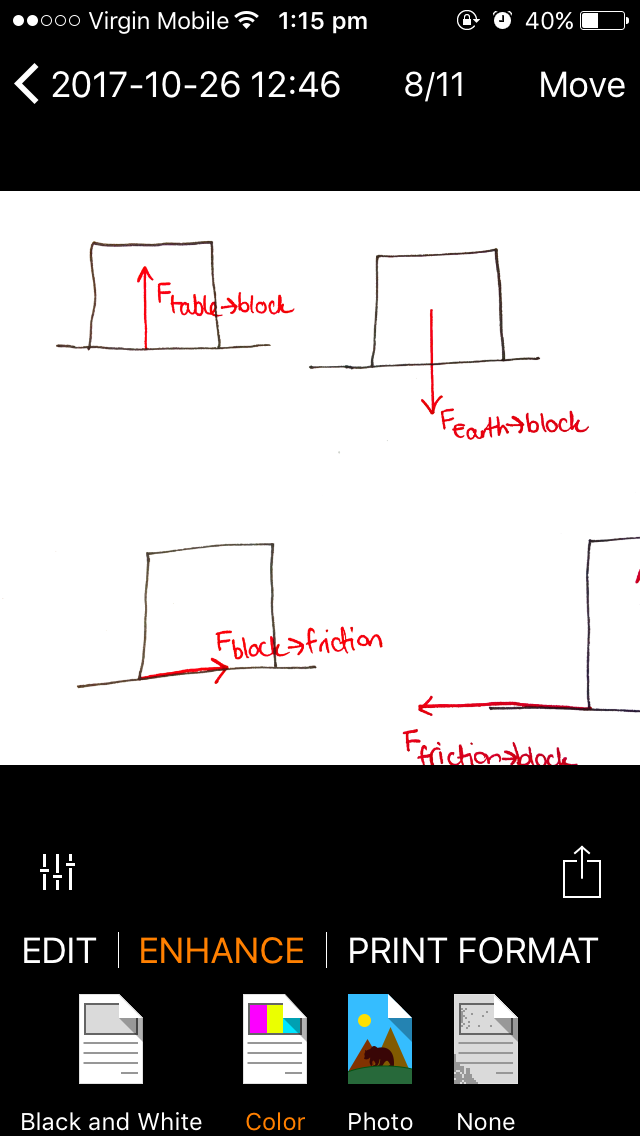
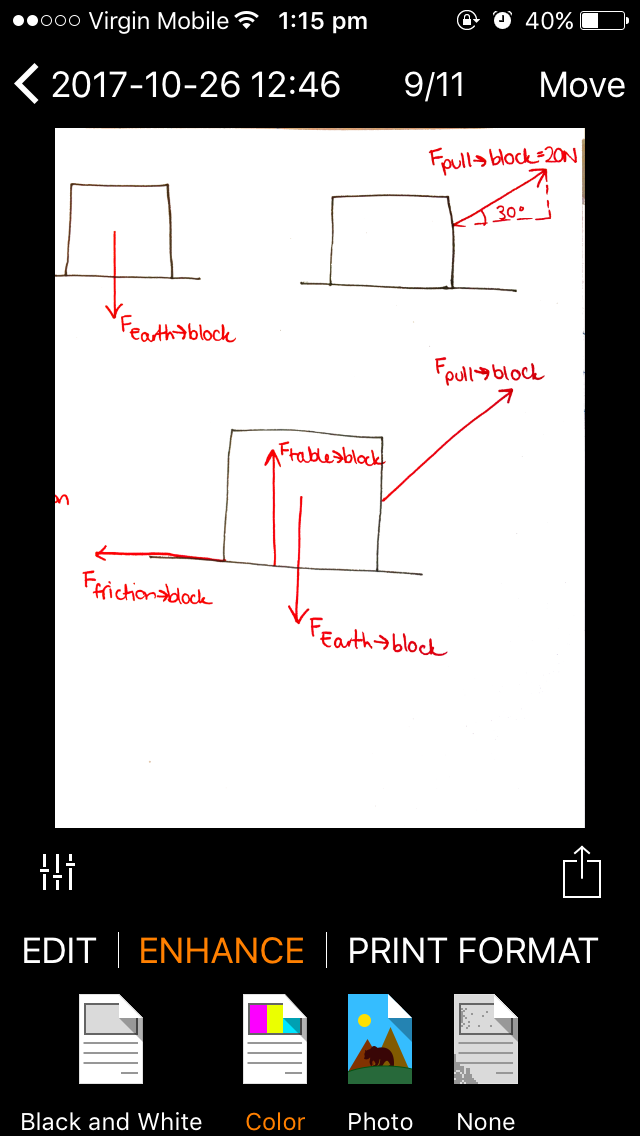
* First, we shall draw a diagram of the whole scenario with all the forces present, we will then pick out the ones that are acting on the block as these are the only ones we are concerned with.
* So, there is a force exerted by the table on the block, , the force of the block on the table, . The force of gravity, exerted by the Earth on the block, , and the force of gravity exerted by the block on the Earth, . The force of the pull on the block, , and its reaction force of the block on the pull, . Finally, the force of friction exerted by the table on the block, , and the force of the friction exerted by the block on the table, .
* Picking out the ones that are acting on the block only to calculate our net force acting on the block we have: the contact force of the table, , gravity , the pulling force , the friction force .
* Qualitatively explaining the situation: We know from Newton’s First Law that since the block is at rest, there must be a total net force of zero acting on it. So, the force of gravity (exerted by the Earth on the block) must balance the contact force of the table on the block. Similarly, the force of the pull must be balanced by the force of the friction on the block.

Example 2

A block of mass 2kg, is being pulled along a table. The pulling force is 20N at an angle of 30° to the horizontal, as drawn below. Add in all the other forces acting on the block, assuming there is a force due to friction of 10N. What is total horizontal acceleration? Resolve the vertical forces and explain why the block doesn’t fly upwards.

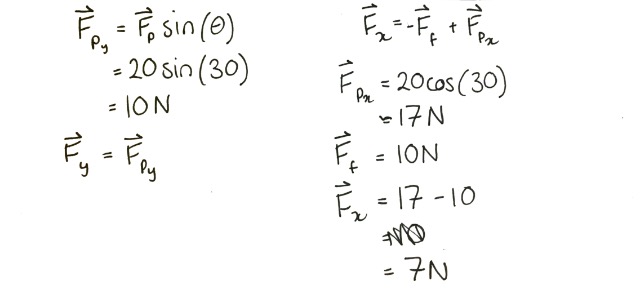
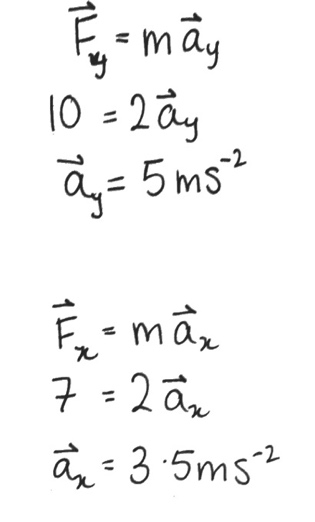
* So, firstly we draw a diagram adding all the forces present.

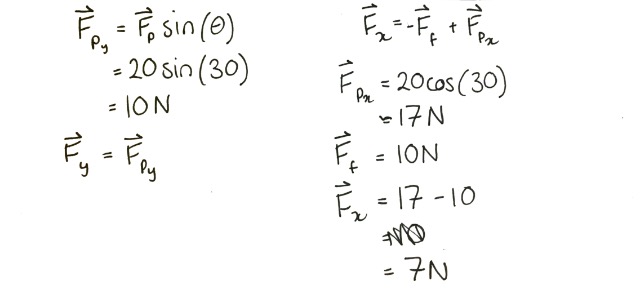
We have the force due to gravity, , and its force pair the force of gravity exerted by the block on the Earth . The contact force exerted by the table on the block, , the contact force of the block on the table, , and we have the force due to friction exerted by the table on the block which has a force pair . And finally, the force of the pull on the block, (at 30°) and its pair the force of the block on the pull . So, picking out the forces that are acting on the block we are left with: , (contact force), and (at 30°).

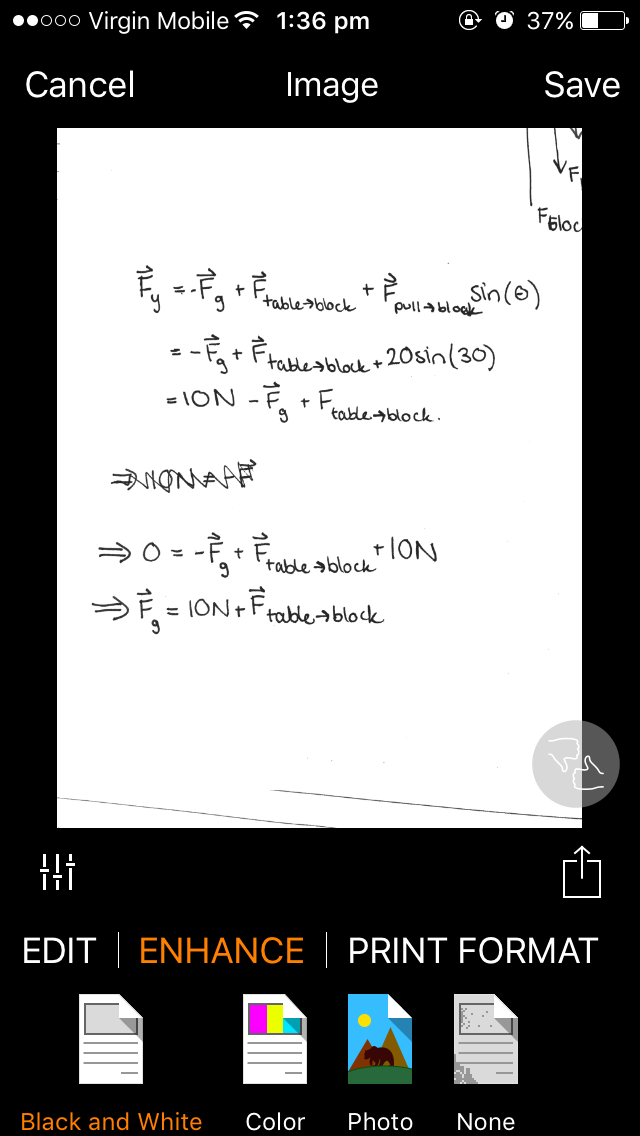
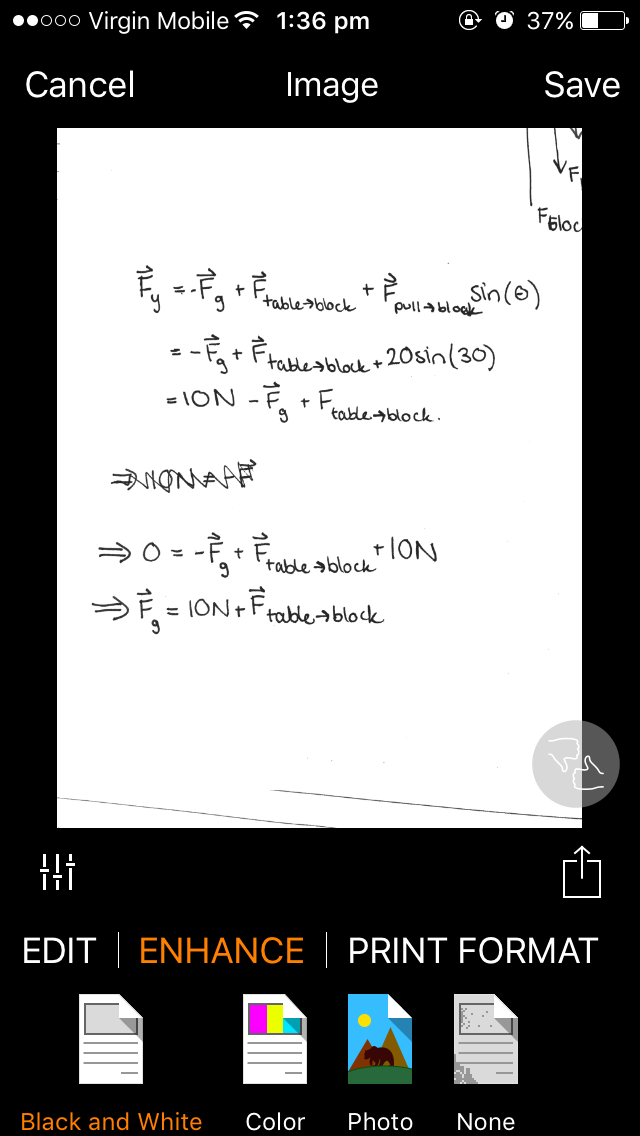


* Now, we need to resolve each of the forces into their components. Since the force due to gravity on the block and the contact force of the table on the block cancel each other out, we will ignore them in our calculations

So, we only need to calculate the vertical and horizontal component of the pulling force and the friction force on the block using trigonometry and use to calculate the acceleration.



* The horizontal acceleration is ~3.5ms-2.
* As for the vertical acceleration. We know the block won’t fly upwards if we pull it at a slight angle, so our total vertical forces must be balanced:
* Since the force due to gravity of the Earth on the block is a constant and won’t change but we are adding the vertical force due to the pull on the block, the contact force from the table on the block must decrease to ensure everything is balanced. This means that the block won’t accelerate upwards, however, it will sit on the table with less force.