INTRODUCING NEWTON TO SECONDARY SCHOOL STUDENTS

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This write-up is a **draft** that could serve as a starting point for a **project.** The goal of the project is to design learning materials to help secondary school students investigate the nature of motion in the physical world, and construct an approximation of Newtonian mechanics.

It tries to illustrate what can go into creating "teacher-independent" learning resources for inquiry-based learning. Once such resources are created and polished, they would make minimal demands on teachers, such that even teachers who are not initiated into inquiry and inquiry skills may implement the material with some success.

Structure of the learning material:

Part 1 uses a series of *thought experiments* to develop the idea (expressed as a law) that an (inanimate) object at rest moves only if there is a force that makes it move. This *seed* of a law, combined with the generalization that would emerge in Part II, can grow into Newton's First Law of motion. Though presented as thought experiments, they should ideally be also conducted as real experiments wherever feasible.

Part II uses another set of thought experiments to develop the second part of the Law, that an object in motion continues to move in a straight line unless a force acts on it to increase or decrease its speed, or change its direction. When we put Parts I and II together, we arrive at the law that: **unless a force acts on it, an object at rest remains at rest and an object in motion continues to move in the same direction at the same speed**.

Part III develops the ideas in part II to help students see that if an object has started moving at a steady speed in a straight line because of the application of force A on it, the continuous application of another force B that pushes/pulls the object in a direction that is perpendicular to the existing motion will result in the object moving in a curved path (circle, parabola, ellipse). This insight builds the foundations for understanding the motion of projectiles on earth and planets in the sky.

Part IV is a set of sketchy ideas (not converted into a script) for the second and third laws. (Should this come before part III?)

Part V begins with an apparent counterexample to the 'law' developed in Part II. It nudges learners to think of "earth-pull" as a force that continuously acts on an object. If we adopt the idea of earth-pull, what looked like a counterexample is not a counterexample any more. Earth-pull can later be developed as a force that makes objects move towards it. This would be the first step towards the concept of **gravity** and the Law of Gravitation. When combined with Part III, this will automatically explain the (parabolic) path of projectiles on earth.

PART I

Teacher: Suppose we do an experiment.

Experiment: Make two marks on a table; call them X and Y. Place an ant on X and a coin on Y.

Let's look at the ant and the coin and see what they do.

A) Will they both remain in the same place?

B) Will they both move away?

C) Will the ant remain on X, and the coin start moving away from Y?

D) Will the coin remain on Y, and the ant start moving away from X?

For the teacher:

This is an example of a ***thought experiment***. In a real experiment, we do some activity, observe the results of what we have done, and arrive at a conclusion on the basis of the observation. In a thought experiment, we imagine the scenario in our mind, and arrive at a conclusion on the basis of our prior knowledge and intuitions. Both thought experiments and real experiments are valuable strategies for inquiry.

Activity: Give the children two or three minutes to discuss the problem among themselves in buzz groups of three or four, then ask them which groups opt for options A, B, C or D, by raising their hands. Chances are that they would all select D. Even though the answer is somewhat obvious, thinking about the question and making a choice will prime the children to do the same in more complex tasks with less obvious answers.

Teacher: Suppose we repeat this experiment with pencils, erasers, lizards, snails, nails, frogs... What do you think will happen?

For the teacher:

Most likely the children would all say that pencils, erasers, and nails will stay where they are placed, while lizards, snails, and frogs will move away (unless they are dead or asleep). Once they give their answer, we can proceed to the next question.

Teacher: Can you make up a general principle (*niyam*) to explain the contrast between (a) coins, pencils, erasers and nails, and (b) ants, lizards, snails and frogs?

For the teacher:

To answer this question, children need to be aware that ants, lizards, snails and frogs belong to the category of living things while coins, pencils, erasers and nails belong to the category of non-living things. If they don't come up with this category straight away, we may need to bring in other examples till they see the pattern.

The children are likely to answer the question with something like:

Non-living things do not move.

Activity: If they give the above answer, try dropping a coin on the floor, throwing an eraser to one of the children, or rolling a pencil on the table, and asking them: "Is it living? Did it move?" When faced with counterevidence, they will have to revise their principle to:

Non-living things do not move on their own.

If they say this, ask: what does it mean to say, "move on their own"? It might be necessary to invite their attention to such things as:

Pieces of paper fly around when there is a strong breeze.
A ball moves if we hit it with a bat.

See if they can be nudged to see the following pattern:

Non-living things do not move unless there is a force that makes them move.

Make sure that every principle that children come up is written on the black board/white board. Select the best principle (which is likely to be a variant of the above principle) after going through a discussion, and write it down on one side of the board.

Now ask them to ***test*** this principle by doing actual experiments (not just thought experiments) with a number of living and non-living things, going beyond the original set of things they used in the thought experiment. Suggest such things as flies, books, glasses, cats, dogs, and birds.

Teacher: How do living organisms move? This is a question for biology to find out, so let us leave it aside for now, and think about how non-living things move. Like coins, stones, books, paperweights. The principle we have formulated is:

Non-living things do not move unless there is a force that makes them move.

This is a principle of motion in the physical world.

PART II

Teacher: Imagine a carom board with a striker on it. In your mind, hit the striker with your finger and watch it move. Again in your mind, put the striker on a rough floor (say on sandy ground), hit it with the same force, and watch it move. Do you think the striker would move:

A) faster on the board than on the floor?

B) faster on the floor than on the board?

C) at the same speed on both?

For the teacher:

The children would most likely choose (A).

Activity: Ask them to state a general principle that explains this result. They would probably say something about friction causing moving objects to slow down. (They may not, of course, use the term 'friction'.)

Teacher: Now imagine the striker on a carom board made smooth with some talcum powder on it. In your mind, hit it with the same force you used on the carom board without the powder, and on the rough floor. On which surface would it move fastest, on the carom board with talcum powder, the carom board without the powder, or the rough floor?

For the teacher:

The children would most likely say that it moves fastest on the carom board with talcum powder. Why? Because it has the least amount of friction.

Teacher: Now imagine a huge carom board, an infinitely large one. It has an ideal surface with absolutely no friction. A surface so perfectly without friction that only a god can create it. In your mind, keep the striker on that carom board, and hit it with the same force you used on the ordinary carom board and on the rough floor. What do you think would happen?

For the teacher:
At least some children would see that the striker would keep moving forever, without ever stopping or even slowing down.

Teacher: Can you state a general principle — a *niyam* — that explains this result?

For the teacher:
The children would most likely say: a moving object keeps moving unless some force acts upon it to decrease the speed or stop it. Ask them if the object would increase its speed. If they say no (which they most likely would), ask them to include that in the law. Ask them if the object would change its direction, go to the left or right, or go zigzag. If they say no, ask them to include that too in the law.

Teacher: Okay we now have two laws.

Unless a force acts on it, a non-living object at rest will continue being at rest, without moving.

Unless a force acts on it, a non-living object in motion will continue to move in the same direction at the same speed.

Can you put the two together as a single principle?

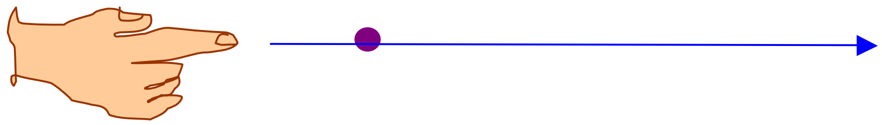
For the teacher:
Nudge the children to formulate the combined principle as some version of:

Unless a force acts on it, an object at rest remains at rest and an object in motion continues to move in the same direction at the same speed.

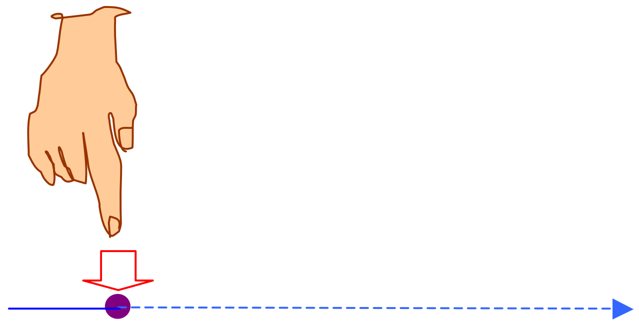
This is Newton's First Law of Motion, originally formulated by Galileo.

PART III

Teacher: Good. Now imagine that on our infinitely large carom board with absolutely no friction, you have hit a striker and it is moving in a straight line with uniform speed, like this:

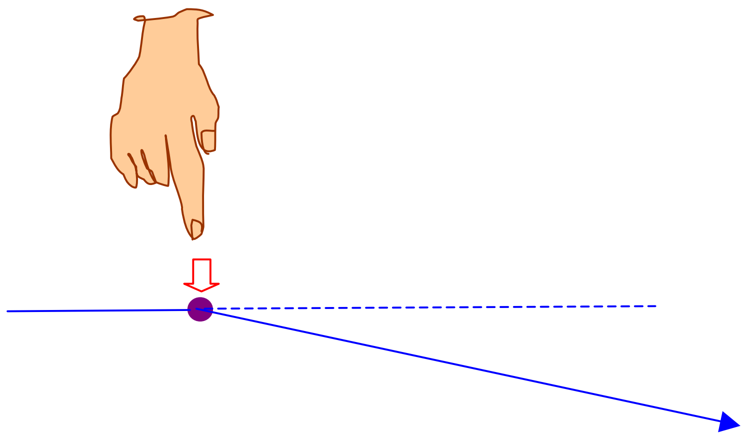


Teacher: What do you think would happen if, while the striker is moving as described above, we hit it in the direction perpendicular to its line of movement, like this?



For the teacher:
The red arrow indicates the location and direction of the force (the finger hitting the striker). The dotted line is the path the striker would have taken if we had not hit it. The continuous line is the actual path of the striker.

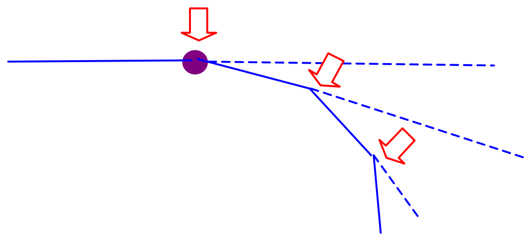
Activity: Get the students to draw a picture indicating the direction of movement. See if they do something like the following.



Teacher: Now, what do you think would happen if we keep hitting the striker again and again, each time perpendicular to whichever way it is going at that moment?

For the teacher:

They would most likely indicate something like the following.

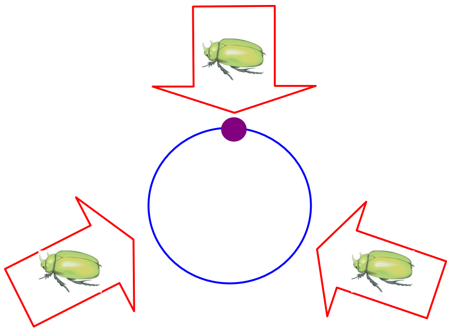


If the carom thought experiment doesn't work, ask them to do a real experiment of hitting a moving ball several times, each time at right angles. (The ball has to be moving slowly for them to see the effects of force.) Another alternative is a moving toy car.

Teacher: Instead of someone hitting the striker again and again, imagine a beetle continuously pushing the striker in a direction that is perpendicular to whichever way it is going at that moment. How do you think the striker would move? Can you draw a picture to describe the motion?

For the teacher:

The idea is to help them see that the path of the striker in this case would be an arc. At a later point, this realization can be connected to the curved path of both projectiles on the earth and planets in the sky.



The big arrow with the beetle inside it indicates a force that continuously acts on the object. The direction of the arrow indicates the direction of the force at a given instant of time.

PART IV

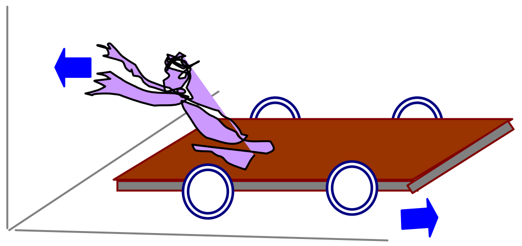
This section is not worked out yet: it is just a set of initial ideas on how do get students to come up with the equivalents of Newton's second and third laws.

Idea 1: Get the children to push:

- the same object (carom striker, ball) with varying forces.
  They should be able to see that the greater the force, the greater the speed.
- different objects with different weights but with the same force.
  They should be able to see that the greater the weight, the less the speed.

They should be able to come up with a law that approximates Newton's second law: the speed that a force produces on an object increases when the force increases, and decreases when the weight of the object increases. (They may not be able to understand the concepts of mass and acceleration yet.)

Idea 2: Find something with three or four wheels such that someone can sit on it and it moves easily when we give it a push (e.g., a tricycle, a push cart, …) Place it near a wall and ask one of the children to sit on it. Ask the child to give the wall a sudden push. Observe what happens.



The cart moves in the direction opposite to that of the child's pushing. Ask the children where the force that moves the cart came from. Get them to explain this. And they might come up with something similar to the idea of the wall exerting a force on the child-and-cart. Ask them for a general law, without mentioning people and wall. (Third law: To every action, there is an equal and opposite reaction.)

Another possibility: place a marble on a table. Let it be hit by another marble that is moving. What happens? The marble that is hit moves in the direction of the moving marble, but the moving marble slows down or starts moving in the opposite direction. Get the children to propose a law to explain this.

It isn't necessary that what the children come up with is exactly what Newton came up with. (It would be foolish to expect a school children to come up with $F = ma$) What we are looking for is a close enough variant, in their own words.

PART V

Teacher: Let us do another experiment. Observe the results.

Experiment: The teacher places a coin on the table, and flicks it with a finger, as when playing caroms.

What do you see?

(Children observe that the coin moves.)

Teacher: Coins are not living things, and our principle says that non-living things do not move unless there is a force that makes them move. Is the principle wrong?

(Most likely the children would say "no".)

Teacher: If our principle is right, then there must have been a force acting on the coin. What do you think that force is?

(Children respond. They would probably say that you hit it with your finger.)

Teacher: Okay, let us do another experiment. Observe.

Experiment: The teacher holds a coin in front of the students, and drops it.

Teacher: Did the coin move?

(Children respond. "Yes.")

Teacher: Did I exert any force on it?

(Children respond. "No")

Teacher: Right. It moved, but I didn't exert force on it. So we have two conclusions to choose from:

either I: There is no force that makes the coin move, so our principle is wrong.

or II: There IS a force acting on the coin that makes it move, so our principle is not wrong.

Which one do you choose?

For the teacher:

Activity: If they choose option I (which means rejecting the general principle in part I), ask them how they would explain the contrast we observed earlier. One way of saving the older principle from what looks like a counterexample is to revise it as:

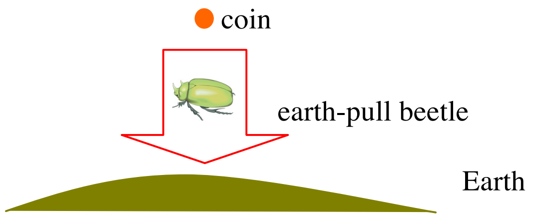
Non-living things do not move unless (i) there is a force that makes them move, or
(ii) it is dropped from above.

Do we really need the second clause? Even if we use it, how do we explain the fact that when dropped from above, an object goes down, not sideways or up, and in a straight line, not a zigzag one?

Suggest to students that we try option II, to see if it gives us a better alternative. What could possibly be the force that makes things go down when dropped?

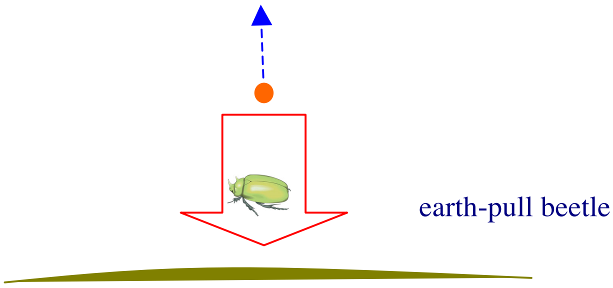
Do a few experiments with magnets to show that iron moves towards a magnet. Once we establish the idea of **attractive** force, nudge them towards the idea of "earth-pull" as the force that makes things move down when dropped. Earth-pull can later be expanded as "gravity".

Teacher: Remember our beetle who continuously pushes the striker perpendicular to the motion of the striker? Suppose we think of an invisible beetle that pulls everything towards the earth; let's call it the 'earth-pull beetle'.



Let us test the earth-pull idea. Suppose we are in outer space and we throw a coin away from us. If our principle is correct, then we should observe it moving away from us in a straight line in the same direction forever, right?

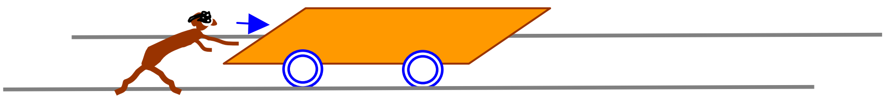
Now suppose we are standing on earth and we throw a coin straight up into the air, away from us, like this:



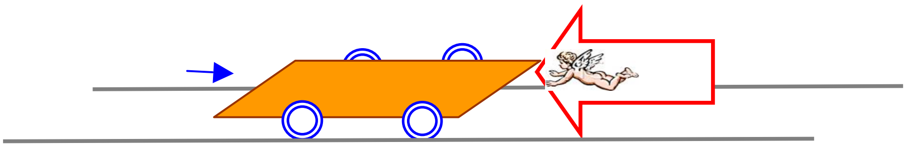
Teacher: What do you think would happen?

For the teacher:

Check if the children can see that the coin moving upward would gradually slow down till it comes to a stop, and then it would start coming down. If they can't see it, ask them what would happen if someone pushes a four wheel buggy on a rail road, like this:



And once it starts moving, a little angel continuously pushes it in the opposite direction:



They should now be able to see that the buggy would gradually slow down, stop, and start moving in the opposite direction. They can now extend this to make the right prediction for the earth-pull beetle's action on the coin.