

IT'S DYNAMIC !

The relation between motion and force

YOUR NAME:



1 Teacher Supplement

INTRODUCTION TO DYNAMICS

Objectives and Resources

Lesson Objectives: Learners should be able to:

5.0 Broad domain appreciation

5.1 State that dynamics is an explanation of how motion and forces relate.

Lesson Resources:

Notebooks/pencils/colored pencils

Assorted demo supplies:

Basketball

Blue Carts (1 per teacher)

Whiteboards (as ramp, one per teacher)

Bricks (4 per teacher)

Bowling Ball

Fancart

Color Coding:

BLACK: general text (**BOLDED** for essential points)

BLUE: action notes for teachers

GREEN: student inputs - spoken, written, drawn (students may fill in as they go)

RED: *outline topic and approximate timing*

Lesson # 1 - [-20 min]

Let's stand up, and move a little... take a stretch after all that writing... [Students stretch etc.](#)

WELCOME to "Way To Go" Summer Science. Let's think about **motion**. What are some different ways things can move? Feel free to use your arms and hands to demonstrate motions. [\[Get examples from kids\]](#).

Motion is everywhere around us and it's very **important** in our lives. It can range from very simple to very complex. On page 1 we have a colorful picture to remind us of how **many different ways** things can move. Let's look at **various types of motion**... and describe and classify them.

Can you point to two of these pictures that show the same type of motion? What do these have in common? [Elicit several student examples of common elements of motion and guide toward including](#) *at rest *steady motion (slow/fast) *changing motion (speeding up, slowing down) *straight line motion *curved motion

To summarize, we can look at these examples and see objects not moving (**at rest**), objects moving along at the same speed, whether slow or fast (**steady motion**), and objects speeding up or slowing down (**changing motion**). [\(Teachers may write these types of motion on a transparency of Page 1, and students may copy\)](#)

I have a basketball here [\[holding it still\]](#) Is there any motion?...Ok, so we can say the ball is *at rest*. Can you suggest ways that I can make this ball move? If you have ideas of how it could move, tell me what to do with it, and show me with your hands the path it will take. [\[elicit student ideas and demonstrate... roll in straight line motion, drop the ball in straight line fall, bounce or toss in curved motions\]](#)

From everyday experience, we are familiar with many types of motion, but for this class, we are going to **focus on straight line motion**.

What we really want to explore is **WHY DO OBJECTS MOVE THE WAY THEY DO?** Do you have some ideas? [\[Get student ideas; can demo with the ball again. What makes the ball roll or drop in a straight line? What makes a golf ball or a train move as they move?... aim is to have students bring up the idea of "force"; they may also bring up "push" and "pull" and "gravity." This will be topic of lesson #2... but the idea is how motions relate to FORCE \]](#)

So, it seems that there is a **relationship between the motion of an object and the forces** that are acting on it. This is the domain of DYNAMICS ... **HOW MOTION IS RELATED TO FORCE**. [\(students fill this into the blank line at the bottom of page 1... and write FORCE in the blank on the title page above Newton\)](#)

It is important to understand why and how everyday objects like **basketballs** and cars move as they do. Over the next several days we will be looking at different situations and objects, exploring what is happening, and trying to understand why.

And of course, we will all get to look at and experience the motion of the HOVERCRAFT that the famous scientist **Isaac Newton** is “riding” on our cover.

Scientists (like Isaac Newton) have been studying how and why objects move *for centuries*. We'll just spend the next two weeks doing so. The complicated principles of **dynamics** are now so well understood that we have launched spacecraft from earth and made them travel through a complex motion path through space, and land gently at a chosen spot on the moon ... so that human beings have been able to explore the moon in person! We have sent out **space probes** to investigate Mars and the other planets as well.

In science we don't start by studying the most complicated motions we see around us. We'll start with the simplest cases, like an object **at rest** or **moving in a straight line** ... and we'll consider how these simple kinds of motion relate to forces acting on the object.

After that, we can begin to understand the more complicated situations. You might be able to accomplish even more amazing new feats in science and engineering someday, if you learn a lot about Dynamics!

FROM THE EVERYDAY...
TO THE AMAZING

From a basketball ...



... to a space probe



Motion can become complex ...

... but we'll start simple

THE GOAL IS TO ENJOY LEARNING...

- 1) ...that "dynamics" is an explanation of how motion and forces relate
- 2) ...Newton's 1st and 2nd laws of motion
- 3) ...how to apply basic laws of "Dynamics" to answer questions, explain new situations, and solve problems

Have Fun!

2 Teacher Supplement Force and Net Force

Objectives and Resources

Lesson Objectives: Learners should be able to:

1.0 Forces

- 1.1 State that a force is a push or pull by one object on another at that moment.
- 1.2 State that some forces act by contact, others at a distance, and give examples.
- 1.3 Measure forces in units of Newtons, using spring scales.
- 1.4 Add forces in the same direction and subtract forces in opposite directions, to get the net force, including a net force of zero in the case of balanced forces.
- 1.5 Represent forces on an object in force diagrams.

6.0 Scientific inquiry objectives

- 6.1 State that scientific investigations begin with a question.
- 6.2 State in own words that evidence is required for accepting a scientific claim

Lesson Resources:

Notebooks/pencils/colored pencils/pencil pack

Basketball

Blue Carts (1 per group)

Sandpaper (1 notebook size paper per group)

Masking tape (1 per group)

Whiteboards (1 large per group)

Balloon pucks (1 per group, couple spares) Straws (1 per person, hand out at appropriate time)

Magnets (plastic encased wands) (4 per group?)

Magnets (teacher demonstration, push without touching)

Weights (2 N) (4 per teacher)

Lab scales - 2 x "20 Newton" scales per teacher, Welch Scientific, Skokie

Wood ½" dowel rods (1 per group, plus 2)

Spring scales, 20 Newtons (2 per student group, plus 2)

Meter sticks (1 per group) Cord/string

NOTE: WORD WALL pieces may be displayed as needed

COLOR CODING:

BLACK: general text (**BOLDED** for essential points)

BLUE: action notes for teachers

GREEN: student inputs - spoken, written, drawn (students may fill in as they go)

RED: outline topic and approximate timing

Lesson # 2 - [~ 70-75 min]

(Force ~10 min)

What did we do yesterday at the end of the day? What did we talk about?

[teacher elicits...] That's right, we talked about **motion**... slow, fast, steady speed, changing speeds, at rest....straight lines... curving motion... many kinds! That led us to the question of **why do things move as they do?** We proposed that the motion of an object is related to the **FORCES** acting on the object ... next we'll **explore** this relationship.

We begin by paying closer attention to the idea of **force**. What **IS** a force, anyway? Gently apply some "forces," and record your actions in your notebook... [as in green]

"What kind of things are we doing as we apply forces?" Does anyone have a simple way to describe what we mean by force? [Through discussion, teacher leads students toward a simple **generalization**, defining **FORCE** as a **PUSH** or a **PULL on an object by another object** and then states/writes this on transparency, students **COPY** in their notebooks]

So far we have lots of examples of forces ... let's try one more. You have a blue cart at your table. **Apply force to it in any way you can think of.** Go ahead.

Teacher walks around and asks kids to demonstrate **HOW they applied a force.**

So we see that you can do a variety of things

[hopefully! ... otherwise teacher applies forces several ways

Possibilities: elicit or quietly demonstrate **all of these four**, if not volunteered

1__Push directly down on the cart (toward the table!)

2__Push on cart with two hands from opposite sides (squeezing it!)... or from top to bottom

3__Push a blue cart (or pull a blue cart) along continuously ... (keep touching) **VERSUS**...

4__Push a blue cart (or pull) momentarily... and watch it roll on its own]

Let's look closely at these situations... When we push **down** on a cart [do this (1) without moving it] Am I applying a force to the cart at this moment? **[YES!!]**

[next, remove your hand from cart] How about now? Am I applying a force to the cart at **this** moment? **[NO!!!]** [Repeat this process squeezing the cart between your hands (2) without moving it]

Let's check another kind of situation... as I push/pull this cart along the table [do this (3) with continuous contact] ... am I applying a force to the cart **NOW?** at **THIS** moment?

[YES] Now, I give this cart a push... and let it roll [it rolls away and **AS** it rolls teacher asks...] am I applying a force to the cart **NOW?** at **THIS** moment? **[NO!! but if they say YES, we ask "How can my hand be acting on the cart when it is not even touching the cart? (MAGIC?)]** Remember that objects apply forces to other objects. After the cart is out there on its own, away from the hand, the hand can no longer affect it. ...

SUMMARY: Pushes and pulls from touching - which we call "Contact" forces - can only be acting **WHILE** there is touching/contact.

2 - FORCE AND NET FORCE

DEFINITION OF "FORCE"?

Applying Forces...

Question: What *is* a force?

EXAMPLES... pushing a chair, a person, lifting a weight, pulling an object... etc.

Classroom definition of FORCE: a push or pull on ane object by another object

Clarification ...

the presence or absence of force :

FORCE MAY OR MAY NOT BE ACTING ... at a given moment

(Forces can act by contact ~ 10-15 min)

So we've seen that forces can act **by contact** [copy onto page 2... next an application]. Like when I kick this ball. [do this] After contact, as it rolls away, is my foot still applying a force to the ball? **NO** What's going on with the ball now?

Well, I have a thought experiment for you regarding this basketball. Scientists sometimes imagine experiments that they cannot actually conduct. Close your eyes and imagine an empty room that is so big that when I kick this basketball it could roll without ever hitting anything else. Would it ever stop rolling? [Pause for student responses, but no conclusions yet]

Students test: Let's come back to reality and try a test. On your tables you have a whiteboard, some sandpaper, and a balloon puck. [no straws yet, so no balloon inflations yet] Try giving a little push on the balloon puck across the whiteboard, and then a similar little push across the sandpaper. Compare how far/easily they move. [Now pass out straws] Inflate the balloon and conduct the simple test on page 2 for all three surfaces. Record your findings... [green!]

So what is it that causes the puck to move differently on these surfaces? [Pause for student responses, elicit ... smoothness, roughness, FRICTION!!!!].

That's it, **FRICTION---** the puck was touching your hand only at the start, but it was touching the surface the whole time!

Does this help us answer the question in our thought experiment about a basketball in a huge room? [Pause for student responses] Yes, friction will eventually slow the ball to a stop.

SUMMARY: We have uncovered another touching/CONTACT FORCE ... **FRICTION** ... which affects motion, is all around us. So we'll keep this in mind as we study force & motion.

(Forces can act at a distance ~ 5 min) We've been talking about contact forces. Is that the only way that forces can act? Can a force ever act without objects touching each other? [Pause for student responses... if they bring up magnetic force and gravity... great]

In your supply box, you have some magnet wands... get them out and play with them a bit.

What do you FEEL? Pushes and Pulls!! Even without the magnets touching? **YES!**

[Teacher can demonstrate on board, magnets pushing magnets with no contact.] So, we observe that magnetic forces can act with no contact, without touching.

Any other forces that can act without touching? [pause for student responses, whether or not they said "gravity" you can bring out the basketball and let it drop]. What causes this ball to move when I take away the CONTACT FORCE of my hand? (no more contact, yet it started moving!!) [the pull of Gravity] Does there have to be contact for this force of gravity to be acting? **NO** What can we INFER? GRAVITY too, can act **without contact**... and we say that it can act **AT A DISTANCE** ... same thing for magnetism, it can act at a distance

SUMMARY: notice that we have found that forces can act either

BY CONTACT or **AT A DISTANCE** (fill in the blanks on worksheets)

(Describing forces ~ 5 min)

FORCES CAN ACT:

1) _____ by contact _____

Testing movement on different surfaces:

Rank the amount of movement on each surface (same applied force):

- 1) *very little* movement
- 2) some movement
- 3) most movement

puck on whiteboard _____ 2) SOME MOVEMENT _____

puck on sandpaper _____ 1) VERY LITTLE MOVEMENT _____

puck on air cushion _____ 3) MOST MOVEMENT _____

We discover that... _____ FRICTION is another example of a contact force
(that affects movement) _____

Question: Can a force act without contact? Ideas? Examples?

magnetic forces

gravity

FORCES CAN ALSO ACT:

2) _____ at a distance _____

If you are holding a ball in your hand you can feel the downward weight of it, and even with your eyes closed you can feel the difference between a basketball and a bowling ball. [you may try this if you like] Do you think it's enough for scientists and engineers to see or feel differences in forces? What else might be useful or informative for completely describing forces and working with them scientifically? [Elicit the importance of "exactly how much?" (size/magnitude)... "how much of WHAT?" (units or labels)... "which way?"(direction)]

Scientists and engineers use three concepts when they work with forces...

magnitude, units, and direction [fill in blanks]

The **magnitude** of a force is its **size**... amount, quantity, how big. How do we tell how much? [elicit the need for instruments for "measuring"]

Yes, we measure **magnitude** or amount of force with instruments (**scales**) .

You are familiar with **force from gravity** as "**weight**." What units of force do we commonly use to measure "weight"? [PAUSE ...] Pounds! Right, but the standard unit used around the world, for the benefit of scientific communication, is the **Newton**, named after the guy on your front page.

[Teacher demonstrates using a 2 Newton weight and 20 N dial scale... then adds a second 2 N weight (to make 4 N force down).

Draw attention to the two different readings of force, and the fact that the direction is down (a force is pulling the scale hook down)]

(Drawing force diagrams ~ 10 min)

It will be helpful for us to **represent forces** on objects in some quick, visual way, a **FORCE DIAGRAM** ... which is often very useful in science and engineering. We'll keep it **simple** (avoiding unimportant properties of the object); let's just **draw a box** to represent the object. Draw along with me in your notebooks [we all draw a box!]

How about **showing a force on the object**? How might we show the force diagram for the weights you just measured? It pulled the hook down, correct? How could we show that? [elicit the idea of arrow for direction, and draw force as an **arrow down**...]

How about when you put **more weight** on the hook? How could you show a **bigger force** pulling down? [gather ideas... **longer downward arrow works!**]. We can also label the magnitude/units.

Now, instead of a mass pulling down on the scale, I will pull sideways on the scale

DESCRIBING FORCE...

Force has...

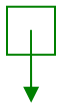
... Magnitude

... Units (like Newtons or pounds)

... Direction

"DRAWING" FORCE DIAGRAMS...

Represent force showing
magnitude, units, and direction



2 N (Newtons)



4 N

(to the left)... How do you think we should draw this?

[Teacher note: from student suggestions, draw simple force diagram for certain amount of Newtons pulling sideways...]

Now I'm going to pull in the opposite direction ... how should we show the force diagram?...

[Yes, we simply draw the arrow the other way]

And if I pull harder (more Newtons!), there is a bigger force?

[We simply draw a longer arrow]

SUMMARY: So the arrow is drawn in whatever direction the force is acting, and the bigger the force the longer we draw the arrow.

(How forces combine ~ 25 min)

So far we have been looking at **one force** acting on an object... is this the only possibility? **[NO]** Right, often there is **more than one force** acting. How should we handle that? **[DISCUSS and lead toward: forces combine into a resultant force that we call the NET FORCE. Students write this on page 4]**

The net force is a single force that could replace the combined forces and have the same effect.

So, when we say **NET FORCE**, we are "netting" a bunch of forces into a collection or combination of forces... sort of like a hairnet or a fishing net collects things.

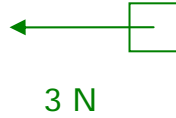
The last goal for today is to understand **how** forces combine into a net force. What can we do to answer the question of how forces combine? Scientific investigations center around questions. We may be able to form a theoretical hypothesis (a tentative claim) about how forces might combine... would that be sufficient? What do you suggest? **[Elicit that... then we'll have to test the hypothesis experimentally.]** Scientists rely upon evidence to support their claims.

There are different general cases to consider. An example of each is shown in the

One Applied Force

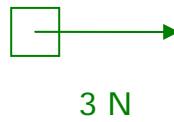
Force to the left

Diagram:



Force to the right

Diagram:



Bigger force to the right:

Diagram:



HOW DO FORCES COMBINE?

When more than one force is acting on an object... forces COMBINE...

and the result is called the NET FORCE

table on page 5. In the first case we wonder **how to combine two forces acting in the same direction into a NET FORCE**. Any ideas? [if needed assist toward **adding forces, using a scenario like 2 people pushing something in the same direction**]
Record our hypothesis [**ADD**] in the first column, and draw the appropriate NET FORCE DIAGRAM below it.

[NOTE: If short on time, run through all three hypotheses first, followed by all the testing, and then all the conclusions. Otherwise continue with testing of the first case, form and record conclusion. Follow with 2nd general case, and then 3rd]

At your desk you have a wooden dowel rod, a meter stick, some spring scales, and tape. This equipment can be used to test your hypothesis. On page 6 you will find a picture and instructions to help you set it up on the floor.

How can we test the addition hypothesis using this set-up? [We will use two forces, 4 N and 7 N, together and record deflection in cm. to the right... then use a single force of 11 N and see if the deflection is approximately the same] Go ahead and run your tests.

[Teacher, as needed, can explain and clarify the instructions on the paper...
Walk around checking and assisting student set-ups.]

NOW... MINDS ON, folks... are your experimental results consistent with your hypothesis? [Point out that this is pretty simple equipment so we don't expect extremely precise results.]



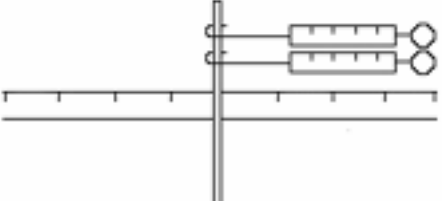
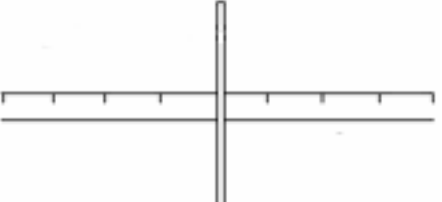
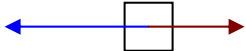
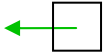
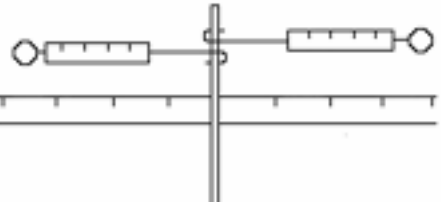
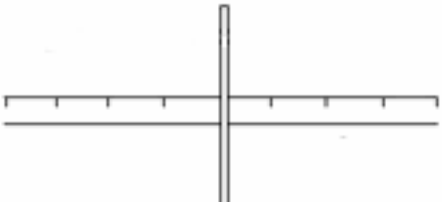


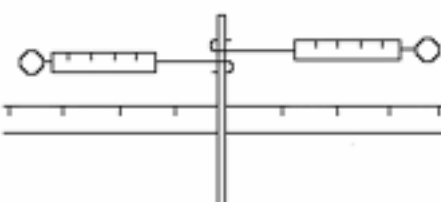
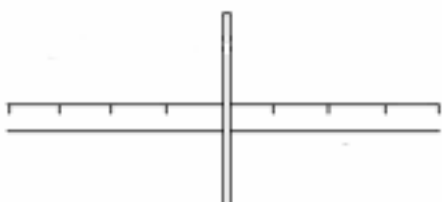
If so, we can conclude that our hypothesis was valid, and we can say (and write) that two forces applied in the same direction **ADD TOGETHER for the NET FORCE**.

[If you are doing the TABLE row by row, continue for the other two cases]

(Summary ~ 5 min)

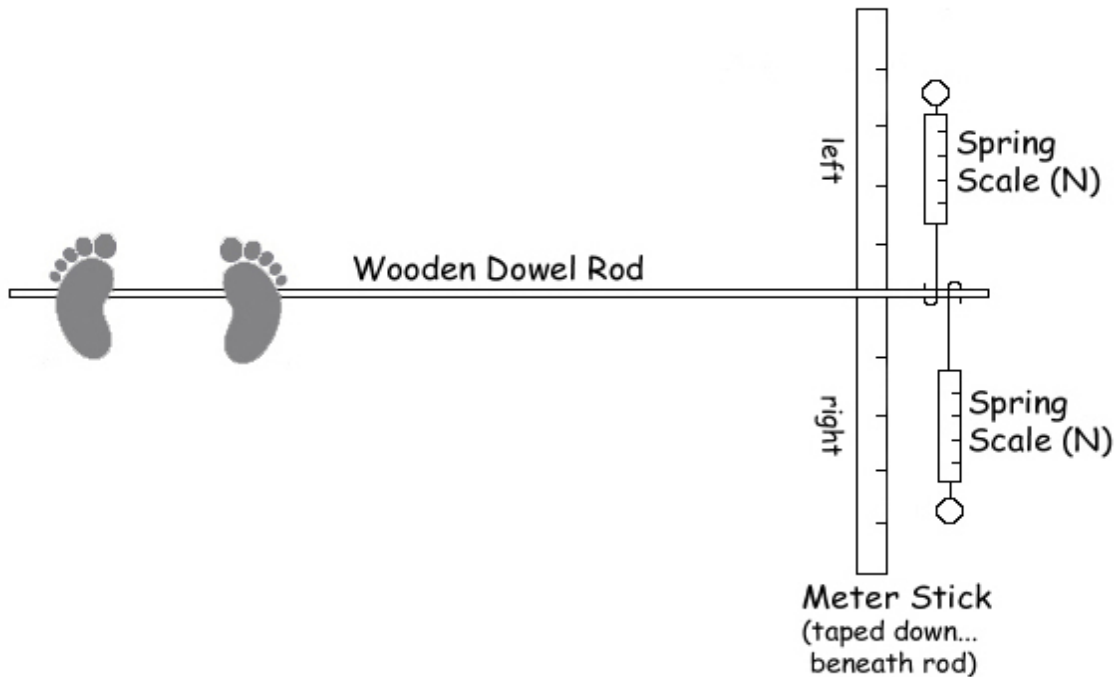
FINAL SUMMARY: Today we have learned that a force is a push or pull acting on an object at a given moment (now). Scientists and engineers work with forces in terms of magnitude, units (called Newtons), and direction. We also learned how to represent forces in simple force diagrams. When two or more forces act together on an object, we can think of them as combining into what we call the NET FORCE. To find the net force, we add forces acting in the same direction and subtract forces acting in opposite directions.

TABLE FOR DEFLECTION ROD ACTIVITY

HOW DO FORCES COMBINE?	TEST HYPOTHESIS - Measure Effect SIZE (cm.) & DIRECTION (L/R)	CONCLUSION
<p>4 N</p>  <p>7 N</p> <p>HYPOTHESIS <u>add</u></p>  <p>11 N</p> <p>NET FORCE DIAGRAM</p>	 <p>_____cm. to the left/right</p>  <p>_____cm. to the left/right</p>	<p>Two forces applied in the same direction. . . <u>add together for a NET FORCE</u></p>
 <p>7 N 4 N</p> <p>HYPOTHESIS <u>subtract</u></p>  <p>3 N</p> <p>NET FORCE DIAGRAM</p>	 <p>_____cm. to the left/right</p>  <p>_____cm. to the left/right</p>	<p>Two different forces applied in opposite directions. . . <u>subtract from one another for a NET FORCE</u></p>
 <p>7 N 7 N</p> <p>HYPOTHESIS <u>subtract</u></p>  <p>0 Newtons</p> <p>NET FORCE DIAGRAM</p>	 <p>_____cm. to the left/right</p>  <p>_____cm. to the left/right</p>	<p>Two equal forces applied in opposite directions. . . <u>are BALANCED and make ZERO NET FORCE</u></p>

Instructions for Deflection Rod Activity

- 1) Set up your equipment on the floor as shown in the diagram below:



- 2) Tape the dowel rod to the floor at the two foot locations, and have one person anchor the rod by standing upon it firmly over the two pieces of tape.
- 3) Tape the meter stick to the floor also, and be sure that the rod is at the middle position of the meter stick (undeflected) before each case of applying forces.
- 4) Forces are applied by attaching one or two scales to the free end of the rod.
- 5) When pulling spring scales, pull them slowly and smoothly (... at the same time, when two).
(Be careful not to pull the scales too hard; they may break.)

3 Teacher Supplement

SITUATIONS WITH NO NET FORCE - Part I

Objectives and Resources

Lesson Objectives: Learners should be able to:

2.0 Motion where there is no net force ('unforced' motion)

- 2.1 Given a situation where no force (or no net force) acts on an object, state or predict that it will continue its motion in a straight line or remain at rest.
- 2.2 Vice versa, given a situation of an object at rest or moving steadily in a straight line, infer that there is either no force or no net force on the object (i.e. any forces balance).

6.0 Scientific inquiry objectives

- 6.2 State in own words that evidence is required for accepting a scientific claim.

Lesson Resources:

Notebooks/pencils/colored pencils/pencil pack

Apple 1 per group

Bowling ball 1

Basketball 1

Hover puck 1 per group (charge in advance)

Tablecloth & crockery (3juice cans per group, 1 for teacher)

Pile of about 6 – 8 books

Sturdy plastic cups (1 per group)

Card to go on cup (1 per group)

Coins (nickels) (1 per group)

Hoop 1 per class

Bottle 1 per class

Wood plug and/or chalk pieces (several per class)

COLOR CODING:

BLACK: general text (**BOLDED** for essential points)

BLUE: action notes for teachers

GREEN: student inputs - spoken, written, drawn (students may fill in as they go)

RED: outline topic and approximate timing

Lesson # 3 - [~ 70-75 min]

(Review ~10-15 min)

We have been learning about force and motion. Force is a **push or a pull** on an object. Forces can act by **touching/contact** an object or **at a distance**.

Force has **magnitude** or size which scientists and engineers measure in **units** of Newtons, and force has **direction**. We learned to use **Force Diagrams** to represent forces, and that the **Net Force** represents **combinations** of forces.

Let's remind ourselves how to calculate and represent the **Net Force** in different situations. [Create some scenarios to fit at least the 3 (shown) diagrams of forces acting on an object... assign magnitudes in Newtons, and have student draw and calculate the Net Force. Refer to the Table from Lesson # 2 if needed]

So we have seen that we find the **Net Force** by **adding forces that act in the same direction, and subtract forces that act in opposite directions**. We saw a specific case in which even though there were forces acting on an object, the result was a **ZERO NET FORCE** (when two forces of the same magnitude acted in opposite directions). We might also have a ZERO NET FORCE when there are no forces acting in *either* direction.

So, there might be a **NET FORCE**, or there might be **ZERO NET FORCE** on an object. Our next goal is to learn about both situations, and how they relate to the motion of an object. First we will explore situations with **NO NET FORCE** on an object which might be at rest (zero motion) or which might be moving.

(NO NET FORCE - Objects at Rest ~10 min)

For **CASE 1** ... we are wondering what will happen when **NO NET FORCE** acts upon an object at rest.

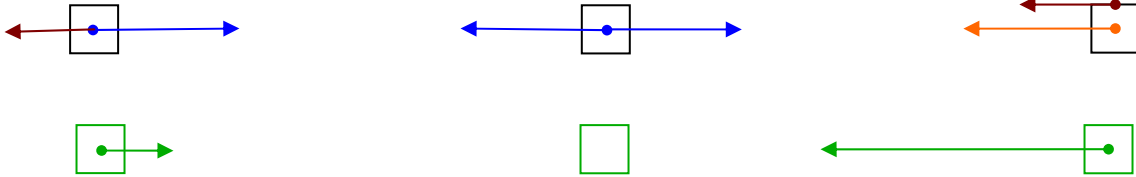
You have some objects at your tables. How will we explore this? Ideas? [Guide them toward starting with **objects at rest, and trying both ways of NO NET FORCE, i.e. no horizontal forces at all, or BALANCED forces (squeezing or pulling)**] Try it out, record your observations in your notebooks, then we'll discuss our findings [allow a little time... discuss]

So, we seem to have noticed that no matter how we reached **ZERO NET FORCE**, **objects at rest remained at rest**. Could we have made this claim from observing only the apple? [ask about/reinforce why sufficient evidence is important to support claims]. But you have gathered additional examples to support the claim that objects at rest tend to stay at rest.

How might we represent this case in a diagram? [take ideas... leading toward...] ... Right, we don't draw a force arrow, simply because there is no net force acting on it! [Draw the simple box]

3 - SITUATIONS WITH NO NET FORCE - Part I

REVIEW OF FORCE & NET FORCE -



EXPLORE A PARTICULAR SITUATION -

NO NET FORCE (net force is zero)

CASE 1 - OBJECT(S) AT REST



What happens when no net force acts on an object at rest?

it stays at rest

DIAGRAM?



Now let's record our claim at the top of page 2 [shown in green] ... and then see if it continues to apply in some more complicated situations...

(Interesting Evidence 20-25 min)

At your tables we have materials for doing three activities.

- 1) cloth with lemonade cans [no carbonation!]
- 2) stack of books
- 3) cup, card and penny

[Briefly explain how to do each one (as needed) then let students do the activity.]

[Afterward... Call on different groups to report on what happened in each particular case, and whether it provides additional evidence for our claim]

Did we find more evidence for our claim...?

[Note: Students may notice that these "tricks" only work well with a *quick pull*. If asked, you can simply explain that, the quicker the horizontal pull, the shorter the amount of time any (horizontal) contact/friction force is acting... *between* the tablecloth and the cans, and the cans hardly move]

From our observations, we can conclude that, **when there is no net force, objects at rest tend to stay at rest.**

If you think those are neat tricks, watch this...

[Teacher does the bottle activity - this takes practice! Students may try later: Balance hoop vertically atop bottle mouth... and balance chalk/plug standing upright atop hoop... knock hoop out from under chalk/plug so that it drops directly down into bottle.

[Conclude this "at rest" Case by discussing if and how this evidence supports our claim for what happens when objects at rest with no net force acting.]

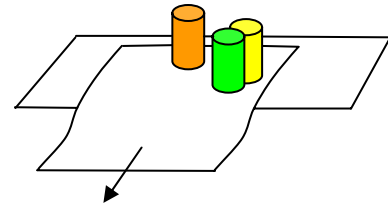
CLAIM - If no net force acts on an object at rest, the object . . .
_____ tends to stay at rest _____

SOME INTERESTING SITUATIONS -

Three challenge activities

1. Tablecloth and objects

Set the juice cans on the cloth. Pull the cloth "straight" out from the table *very quickly*.

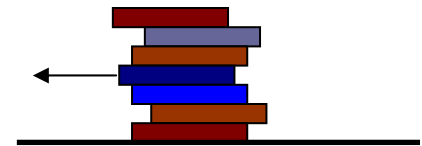


(A) What happens to the juice cans? _____

(B) Is this evidence for our claim? _____

2. Book Pile Activity

Stack up the books on your table, and then *very quickly* pull out one of the middle books from the stack.

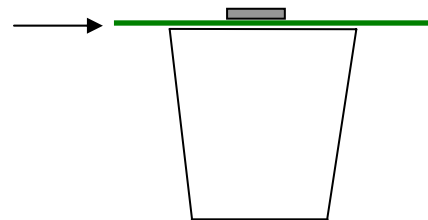


(A) What happens to the books above? _____

(B) Is this evidence for our claim? _____

3. Cup and Nickel Activity

Place the card on the cup and then place the nickel on top the card. Give the card a quick flick to the side with your finger.



(A) What happens to the nickel? _____

(B) Is this evidence for our claim? _____

CASE 1 - Conclusion: Evidence supports that...

...when there is no net force, objects at rest tend to _____ stay at rest _____

(Objects in Motion ~ 15 min)

For **CASE 2** ... we are now curious about what will happen when **NO NET FORCE** acts upon a **MOVING** object.

How can we **explore this**? Ideas? [With basketball in hand, lead students toward push/kick/strike the ball just to get it **moving** across the floor, as shown]

What do we observe when I send this **basketball** rolling across the floor? [do this, students can return it or try it... elicit the following] **even after I am no longer applying any contact force to it (no hand! no foot!), it still has the tendency to keep moving in a straight line.** [Students may suggest that it will eventually stop... discussion continues...]

Can we really satisfy the condition of zero net force with this rolling basketball? [Refer as needed to the thought experiment from yesterday, where we realized that...] The basketball is somewhat **rough**, right? So there is a **friction force** between the ball and the floor that will slow down the motion.

Our test conditions were supposed to have **NO NET FORCE**... how can we minimize the friction force from this rough basketball? [guide toward...] **we need something with a smoother surface... like that bowling ball you've got sitting there.** [show how well bowling ball tends to continue to roll in a straight line across the floor... students can send it back to you]

So, the bowling ball meets our conditions better than the basketball. Any other ideas of how we could minimize friction force? [Elicit the idea that the **balloon pucks** from yesterday had very little friction...] Right, we could use something with a **cushion of air** at the **contact surfaces**. Guess what we've got... **Hoverpucks!**

Tomorrow, you'll get to test these out yourselves, but for now, let's just try to describe what kind of motion we observe with a moving object that has **very little friction**, and therefore **virtually no net force** acting on it. [hoverpuck turned **ON**... and give it a push, in as long and flat an area as you can find, whiteboards are fine. **ELICIT THAT "the object will continue to move at a constant speed in a straight line"**] Let's record that in our notebooks at the bottom of page 3... by the way, why do you think we call this a tentative claim? [because we'd like more evidence]
[If you found it veering away from straight, you can discuss the need for a perfectly level surface, but you don't need to discuss gravity as the cause]

We can draw a **simple diagram** to show this case. Should we draw a force arrow? [**NO**] Right, we don't draw a force arrow, simply because (ideally) we are claiming that there is no net force acting on it. But this time, our diagram needs to somehow indicate that the object is moving in a certain direction. So we will show that motion by using a dashed arrow above the object. [Draw simple box with dashed arrow above... students copy]

(Summary & Application-10) Today, we found that in situations where there is **virtually NO NET FORCE** (at least in an ideal example!)... an object at rest tends to stay at rest, and a moving object tends to keep moving in a straight line at a steady speed.

We know how to draw simple diagrams that depict these situations, and tomorrow we will do an investigation of objects in motion with no net force acting upon them. We'll also get out a giant version of the hoverpuck, upon which *you may ride*.
[DO APPLICATION... plus, if time, students can do demos (hoop drop...), build bottle rockets, etc.]

CASE 2 - OBJECT(S) IN MOTION



A basketball is rolling to the right...



A bowling ball is rolling to the right...



A hoverpuck is moving to the right...

What happens when no net force acts on an object in motion?

_____ the object tends to stay in the same motion _____

DIAGRAM?

-----> *dashed arrow shows the motion*



TENTATIVE CLAIM - If no net force acts on a moving object,
the object _____ tends to keep moving at a
steady speed in a straight line _____

(to be continued...)

APPLICATIONS -

Bowling ball rolling down the alley

1) In a bowling alley you start the ball rolling and then it keeps going steadily toward the pins. Which is the best statement about the ball while it is moving steadily?

- A. All objects naturally keep going, unless there is an opposing force to stop them.
- B. The floor of the bowling alley must slope slightly downward for the ball to keep going.
- C. The force you applied to start the ball moving continues to act on it while it is moving.
- D. There is still a forward force on the ball while it is moving, acting at a distance now instead of by contact.
- E. The ball is attracted to the pins at the end and repelled from your hand.

Explain your answer.

2) At an instant while the ball is rolling, and there is no friction, what is true of the horizontal forces on it, if any?

- A. There are no horizontal forces on the ball.
- B. There is a forward force on the ball.
- C. There are forward and backward forces, which are equal and opposite (balance).
- D. There are forward and backward forces on the ball, the forward being greater.

Explain your answer.

Boy and dog tugging a shoe

In the bowling alley a boy and a dog are both tugging on a bowling shoe. A girl says that the shoe is not moving one way or the other. Which one of the following is true in this situation?

- A. The shoe could never remain at rest with both of them tugging on it.
- B. There are no forces acting on the shoe.
- C. The only force on the shoe is due to gravity.
- D. The forces due to the boy and dog are equal and opposite.
- E. The dog applies a bigger force than the boy.

Explain your answer.

4 Teacher Supplement

SITUATIONS WITH NO NET FORCE - Part II

Objectives and Resources

Lesson Objectives: Learners should be able to:

2.0 Motion where there is no net force ('unforced' motion)

- 2.1 Given a situation where no force (or no net force) acts on an object, be able to state or predict that it will continue its motion in a straight line or remain at rest.
- 2.2 Vice versa, given a situation of an object moving steadily in a straight line, infer that there is no net force on the object (i.e. any forces balance).
- 2.3 For a moving object, given distance traveled and time taken, be able to calculate speed, including units.

6.0 Scientific inquiry objectives

- 6.1 State that scientific investigations begin with a question.
- 6.2 State in own words that evidence is required for accepting a scientific claim.

Lesson Resources:

Notebooks/pencils/colored pencils/pencil pack
Newton's poster (inquiry class - reveal each section after learning it)
Apple (1 for teacher)
Blue cart 1 per group
Juice can 1 per group
Bowling ball 1
Stopwatches (optional)
Hover puck 1 per group
Hovercraft & blower & battery charger 1 per class (charge in advance)
Masking tape to mark floor 1
Meter stick 1
Tape measure
Push scale (with handle) 1 per class
Calculators (1 per group)
Bright index cards or bean bags (to place on floor as markers, 2 colors - 5 of each)

COLOR CODING:

BLACK: general text (**BOLDED** for essential points)

BLUE: action notes for teachers

GREEN: student inputs - spoken, written, drawn (students may fill in as they go)

RED: outline topic and approximate timing

Lesson # 4 - [~ 70-75 min]

(Review ~10 min)

We have been exploring situations where there is no net force acting on an object, whether the object is at rest or moving (and we studied these two cases).

When the object is **at rest**, and no net force acted upon it, we found that the object tended to stay at rest.

[Note: you might ask what we did that showed this tendency to stay “at rest.” Remind them that we can show this situation and case in a simple diagram as shown]

Based on qualitative evidence, we also proposed a tentative claim that when there is no net force acting on a **moving object**, it tends to continue to move in a straight line at a constant speed.

[Note: you might ask what we did that showed this tendency to “keep moving.” Remind them that we can show this situation and case in a simple diagram as shown, still no force arrow but has a dashed motion arrow]

Interestingly, we can interpret our claims two ways. What might you infer about the **NET FORCE** in a situation where something is at rest and remaining at rest, like this apple, or this blue cart? **[pause... Elicit that you can infer that the NET FORCE is ZERO].**

What might you infer when you observe that something is moving with a constant speed in a straight line? **[pause... Elicit that you can infer that the NET FORCE is ZERO].**

Recall that there are **two ways** that the **net force can be zero**, either there is **no force acting** on it, or all the forces are **balanced**.

There are plenty of examples of Case 1 ... if we look around us, lots of things are at rest and remaining at rest.

But let's try to think of some **examples of CASE 2**.

[gather some ideas from the kids, additional suggestions are shown in green]

(CASE 2 - Objects in motion)

Notice that in our explorations and examples so far, like the bowling ball, we've relied on qualitative observations, what it “looks like” to us. The bowling ball “looked like” it continued to move at about a constant speed. Would that be good enough evidence for scientists or engineers? **[NO]** What would they do to develop and support their claim further? **[Elicit need for quantitative evidence that speed remains the same - measurements]**

4 - SITUATIONS WITH NO NET FORCE - Part II

REVIEW -

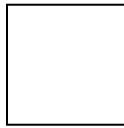
Our claims so far:

If no net force acts on an object . . .

CASE 1 an object at rest will stay at rest,



CASE 2 and a moving object will continue to move
at a constant speed in a straight line.



...more on CASE 2:

Try to suggest some examples of moving objects with “no net force” from your experience in everyday life:

coasting on a road bike (but has some friction in real life)

ice skating

car sliding on icy road

rollerblading

air hockey (very low friction!)

seeing astronauts floating in space

etc.

(Bowling Ball ~20 min) So that's what we should do next. We'll take some measurements and see how they relate to our qualitative observations from yesterday.

So what exactly is it we want to find out? Scientific investigations begin with a question...right? What is **our question**?

[Get student ideas on good questions... guide to a question similar to:

"DOES A BOWLING BALL CONTINUE TO MOVE AT A CONSTANT SPEED?"]

What is **speed** anyway? And how will we measure it?

[pause for student comments; show bowling ball go down the track... through discussion clarify **speed as simply distance traveled over time interval**, which can be measured in units like miles per hour, meters per second, etc....Elicit the **need to take measurements of distance traveled over successive equal time intervals.**]

[NOTE: The bowling ball track/surface should already be prepared. Select two students to be runners on either side of the track (could use name sticks to choose students) They each should have a set of markers. Explain that they only place their marker exactly where the ball is on the count of THREE. **Practice** several times – **Run trial** ... ask why we have two runners/markers? Lead students toward idea of minimizing experimental error in measuring process (reaction time, judgment, etc.). **Share data** among all students (whiteboard?). Students calculate speeds and report the three average speeds to be recorded on your whiteboard.

Have the students answer the questions in groups and then go over as a class.

Discuss if our findings support our earlier tentative claim of steady speed.

If the speed values vary quite a bit you can ask the students whether this invalidates their prior claims or are there possibly other explanations.

ONE possibility: perhaps the **measurements need to be more accurate.**

ANOTHER: **if the speed decreases, then there might be some friction after all...**

So, maybe the bowling ball actually did (or would) eventually slow down a bit, right? In day two, we talked about that **contact force of Friction** that is with us all the time.

Let's continue our familiar "thought experiment." Close your eyes. I imagine that we are in the longest bowling alley in the world. The lanes are so long that we can't even see the pins at the end. Now imagine that the surface is super-slick ice. We start the ball rolling along the lane toward the pins — which we can't see because they are so far away! Is there anything to stop the ball? [pause for responses ... **NO!**] With the ice there is almost no friction so the ball will keep moving until it is out of our sight. Can you imagine the ball disappearing into the distance? It will roll forever or until **SOME FORCE** stops it.

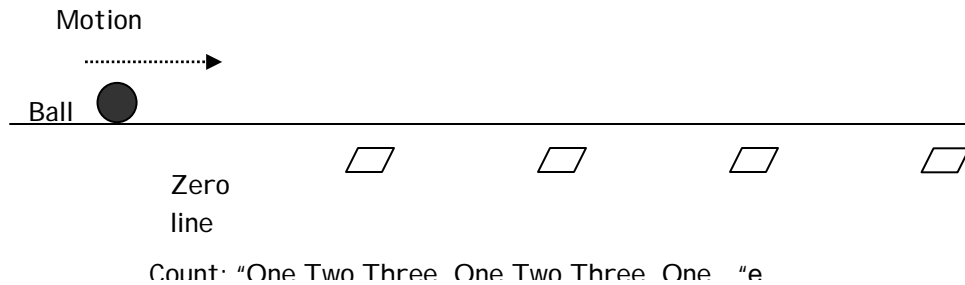
Open your eyes! Back to the real world! Can we get rid of friction completely? [**No...**] but what about reducing friction ever more? Ideas? [**we can reduce friction quite a bit with a hoverpuck that rides on air.**]

MEASURING THE SPEED AT DIFFERENT STAGES

RESEARCH QUESTION: DOES A BOWLING BALL CONTINUE TO MOVE AT A CONSTANT SPEED?

Roll a bowling ball along a smooth track/surface, and measure the distance it travels in the first 3 “seconds,” the next 3 seconds, and the next 3 seconds, to find out whether its speed is constant.

Method



1. Gather around the track.
2. A student rolls the ball. At the moment the ball passes the starting line, the teacher calls out one, and counts off “seconds,” i.e. “one, two, three, one, two three, etc. Students should count with the teacher, helping keep the beat.
3. At each third count, students on both sides drop markers exactly where the ball is at that moment.
4. Measure distances traveled (distance between markers) and calculate the speed for the three stages.

DATA TABLE for BOWLING BALL			
	Distance traveled in first 3 “seconds”	Distance traveled in next 3 seconds	Distance traveled in last 3 seconds
Measure 1			
Measure 2			
Average* of distance measurements			
Speed = $\frac{\text{Distance}}{\text{Time interval}}$			
<p>Did the bowling ball move at a constant speed?</p> <p>Does this provide more evidence to support our claim?</p> <p>Why or why not?</p>			

(Hoverpuck activity ~10min.)

So now we'll explore in the same **quantitative** manner with the hoverpuck ... with the goal of **reducing friction** to the point where the **actual NET FORCE** is even closer to **ZERO**, closer to one of the conditions of our claim.

[class effort, unless there is a way to have each group of students run one good trial with the hoverpuck moving rather slowly on a smooth, even surface. Same manner as with bowling ball]

[**COMMENT**: if teacher chooses, there's no real need for speed **calculations** again, because we saw that the distance traveled per equal time interval is proportional to speed – may just compare distance traveled]

Have the **students answer the questions** in groups and then go over as a class. Discuss if our findings support our earlier tentative claim of steady speed.

(SUMMARIZING OUR FINDINGS ~ 5 min)

For CASE 2, of an **object in motion** -

Conclusion: Both qualitative and quantitative **evidence supports our claim** that when there is **no net force** acting on an **object in motion**, ... [pause for student input...] **continue to move at a constant speed in a straight line.** [students record]

As we have seen today, **no NET FORCE** is needed to keep an **object moving** once it is going... it has a **natural tendency** to keep moving.


[when friction interferes or when the moving object bumps into something, there is then an opposing force that slows and stops the moving object — but if there is no opposing force, the object keeps moving.]

Also, recall that yesterday we discovered that an **object at rest** has a **natural tendency to remain at rest** . . .

SMALL SCALE - Hoverpuck experiment

MEASURING THE SPEED AT DIFFERENT STAGES ... with even *less* friction

RESEARCH QUESTION: DOES A HOVERPUCK CONTINUE TO MOVE AT A CONSTANT SPEED?

DATA TABLE for HOVERPUCK			
	Distance traveled in first time interval	Distance traveled in next time interval	Distance traveled in last time interval
Measure 1			
Measure 2			
Average of distance measurements			
Speed = $\frac{\text{Distance}}{\text{time interval}}$			

Did the hoverpuck move at a constant speed?

Does this provide more evidence to support our claim? Why or why not?

CASE 2 - Conclusion:

Both qualitative and quantitative evidence supports our claim that . . .

. . . when there is no net force acting on an object in motion,

the object will _____ continue to move at a constant speed

in a straight line _____

At this point we are confident that we have two strong claims regarding situations with no net force... what are those claims?

When no net force acts on an object, an object at rest will stay at rest, and a moving object will continue to move at a constant speed in a straight line.

Back in the 1600s, one of the greatest of scientists, Sir Isaac Newton, formulated this scientific law. It's very famous, and it's known as Newton's First Law of Motion.

[Put the poster of the First Law up on the wall]

A simple form of Newton's First Law is:

When NO NET FORCE ... NO CHANGE IN MOTION.

[Note: The term 'inertia' is often used to describe the tendency of an object to keep doing exactly what it was doing – to either keep moving or remain at rest. In everyday language we often say an object has a property of 'inertia', indicating that it doesn't naturally change what it was doing before – either its state of motion or its state of rest. Indeed, the first law is sometimes called the 'law of inertia.'

But, "inertia" does not need mentioning unless someone asks.]

(LARGE SCALE DEMO, in suitable location ~20 min.)

You have used the "hover pucks" . . . but we've got a bigger version that you can actually ride on! So... it's time for a ride *with the physics in mind.*

According to Newton's First Law, what should we predict about the natural motion of the hovercraft? **[when moving, it will tend to keep moving]** Let's check it out.

We'll have one person (at a time) sit on the hovercraft. They can control the on/off switch, and once they turn it on and get balanced (it'll be loud), we'll give them a push or a pull just to get them moving. After that, there should be virtually no net force acting on the "moving object" (remember how an air cushion minimizes friction!). Let's **look carefully** at what happens...

[Note: Do demo with teacher giving the push or pull. Do several times with different kids. **Pointedly discuss the fact that the object tends to keep moving at a constant speed in a straight line.** Also, have fun ☺]

(BACK TO ROOM... Application ~10 minutes)

[We have a summing-up Application to do on Newton's First Law... but if you are short of time the Application can hold till Day 5— discussion is planned for Day 5 anyway.]

Through our investigations we found evidence for two claims about the behavior of an object when no net force acts upon it...

When no net force acts on an object,
an object at rest will stay at rest,
and a moving object will continue to move
at a constant speed in a straight line.

THIS IS THE STATEMENT OF
ISAAC NEWTON'S
FIRST LAW OF MOTION

In other words, when no net force ... no change in motion.

LARGE SCALE DEMO
of
NEWTON'S FIRST LAW

Hovercraft ride (no force)

Prediction from Law: will move at constant speed, straight line

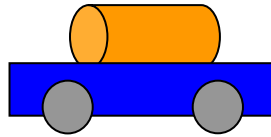
Observation: YES, it does



APPLICATION -

CART 'N CAN

Blue cart & juice can



TEST 1 -

If the cart is stationary and we suddenly give it a hard push forward, what will happen?

Why is this? Explain your reasoning.

Now try it. What happens? To the cart and to the can?

Cart moves forward suddenly, can stays at rest, and so falls off the cart.

Was your prediction right?

Was your reasoning good?

TEST 2 -

Get the cart moving at a steady speed with the can on it, then suddenly stop the cart. What will happen?

Why is this? Explain your reasoning.

Now try it. What happens? To the cart and to the can?

Cart stops suddenly, but can keeps moving, and so falls off the cart.

Was your prediction right?

Was your reasoning good?

So, using the cart 'n can, we can see both aspects of Newton's first law at work!
The 'at rest' aspect and the 'moving' aspect.

5 Teacher Supplement

Situations with NET FORCE: Part I

Objectives and Resources

Lesson Objectives: Learners should be able to:

3.0 Motion where a net force acts ('forced' motion)

- 3.1 Describe the effect of a net force on motion, i.e. that the object will speed up or slow down, depending on the force direction. Vice versa, given situations where an object is speeding up or slowing down, be able to infer that there is a net force and identify its direction.

6.0 Scientific inquiry objectives

- 6.1 State that scientific investigation begins with a question.
- 6.2 State in own words that evidence is required for accepting a scientific claim
- 6.3 Develop and defend a scientific claim based on evidence.

Lesson Resources:

Notebooks/pencils/colored pencils/pencil pack
Hovercraft (1 per teacher) & helmet (charge leaf blower in advance)
Bathroom push scale (1 per teacher)
Skateboard, with little friction (1 per teacher)
Blue sail-carts (1 per student group)
Black fan carts, battery powered (4 per teacher)
Hoverpucks (1 per group, plus 2 per teacher)
Spare batteries (AA)
Hair-blowers (1 per group)
Extension cords (1 per group)
Spring tube scales, 20 Newtons (4 per teacher)
Masking tape
Tape measure, 25 ft. (1 per teacher)
Cheap calculators (1 (1 group)
Bright index cards or bean bags (to place on floor as markers, 2 colors - 5 of each)

COLOR CODING:

BLACK: general text (**BOLDED** for essential points)

BLUE: action notes for teachers

GREEN: student inputs - spoken, written, drawn (students may fill in as they go)

RED: outline topic and approximate timing

Lesson # 5 - [~ 70-75 min]

(Review ~5 min)

Welcome to the second week of "Way 2 Go" Summer Science. Let's remember that the goal of this unit is to understand **how force and motion are related**.

What have we done so far? We started with the **concept of force**, and defined it simply as a **push or a pull** on an object. We described forces in terms of **magnitude, units, and direction**. And we represented forces in **force diagrams**.

When more than one force acts on an object, we learned how to **combine forces** into a **NET FORCE** by adding forces if they act in the same direction, or subtracting them if they act in opposite directions.

To study how force and motion are related we wondered about and explored so far situations without NET FORCE ... which are addressed by **NEWTON'S FIRST LAW**. Can you tell me what Newton's First Law says?

[Guide them to complete and summarize LAW as follows...]

"With zero net force, objects at rest stay at rest, and objects in motion stay in that motion... **NO CHANGE!!**

Can you recall how we developed Newton's First Law?

[you can illustrate showing hoverpuck - at rest, and in motion. You might ask why the hoverpuck was a particularly good object to be used...elicit the need to simplify, and satisfy as well as possible the condition of zero net force.]

(Generate new questions ~20 min.)

Ok, we found out already what happened when there is no net force acting on objects. What do you think we should explore next in our attempt to understand why objects move as they do?

PAUSE/ELICIT the need to apply a force to on object and observe its motion.

That's right, we'll ask the question of **"What is the effect of a NET FORCE on an object? (write the question on the transparency, students write it in their notebook)**

If this is our question, how should we go about answering it? **[PAUSE, with hoverpuck in hands]** .

Students hopefully suggest, if not guide them toward ...the need to apply a force to the hoverpuck, not only by an initial touch but rather by keeping pushing on it, and carefully observing its motion.

How can we apply a **constant force to the hoverpuck?** Suggestions?

Students may propose a variety of ideas ...fingers, possibly a leaf blower ...

Let's try it! (demonstrate yourself, and ask students to communicate their observations)...They may notice that force applied to a hoverpuck at rest...

Causes it to move in the direction of the force (speeds up from zero) (DRAW DIAGRAM as shown)

When applied to a moving hoverpuck, in same direction as motion...

hoverpuck seems to move faster and faster

5 – SITUATIONS WITH NET FORCE - Part I

REVIEW:

NET FORCE is the sum of the forces acting upon an object.

NEWTON'S FIRST LAW: With ZERO NET FORCE,
objects at rest stay at rest
and objects in motion stay in that motion .

NO CHANGE !!

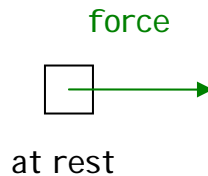
GENERATE QUESTIONS:

Research question: what is the effect of a NET FORCE on an object?

Initial exploration...

THE STORY OF THE HOVERPUCK...

Diagram:



Observation: starts moving in direction of force

Great, Let's try something else with this setup: Would someone please send the hoverpuck in my direction? [blow against the motion of the hoverpuck] What did you notice? It slowed down!

How is this case different from the previous one? Elicit that in this case we applied a force against the motion.

Ok, what can we infer from this experiment? Elicit ... force can be acting in the direction of the motion or against the motion, influencing how objects move.

At this point we have made some observations of how a force affects motion. Could you suggest a way to represent the story of the hoverpuck in simple diagrams? Guide students to complete diagrams and record the appropriate case observations.

Invite students to GENERATE TENTATIVE CLAIMS (HYPOTHESES) in regard to the relationship between force and motion, and elicit the need to TEST THESE HYPOTHESES by seeking supportive evidence.

In your bins, you have a blue sailcart and a hair-blower. How can we use these items to help us test the hypotheses? [or to help us answer our question? Keep the question in view...it is what guides the investigation] [get ideas from students]

Test 1. GUIDE TOWARD THIS DESIGN - switch on the hair-blower to high speed, and blow directly into the sail from a few inches away. Keep blowing on the sail from same distance as it moves, for constant force! [teacher can also use the leaf blower...it is cordless and teacher doesn't have to be so close to the cart...easier to keep same distance]

Test 2. (GUIDE TOWARD ... Same use of hair-blower, but this time we push the blue sailcart backwards with our hand, and then blow on it in the opposite direction of the motion)

Carefully plug the hair-blower into the electrical cord that you have near your table, (or teachers plug them in!) and set up the blue sailcart on the desk/floor/whiteboards. Clear a path ahead of your sailcart.

Students do each of the tests and record observations. Give time frame.

If time allows, you can do another demo/testing with the fancart:

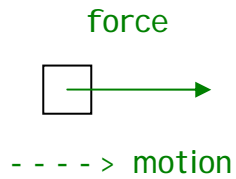
1st Test - turn on a black fancart, set it down, and let it go... [it speeds up]

2st Test - force against direction of motion ... turn on a black fancart, find out which way to set it down so that it would roll toward you. Then, put it down but push it away from you so that its initial motion is rolling away from you ...

Did you notice consistent patterns in all these qualitative exploration? What can we say about our hypothesis? Is it verified/confirmed? Do we have an answer for our question? YES

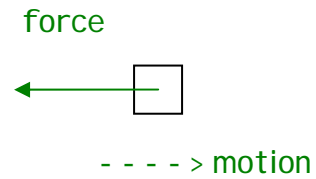
MORE TO THE STORY...

Diagram:



Observation: _____ speeds up _____

Diagram:



Observation: _____ slows down _____

GENERATE HYPOTHESES:

(1) net force in same direction as motion causes speeding up

(2) net force in opposite direction from motion causes slowing down

TESTS:

A) Blue Sailcart - blowing with constant force (hair-dryer)... low friction

Observation: _____ speeds up _____

Observation: _____ slows down _____

B) Fancart - battery-powered with constant force... low friction

Observation: _____ speeds up _____

Observation: _____ slows down _____

HYPOTHESES CONFIRMED?

YES

(Propose Law and Seek Evidence: ~25-30 min) Based on our observations, we can tentatively PROPOSE A LAW (rule) for motion with net force acting.

Teacher holds brief discussions, answers questions if needed, and guides the students toward the following law:

"An object with a net force on it will **change** its motion in the direction of the force ... *so that* the object will **speed up** if the force acts in the direction of the motion, and the object will **slow down** if the force acts in the opposite direction from the motion."

Ok, let's look back and reflect on how we got to this point? ... we started with a research question, and then we explored **qualitatively** (without taking any measurements) how objects behave when a net force acts on them. Our qualitative exploration led to ideas of how force influences motion... for instance, **it looked** to us like objects speed up when a force is acting on them in the direction of their motion.

Are we happy at the "*looks like*" stage in our understanding? We might be in everyday thinking, but what about in scientific thinking? What do scientists and engineers do to gain confidence in their ideas?

Elicit the need for a more careful investigation, with quantitative data to support their ideas. Further invite students to consider what data might be useful for the particular goals of this lesson, and how to collect the data.

Guide toward the following main idea: we need to apply a constant force on an object, and calculate its speed in successive time intervals.

With this main idea in mind, ask students what measurements are needed to calculate the speed?

Elicit the need of measuring distance traveled in equal time intervals, which implies the need of marking object's positions after equal time interval.

The "object" for our quantitative investigation will be a skateboard, with low friction wheels, and we'll put a rider on top.

Before we run our test, make a **prediction** based on the law we proposed.

[rider will keep speeding up when constant force is applied]

Skateboard time!

PROPOSED LAW:

"An object with a net force on it will _____CHANGE_____ its motion.

An object will speed up if the force acts in the direction of its motion, and

an object will slow down if the force acts in the opposite direction of its motion.

Now what?

Predict based on the proposed law...

Our quantitative test involves a rider sitting on a skateboard, being pushed with a constant force in one direction.

CAN I HAVE some VOLUNTEERS?

[Note: Pick a student volunteer to be the rider and one to be the pusher. You may either have the rider drop/place markers on the "beats" if they are able... or else have student "runners" who run alongside "marking" positions on the "beats."]

Recall that we decided we need equal time intervals for measuring speed... so the rest of you are needed to help us keep the beat. The rider will place MARKERS (index cards or bean bags), every 3 seconds while the skateboard is moving. We will clap "one, two, three, one, two, three" and so forth to keep the time. The "pusher" will take the bathroom scale, place it on the rider's back and push with a constant force of about 10 pounds on the bathroom scale. We will make several practice runs before we collect our data.

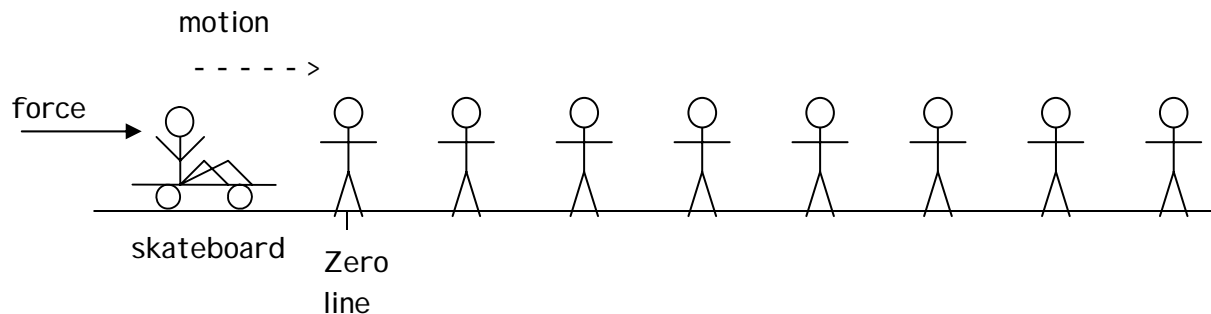
After data collection, we'll calculate the speed for each interval, and verify whether or not the speed keeps increasing (as we predicted). [Describe steps 1-6 as outlined on student page. Run 1 trial after some good practice runs. Help students to record the data and make calculations. Hold brief discussion on results. May include some discussion of "error" elements, even while making main point.]

... now that we have filled in our tables, do these results support our proposed law, which states that a constant force (applied in the direction of the motion) will cause an object to keep speeding up? **[YES!]**

Quantitative Exploration of the Effect of Force on Motion:

Skateboard Activity

Experimental Question: Does a skateboard speed up from a constant force?

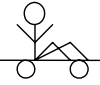


Method (practice and 1 trial)

We will push a skateboard & rider along a smooth floor with a constant force, and measure the distance traveled in each of three equal time intervals.

1. Choose a Start/Zero line on the floor. Teacher leads the clapping & counting: "one, two, three, one, two, three... Students clap/count with the teacher.
2. A student will sit comfortably on the skateboard, holding a stack of bean-bag MARKERS. The "pusher" pushes so that the scale reads about 10 pounds. The rider resists moving by *holding on to the floor to keep from rolling while . . .*
3. Rider will resist moving until he or she chooses a starting BEAT to "let go" on, placing the first MARKER.
4. The rider places a marker every time that beat/number is counted. The pusher must try to keep the scale reading 10 pounds.
5. Measure and record distances over each of 3 time intervals
6. Calculate average speed for each of 3 intervals (distance divided by time)...record in **TABLE**

DATA TABLE

	Interval 1	Interval 2	Interval 3
Distance Traveled (cm.)			
Time Interval ("seconds")	3	3	3
Speed = $\frac{\text{Distance}}{\text{Time Interval}}$ (cm./"second")			

COMPARE SPEEDS OVER THREE INTERVALS...

OBSERVATION: the "object"/skateboard speeds up from a constant force

DOES THIS RESULT SUPPORT OUR PROPOSED LAW? YES

You have just rediscovered NEWTON'S SECOND LAW!

Both qualitative and quantitative evidence supports our claim that . . .

A NET FORCE causes a **CHANGE in the motion of an object in the direction of the force**

(Apply the Law to predict... ~ 20 min.)

We have used fan carts, and blue sailcarts, and a skateboard to uncover Newton's Second Law,... if the law is true then it should apply to motion for any kind of situation when a net force is acting, even with a hovercraft. So we'll check this out with the **hovercraft as our final demonstration. [IF TIME PERMITS]**

FINAL CLAIMS:

Both qualitative and quantitative evidence supports our claim that . . .

A NET FORCE causes a CHANGE in the motion of an object in the direction of the force

THIS IS A STATEMENT OF
ISAAC NEWTON'S
SECOND LAW OF MOTION

In other words, net force ... change in motion.

What do we predict from **Newton's Second Law** about the **motion of the hovercraft** if we keep applying a **constant force** on it? [it will keep speeding up in the direction of the force]

So now we need a **VOLUNTEER** to ride on the hovercraft, wearing a **helmet**.
(Pick a student... others can ride afterward.]

We need someone to push gently with the scale, probably on the back of the rider, [test/practice beforehand] so that they have their hands free to hold and operate the ON/OFF switch. Who'd like to try to push with a constant force?

(Select someone to push **gently**. This person must understand that they will push in one direction with a constant force - about 5N - and that it is likely to involve the ability to walk faster and faster and faster, while reading a scale, and trying not to trip on a hovercraft. We also need to have a group of students "**spotting**" at the final destination of the hovercraft, in case the rider forgets to turn the switch off.)

Let's get set up... for this to work well, let's get our group to spread out along the path, with some of you down where we will end up so that you can help stop the hovercraft if needed. We also need someone to hold onto the hovercraft to resist the force of the pusher until we want to let it go (**ASSIGN** someone as the "holder")
OKAY... turn on the hovercraft's blower and start pushing with a small constant force. Think about Newton's 2nd Law as you watch what happens next.

(You might find an opportune moment to make a connection here to Newton's first law... What will happen to the rider if the hovercraft stops very suddenly?)

Does it obey Newton's Second Law and keep speeding up? **Definitely yes!!**

To **sum up** today's lessons, we have explored and confirmed Newton's Second Law in various situations, which states that a **Net Force** causes a **CHANGE** in the speed/velocity of an **object in the direction of the force**.

Many people **incorrectly believe** that a constant force will cause a constant speed/velocity... but as we saw, and as Newton's Second Law states, a constant force in the direction of motion causes an **increasing** speed in that direction.

LARGE SCALE DEMO
of
NEWTON'S SECOND LAW

Hovercraft ride (force in direction of motion)

Prediction from Law: _____ *will speed up* _____

Observation: _____ *keeps speeding up!* _____



6 Teacher Supplement

Newton's Second Law

How Motion Depends on - Force and Mass

Objectives and Resources

Lesson Objectives: Learners should be able to:

3.0 Motion where a net force acts ('forced' motion)

- 3.2 State that a larger force causes speed to change more rapidly, and apply to particular cases.
- 3.3 State that a larger mass changes its motion less (rapidly) in response to a force, and apply in particular cases

6.0 Scientific inquiry objectives

- 6.1 State that scientific investigations begin with a question.
- 6.2 State in own words that evidence is required for accepting a scientific claim
- 6.3 Develop and defend a scientific claim based on evidence.

Lesson Resources:

Fan carts (3 per teacher, 2 with full battery set, and 1 with 2 blanks)
Batteries (AA's and blanks)
Blue sailcars (1 per small student group... size of group?)
Weights (8 x 2N weights)
Hair-blowers (1 per small group)
Extension cords (care must be taken with these)
Long whiteboards (1 per student group)
Bathroom push scale with handle (1 reliable one per teacher)
Skateboard (1 per teacher)
Bright index cards or bean bags (to place on floor as markers, 2 colors - 5 of each)
Stopwatch (optional)
Tape measure
Cheap calculators (1 per group)

COLOR CODING:

BLACK: general text (**BOLDED** for essential points)

BLUE: action notes for teachers

GREEN: student inputs - spoken, written, drawn (students fill in as they go)

RED: outline topic and approximate timing

Lesson # 6 - [~ 75 min]

(Review ~10 min)

Greetings! Yesterday we started to look at **Newton's Second Law**, which refers to situations where a **NET FORCE** is acting upon an object. We used fan carts, blue sailcars, and a skateboard & rider (*show items, if possible*) to discover the law... what is the statement of this law? [**Net Force causes a change in the speed of an object**], in other words, it causes the object to **speed up or slow down**.

... but there is more to the story of Newton's Second Law. What other questions can we ask about the relationship between force and the motion of objects? [*elicit as shown on student page*] Today we will explore the factors/variables that affect the relationship between motion and force.

What are some things that might affect how much the motion or speed will change? Think about the blue cart for instance. (*PAUSE for student responses - quietly DEMONSTRATE with a basketball, a small tap versus a larger kick, or something like that ... then ... quietly DEMONSTRATE a small similar twack on two objects, like a basketball and a bowling ball, side by side*)... to either elicit or reinforce answers of **magnitude of FORCE & magnitude of MASS**.

Our scientific goal is to explore the **question** of "How does motion relate to force and mass?"... to better understand how the magnitude of force and the magnitude of mass will influence the motion of an object.

[**Control of variables**]...We now have a question that can be explored with a scientific investigation. We need to discuss how you might do such an investigation. If I have two balls (*basketball and bowling ball*), how could I study the effect of different masses (*in this case, different types of balls*) on the motion of the balls? [*see if students respond with "give them the same force" (give them both a push of the same amount, kick the same, etc)*]. Ask... what if I push this one a little (*bowling ball*) and kick this one really hard (*basketball*). Is that a **fair test** of the effect of different masses on motion? Why or why not? [*take responses, and lead to...*] We vary only one factor at a time in order to make a "fair test"... this is known as "controlling variables."

In our case, we will do two experiments: first to vary **only the force** ... and then to vary **only the mass**. We do not change both variables at the same time!

In the process, we will make **measurements, record, analyze, and interpret** them.

6 – NEWTON'S SECOND LAW

HOW MOTION DEPENDS ON – FORCE & MASS

REVIEW:

NEWTON'S SECOND LAW: A NET FORCE causes a CHANGE in the motion of an object, in the direction of the force...

Generate questions:

How much of a change in motion?
What *variables* does it depend on?

_____ Force _____ Mass _____

Research Questions: _____ how does magnitude of force on an object affect its motion? _____

_____ how does an object's mass relate to its motion? _____

Plan an investigation:

How will you proceed to find the answers to your questions?
How will you find the effects of *particular* variables?

_____ vary only one thing at a time, "control variables" _____

(Qualitative Exploration ~25 min)

Before making measurements, we will **explore and form some qualitative ideas** (without numbers), about how each factor, size of force and size of mass, affects the motion.

Let's **draw some diagrams to plan our investigation** (ELICIT the two diagrams for comparing each variable, as shown, and develop the diagrams with students).

We will try out **two tests** with different objects. What do you think is a good way for us to compare the changes in speed of two objects? (pause: **HINT, like maybe race cars or something...?**) Guess what? We're going to have some **racers**. What were our research questions again? How can we investigate our research questions by racing? [Elicit... we can use **different forces, and then different masses, and observe the speeds**] and we are going to record our observations.

Let's consider our first research question [... **the effect on motion of varying the force**]. How could we use a fancart to try to answer this question? [Elicit that perhaps we can **vary the force that pushes them...**] [show that we can use blanks that allow the fancart to run with less than full power, providing a smaller force] So we could use one fancart with a full power supply of batteries, and one with less, . . . one fancart will have a greater force applied to it than the other.

Could we use the bluecards too? Remember how you applied a force to their sails? Can the magnitude of that force vary? [**yes, the hair driers have two speeds, plus you could hold them near or far from the sail**] ... so one blue sailcart can have a greater force applied to it than the other.

Now we'll join up every pair of groups into one group. (3 groups total per class)

Let's **race!** We'll lay down two whiteboards end to end on the floor to make our track (may tape underneath if needed). Then turn on both fancarts and set them down at the "start position" and let them go at the same time ... on your mark, get set, GO. (do this) **Observe... and record** which fancart wins [**the one with bigger force**] traveled the same distance in less time, so we know that its speed was greater, and that it had a **bigger change in speed**, starting from zero. [Invite students to record their observation as shown in first column, using their own terminology.]

Still varying the force, and keeping the same mass, next we'll race the sailcart. Carefully **plug the hair-blower** into the electrical cord that you have near your table, (or teachers plug them in!) and set up **two blue sailcarts** on each track (wavy whiteboard). Two students will operate the blowers, one at high speed and one at low speed to provide two different forces to the sailcarts. **Observe... and record** The winning sailcart (**which one???? with LARGER force**) had a **bigger change in speed** ----- Based on our observations as we varied only the force in a couple of races, can we form a hypothesis about how the magnitude of a force affects motion? **yes, the bigger the force, the bigger the change in speed (motion).**

Can we use these items to answer our second research question regarding mass and motion? (GUIDE TOWARD THIS DESIGN- Race fancarts propelled by the same force (same power supply of batteries) but with or without weights... Race blue sailcarts with same high speed blowers, with or without weights.)

With fancarts and sailcarts, again run the "mass" races, following the same general process as in the "force" races. When you use these blowers, start them above the sail, and then drop them down to the sails at the same time to start the motion... and **REMEMBER to blow into the sail from the same close distance on both sailcarts!!** **Why would we care about that?**

Observe, record, interpret, and form a hypothesis. What was your hypothesis about how the magnitude of mass affects motion? ? **the bigger the mass, the smaller the change in speed (motion).**

What do you suppose we could do in order to become more confident in our hypotheses? To confirm them?

ELICIT, get some quantitative evidence!

YES, so we will do some quantitative testing again . . .Skateboard time!

Qualitative Explorations of *the Effect on Motion of...*

...Varying the Force

...Varying the Mass

Diagram:

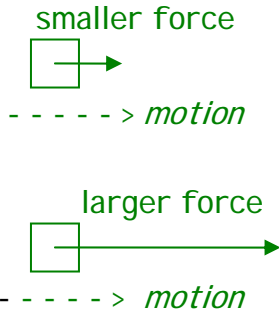
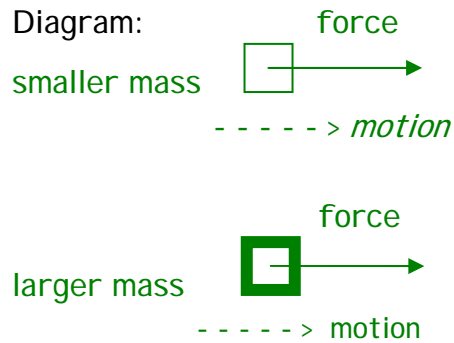


Diagram:



A) Fancart

Test 1 - low battery power vs. full power

Test 2 - without and with extra weight

Observation: the higher powered fancart had a bigger change in speed

Observation: the heavier fancart had a smaller change in speed

B) Blue Sailcart

Test 1 - low speed blower vs. high speed

Test 2 - without and with extra weight

Observation: the bigger wind caused a bigger change in speed

Observation: the heavier fancart had a smaller change in speed

Hypothesis:

The bigger the force, the bigger the change in speed.

Hypothesis:

The bigger the mass, the smaller the change in speed.

(Quantitative Exploration ~30 min)

[Before the skateboard activity, invite students to consider what data might be useful for the particular goals of this lesson, and how to collect the data. Guide toward the following main idea] [we need to control variables ... vary only the force (push with different forces) . . . and then vary only the mass (small or big person, or extra load)].

We need another skateboard rider today, can I have some volunteers? [Pick a student volunteer to be the rider and one to be the pusher.]

Like yesterday, the rest of you are needed to help us keep us keep the beat. The rider will place MARKERS again (index cards or bean bags), every 3 seconds while the skateboard is moving. We will clap "one, two, three, one, two, three" and so forth to keep the time. The "pusher" will take the bathroom scale, place it on the rider's back and push with a constant force on the bathroom scale.

We will run two separate tests to check our claim about how motion relates to these variables (with a skateboard & rider.)

Test 1 will look at the effect on motion from varying the FORCE and

Test 2 will look at the effect on motion from varying the MASS.

Test 1 - Vary the Force

We will perform the following process,

1st for CASE 1 with a small constant force X, and

2nd for CASE 2 with a larger constant force Y. . .

pushing a skateboard & rider along a smooth floor.

For each Case we will use a different color of MARKER, leaving the markers on the floor for later measuring.

May describe steps 1-8 as outlined on student page

Let's do the skateboard activity now... After practice, teacher and students complete the activity,

Do you notice any kind of **pattern** in the locations of the markers left on the floor? [we can notice a difference in the pattern (it gets stretched to longer distances when the force is bigger!).] Let's measure the distances, record them in our Data Table, use them to calculate speeds, and then analyze the results.

Measure... and fill in data table which includes average speeds during 3 intervals for each case)

Do our results **agree with our hypothesis** that a bigger force will cause a bigger change in the speed?
YES!

Test 2 - Vary the Mass

We will perform the following process ,

-1st for CASE 3 with a constant force, and

-2nd for CASE 4 with the same constant force but a bigger mass. . .

both involve pushing a skateboard & rider along a smooth floor. CASE 4 will differ from CASE 3 by having an additional amount of MASS (either a heavy object, or a larger person). (if varying rider weight, pick a rather small person, otherwise you can add a mass like a bowling ball to be carried along by identical rider ... latter is preferred).

As before, we will use a different color of MARKER, leaving the markers on the floor for later measuring.

May describe steps 1-8 as outlined on student page

Let's DO the skateboard activity now...

Teacher and students complete the activity,

As we look at the MARKERS on the floor, do we see any familiar pattern? [tho a constant applied force in both cases, we notice a difference in the pattern (it gets stretched to longer distances when the mass is smaller!)]. Let's measure the distances, record them in our Data Table, use them to calculate speeds, and then analyze the results.

Measure... and fill in data table which includes speeds during 3 intervals for each case)

Do our results agree with our hypothesis that the larger the mass, the smaller the change in speed in response to a force? **YES!**

(Summary and Application ~10 min)

To **sum up** today's lessons, we have developed another aspect of Newton's Second Law . . . with fancarts, blue sailcarts, and with skateboard riders. We can now state the law in a more complete form. [Prompt students for suggestions on how to fill in the blanks and guide toward the words in green with clarification as needed].

In all these situations we found that

A NET FORCE causes a change in the speed of an object that is

directly related to the magnitude of the force, and

inversely related to the mass of the object. . .

(Students copy relevant parts)

By the way, did you notice that the title of today's lesson was incomplete?

Can you use your new expertise to fill in the blank? ___force and mass___

[DO APPLICATION]

SUMMI NG UP:

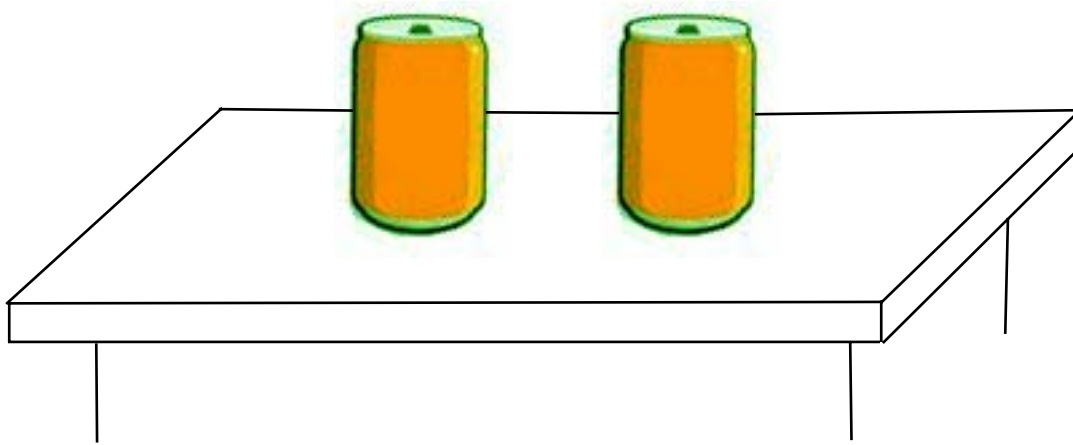
NEWTON'S SECOND LAW

More complete!

A **NET FORCE** causes a change in the speed of an object that is
directly related
to the **magnitude of the force**, and
inversely related
to the **mass of the object**.

APPLICATION -

Apply your knowledge of physics to determine if there is any difference between the two cans on the teacher's desk...*without* lifting them up off of the desk.



What are you going to do... and why?

Try it out...

7 Teacher Supplement

Reality Check! Putting it all together in real situations

Objectives and Resources

Lesson Objectives: Learners should be able to:

4.0 Real situations, friction, and unit consolidation

- 4.1 State that friction and air resistance acting on moving objects affect their motion, and apply to examples.
- 4.2 Explain that if frictional forces are exactly equal to the applied force on an object, it will move at constant speed (and vice versa), and apply to examples.
- 4.3 I identify the forces acting in various situations which include friction.
- 4.4 Apply concepts relating force and motion to real world contexts.

Lesson Resources:

Hoverpucks (2 per teacher)

Stomp rocket (1 per teacher)

Matchbox cars (1 per student)

Leaf Blowers (1 per class),

Beach balls (1 per teacher)

White boards

Card Sets

Rocket Stickers (final page)

Hair driers, ping pong ball (1 per group, plus teacher's, plus spare balls)

COLOR CODING:

BLACK: general text (**BOLDED** for essential points)

BLUE: action notes for teachers

GREEN: student inputs - spoken, written, drawn (students fill in as they go)

RED: outline topic and approximate timing

Lesson # 7 - [~ 70-75 min]

(Review ~5 min)

Hello again! This is a big day in which we will **put everything together** and enrich our understanding by addressing **real world situations**.

So far we've covered the concept of **force as a push or a pull** on an object. We've also described force in terms of **magnitude, units, and direction**, and represented it in **force diagrams**.

We learned how to combine forces into a **NET FORCE**, and we have studied how **net force and motion** are related. We are familiar now with **Newton's First Law** regarding motion with **no net force**, and **Newton's Second Law** regarding motion with a **net force**. [if asked, we don't focus on objects at rest because with no net force they simply remain at rest, as we learned earlier... and with a net force they *become* objects in motion, which is our main focus today]

(CARD game- Review Investigation with ~25 min)

While studying Newton's Laws we've tried to **simplify or "IDEALIZE"** situations by **reducing friction** so that we could see what happened with **no force acting**, or with **only one applied force acting** on an object at a time. What objects did we use? [... a **bowling ball, low friction wheels, skateboard, a hovercraft, and little hoverpucks**]

Our task today will be to **pay closer attention to friction**, and where it fits in our understanding of Newton's laws of motion. We need to find ways to **explore different possible combinations of whether or not** there is an **applied force** and **whether or not** there is **friction** acting on a moving object. **What are the possible combinations???** (Teacher elicits the **NO** and **YES** combinations and completes Table with students... arrange the table as shown, **display on transparency**)

How can we explore each of these combinations? [pause...] How could we have either "an applied force" or "no applied force" on a moving object? [may use cart or ball to help elicit idea of brief push from hand to get it moving, but then no more force acting, versus a continuous push from something like a hand or even a hair-blower].

How can we have either "friction" or "no friction" acting on a moving object? [pause...] It sure would be nice if we had an object with some kind of "friction switch" that let us turn friction ON or OFF . . . hmmm any ideas? [elicit the need for a **hoverpuck ... otherwise, come up with the idea yourself ☺**] Remember that when it is switched ON, the hoverpuck creates an almost frictionless cushion of air to ride upon (**ON, gently tapping it back and forth**) but when it is switched OFF it has plenty of friction when it moves on a surface (**OFF, gently tap with very little response**)... like most things around us in the everyday **"REAL"** world.

Let's see how well we have learned our science by playing a little **card game**. I'll pass out 4 handouts and a set of cards about Forces, Observations, and Newton's Laws. Each handout page corresponds to one of the 4 cases in the table in your notebook [teacher shows on transparency]. **Your goal as a group** is to analyze the pictures, and match them with the appropriate case numbers, recording the case letters [A,B,C,D] in your table. Then **explore each case, 1 through 4**, by testing with your hoverpucks, and any other equipment you may need (like maybe a hair-blower). [Each group should have a **hoverpuck, hair-blower, and two whiteboards to lay on the floor if needed**]. As a group, decide which cards belong in the empty spaces on your handouts, and tape them into the correct locations. **When you're done**, I'll call on groups to explain how you solved each case.

7 - REALITY CHECK!

PUTTING IT ALL TOGETHER IN REAL SITUATIONS

OVERVIEW of DYNAMICS

Motion

Force

Net Force

Newton's First Law

Newton's Second Law

FROM IDEAL TO REAL

CONSIDERING MOVING OBJECTS

Let's investigate...

Case #	Applied Force?	Friction?
1	NO	NO
2	YES	NO
3	NO	YES
4	YES	YES

GROUP CARD GAME

- *) On each handout, place two appropriate cards in the acting "**FORCES**" spots... and decide whether or not there will be a "**NET FORCE**" (place appropriate card).
- ***) For each case, explore with a "moving object"... make "**OBSERVATIONS**" (record them by placing an appropriate card), and then identify which "**NEWTON'S LAW**" applies (record it by placing an appropriate final card).

[When students are finished, call on groups to explain until all four cases have been identified, and appropriate letters copied to empty boxes for each case number, in table and on page 2]

If you have had enough time, let's begin to share what we found out.

Record on transparencies information shown in **GREEN** for all 3 cases shown on students' page 2.

Call for Case #1, which Letter is it? A, B, C or D? **[C]** Have students explain their choice of Net Force Cards and Observation Cards and Newton's Law Cards.

Call for Case #2, which Letter is it? A, B, C or D? **[A]** Have students explain their choice of Net Force Cards and Observation Cards and Newton's Law Cards.

In CASE 2, when we have an applied force, we have a little more to think about... what must we consider now?

[Teacher elicits that]...[we can apply a force to a moving object in two ways... either in the **direction of motion** or in the **opposite direction from the motion.**]

May model this with a hoverpuck and hair dryer.

Draw the second option as well, as shown on the right in green on the student page.

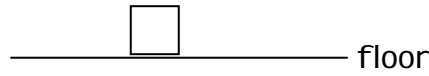
Call for Case #3, which Letter is it? A, B, C or D? **[B]** Have students explain their choice of Net Force Cards Observation Cards and Newton's Law Cards.

Teacher calls students attention to the fact that the object slowed down in Case 2 when the force was applied against the motion, and it also slows down in Case 3 when the friction force is acting against the motion ...

Here we have additional evidence of friction being a "hidden" force that acts against the motion of an object (just another example of a "backward" force!!!). We can represent friction on a diagram just as shown **[in green]**.

CASE # 1

----- > (motion)



FORCES?

NET FORCE?

OBSERVATIONS?

NEWTON'S LAW?

Applied? NO

NO

no change in motion

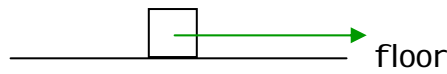
constant speed

FIRST LAW

Friction? NO

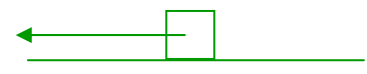
CASE # 2

----- > (motion)



applied force

----- > (motion)



FORCES?

NET FORCE?

OBSERVATIONS?

NEWTON'S LAW?

Applied? YES

YES

change in motion

same direction-

SECOND LAW

Friction? NO

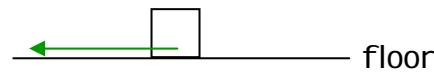
speeds up

opposite direction-

slows down

CASE # 3

----- > (motion)



friction force

FORCES?

NET FORCE?

OBSERVATIONS?

NEWTON'S LAW?

Applied? NO

YES

change in motion

slows down

SECOND LAW

Friction? YES

Call for Case #4 , which Letter is it? A, B, C or D? [D] Have students explain their choice of NET FORCE CARDS and Observation Cards and Newton's Law Cards... Elicit the observation that **they cannot be sure whether there is a net force or not**, or what they would observe, or which Newton's LAW applies... since there are many possibilities for relative direction and relative magnitude of forces.

So, here in CASE 4, for the first time we are going to have to consider how **two forces acting** on an object relate to Newton's laws.

To understand the **combined effect** of an **applied force** and a **friction force**, we need to think about the **NET FORCE**. How do we find net force?

(Elicit idea of **adding the magnitudes of forces acting in the same direction**, **subtracting the magnitudes of forces acting in opposite directions**)

So we'll consider **all the possible situations** that might arise with a **friction force** and an **applied force acting on a moving object** by thinking thru each possibility, aided by force diagrams. What are these possibilities? Let's think first about direction..[**elicit that 2 forces might be in same direction or in opposite directions...**]

WHAT IF ... the applied force on our moving object acts "backwards" (against the motion), in the same direction as the friction force?

How should we represent this in a diagram?

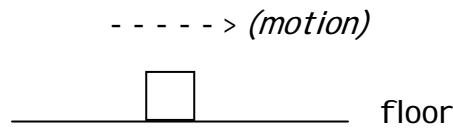
[**show 2 forces acting on the "object", both backwards arrows**]

In this case, do we have a net force? [YES]

Will there be a change in motion? [YES, it will certainly slow down]

Which of Newton's Laws applies in this case? [Newton's Second Law!!]

CASE # 4



FORCES?

NET FORCE?

OBSERVATIONS?

NEWTON'S LAW

Applied? YES

??

??

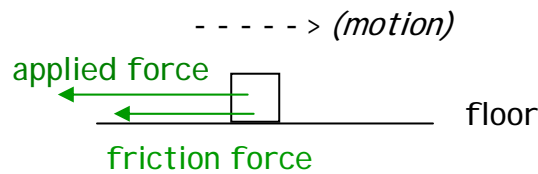
??

Friction? YES

APPLIED FORCE AND FRICTION

*Considering all possibilities... direction and magnitude...
Think it through:*

WHAT IF ... the applied force on our moving object acts "backwards" (against the motion), in the same direction as the friction force?



NET FORCE? YES

CHANGE IN MOTION? yes, it would slow down

NEWTON'S LAW? Newton's Second Law

WHAT IF... the applied force on our moving object acts "forwards" (with the motion), in the opposite direction from the friction force?

Let's start a **diagram** for this situation, to help us think it through. We can draw a friction force acting backward on the moving object. [do this for the first diagram on page 3, transparency]

Next we need to draw our applied force. What do we draw?

(Elicit the problem of how BIG do we make the applied force... and make point that now the MAGNITUDES of the forces matter!

Lead students to realizing that

The applied force may be **less than, more than, or equal to** the force of friction. [and have them place these signs as shown, < = > in the blanks]

Let's draw diagrams and interpret each of these possibilities in terms of Newton's laws, and state what the effect on the object's motion will be.

First we look at the case when the forward applied force is less than the friction force (Elicit that the diagram that must show smaller applied force to right, and the need to subtract to find the net force, as recently mentioned, keeping direction in mind)

How do we interpret this in terms of Newton's laws? What will be the effect on the object? (with a net force to the left, against the motion, the object will obey Newton's 2nd law and slow down)

Second we'll draw a diagram for the case where the applied force is exactly equal to the friction force (the forces are BALANCED). Again, we simply subtract forces to get the NET FORCE...keeping direction in mind.

WHAT RESULT? A ZERO NET FORCE (BALANCED FORCES)

WHICH LAW? WHAT EFFECT? Newton's 1st ... Object will keep moving at a constant speed (motion will not change!) Elicit that this is one way to measure magnitude of friction force!! ALL DO THIS, pushing/pulling hoverpuck at approx constant speed, known applied force = friction force

Last, we'll look at the case when the forward applied force is greater than the friction force

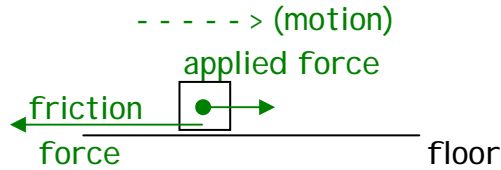
(Elicit the diagram that must show bigger applied force to right, again we subtract to find the net force, keeping the direction in mind)

How do we interpret this in terms of Newton's laws? What will be the effect on the object?

(with a net force to the right, same direction as the motion, the object will obey Newton's 2nd law and speed up to the right)

WHAT IF ... the applied force on our moving object acts "forwards" (with the motion), in the opposite direction from the friction force?

Applied Force $<$ Friction

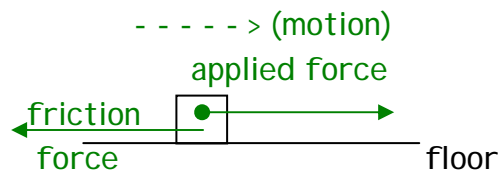


NET FORCE? YES

CHANGE IN MOTION? yes, it would slow down

NEWTON'S LAW? Newton's Second Law

Applied Force $=$ Friction

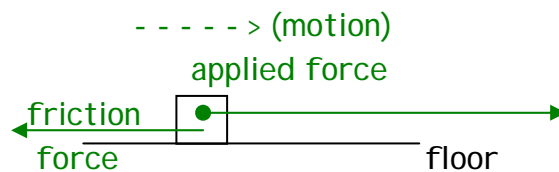


NET FORCE? NO

CHANGE IN MOTION? no (constant speed)

NEWTON'S LAW? Newton's First Law

Applied Force $>$ Friction



NET FORCE? YES

CHANGE IN MOTION? yes, speeds up

NEWTON'S LAW? Newton's Second Law

[Comparisons of IDEAL and REAL, tables ~ 20 -25min] Ok, now that we have considered all these possible situations of motion both with and without friction acting, let's look back and summarize briefly how Newton's Laws apply in both the Ideal and the Real world.

Guide the students to refer to the cases above to complete the TABLE...

(at a glance:

CONSTANT SPEED - top row - no net force

if no friction, no applied force needed

if friction, applied force must be equal to friction

SPEEDING UP - bottom row - net force

if no friction, any applied force in direction of motion

if friction, applied force must be greater than friction)

In the everyday world, our experiences range from situations with very little friction, close to the "ideal" of no friction ... all the way to situations with very great friction. Can you think of some examples of either kind? (bowling, skating, coasting on racing bike, air hockey --- vehicles on road, push box across floor, etc.)

Do our experiences with motion make more sense now that we have a better understanding of Newton's Laws, and understand the role of friction as a force?

Yes (we hope so)

"Making Sense of Our Experiences with Motion"

How much applied force is needed?

	<u>Ideal</u> (no friction)	<u>Real</u> (with friction)
Newton's First Law	For an object to move at constant speed... <u>no applied force is needed</u> _____	For an object to move at constant speed... <u>applied force must be equal to friction (balanced forces!)</u> _____
Newton's Second Law	For an object to speed up... <u>apply any amount of force (in the direction of the motion)</u> _____	For an object to speed up... <u>applied force must be greater than friction</u> _____

Let's now look at a **common real world example**, and discuss it in terms of **Newton's Laws of motion**. We'll use an object we see every single day ... the "car". You each have a **model of a car** on your table to help you **simulate car behavior and think** about the relationship between the forces acting and the effects they have on motion.

OUT FOR A DRIVE (A,B,C,D) create scenario with students

DRAG RACE (D1, D2, D3) create scenario with students

In spite of the fact that the car is a very common and familiar object, the **system of forces** that act in and on a car is **very complicated**. As we've done before, we'll need to **simplify in order to clarify** our understanding of how force and motion relate.

So, we'll consider there to be one **total forward force**, and/or one **total backward force**, and they may vary in magnitude. Another aspect of our cases is that there may or may not be motion.

In your notebook you have a **TABLE** which **describes some cases** regarding the forces that may be acting on a car (big cars OR toy cars!). Your table also contains **force diagrams** for each case.

Based on all that you have been learning here, your **first task** is to **show the Net Force (if there is one)** in the Net Force Diagram. Once you have determined the Net Force, you can tell whether it is Newton's First or Second Law that applies to the situation, and decide what kind of motion the car has.

Let's **work through Case 1 together**. **(do this!)**

Continue through your table, **discussing** with your neighbors, and **demonstrating with your model cars** as needed.

Feel free to ask for clarification ... I'll come around to help.
(students talk and "play" with cars & work on their TABLES ...)

Teacher can go over correct answers with students participation.

Here we have seen a variety of aspects of Newton's laws of motion, and how they relate to common real world situations, mostly in the horizontal direction. Would you expect that Newton's laws of motion apply in all directions? **(hmmmm)**

Case	Description of Case	Force Diagram	Net Force Diagram	Newton's Law	Description of motion
A	A forward force and a backward force are equal (balanced)			No net force? Newton's 1 st Law No change!	traveling at steady/constant speed
B	Backward force			Net force? Newton's 2 nd Law Change!	slowing down (net force, opposite direction of motion!)
C	No horizontal forces acting			No net force? Newton's 1 st Law No change!	sitting still
D1	Forward force that is greater than the backward force			Net force? Newton's 2 nd Law Change!	speeding up (net force, same direction as motion)
D2	Just like Case D1, except greater forward FORCE			Bigger net force? Same mass? Newton's 2 nd Law Bigger change!	speeds up more
D3	Forces just like Case D1, except the object has greater MASS			Same net force? Bigger mass? Newton's 2 nd Law Smaller change!	speeds up less

NEWTON'S LAWS APPLY IN THE REAL WORLD
A CAR ON A ROAD ... A MODEL ON YOUR TABLE



[Challenge ~ 20 min.] Let's look at something that has vertical motion too...

From your bins, get out a ping pong ball. We can hold these up in the air between our fingers ... it's not moving at all, either horizontally or vertically. Which of Newton's Laws applies to this state? Explain ... [Newton's 1st law ... no motion and no change in motion, there must be a zero net force on the ball... even though there are forces acting on the ball (from my hand – contact force, and gravity – distance force), those forces must be balanced.] Great explanation!

In your notebook you'll find a picture of a ping pong ball. Match it up with the force diagram that corresponds to the situation.(discuss..connect to lower right diagram)

We let the ball go. It falls. Wow. Is anyone surprised? Of course not, but again, let's relate this to Newton's Laws. [Newton's 2nd... The hand no longer acts on the ball when it is no longer touching the ball, so there is only one force left acting on the ball, the force of gravity. This is a situation in which the net force acts in the direction of motion, causing the object to speed up (downward)

Do you see a force diagram on your page that depicts this situation? Top diagram (no line to draw, just spoken)

Anyone have an idea of another way we could balance the force of gravity that pulls this little ball down??...(HINT: don't you have a hair-blower somewhere in your bin?) Let's see if we can apply an upward force from air that balances with the downward force of gravity. (all do this) (yes, we can!)

We played with some toy cars that helped us think about the motion of a big car, what about changing the scale of this little experiment too?

(take out the beach ball first, and then . . . reveal the leaf blower!!
Demonstrate the big ball with big force)

Now, we've just looked at a couple of cases with a balance of vertical forces ... what if the upward force was far greater than the force of gravity? Elicit the fact that it would speed up and rise into the air. (Get out the stomp rocket!!)

Here is an object that will shoot up into the sky when we apply the force of a strong blow of air underneath it. Demonstrate in a very slight way in classroom and explain that... This little rocket won't go up forever, because the upward force does not continue, it only acts for a short time at the beginning of the flight. With this in mind, can you find the force diagram that matches with the "Stomp rocket after it has LEFT the launcher? (discuss... connect to upper right diagram)

FROM THE EVERYDAY...

CHALLENGE PAGE:

Draw a line to connect each picture to the corresponding vertical force diagram



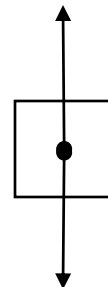
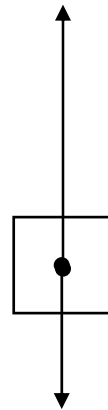
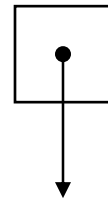
Ping pong ball holding still -



Stomp rocket after it has left the launcher -

???

What might this be?



...TO THE AMAZING!

Maybe tomorrow we'll get a chance to see how high we can get the stomp rocket to rise before it comes back down. But let's imagine if it DID have a continued force that was greater than the force of gravity. Can you predict what would happen then? (According to Newton's Second Law, we would then have an upward net force, and it would continue to speed up)

Let's go back to thinking about SCALE. Can you picture a much larger version of this little rocket? (Real rocketships!) What if we combine that larger version with a continued upward force? If our remaining force diagram matches up with our Question Marks, what kind of picture might belong there?

Do you remember what we talked about on the first day of our lessons? That dynamics is the key to explaining and predicting and controlling how objects move, in relation to the forces acting upon them. . . from ping pong balls . . . to objects like 100,000 pound rocketships on their way to the moon and other planets.

And Newton's laws of motion apply just the same to the the moon itself as they do to this little ping pong ball. Dynamics will take you anywhere you need to go! It takes us from the everyday to the amazing.