**TE Activity: Force Measurements and Applications**

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|---|---|
| **Subject Area(s)** | Physical Science |
| **Associated Unit** | None |
| **Associated Lesson** | None |
| **Activity Title** | Force Measurements and applications |

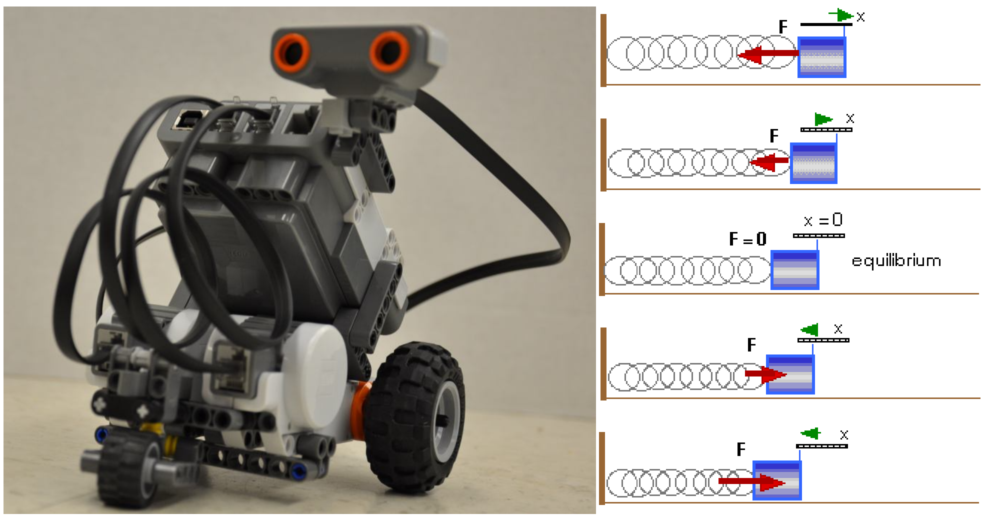


**Image 1**
**ADA Description:**
**Caption:**
**Image file name:**


| | |
|---|---|
| **Group Size** | 3-4 |
| **Expendable Cost per Group** | Assuming the school is currently equipped with a standard Lego Mindstorms NXT© kit the cost is $0 |
| **Grade Level** | 9 (8-7) |
| **Time required** | 45 minutes<br>The time required largely depends on the level of engagement the teacher wishes to involve the student. The curriculum delineates a demo version as well as a student interactive version. For the student interactive version, the teacher should expect four 45 minute lessons to encompass the construction, |

experiment, and guided analysis of the acquired data. For a demo, the teacher should expect one 45 minute lesson to properly encompass the experiment and quick analysis of the data.


**Summary**

This activity focuses on allowing children to qualitatively and quantitatively understand the concepts of forces and springs and their inherent linear relationship. The students will perform a basic experiment in groups and be guided through the simple analysis of the data they gather.


**Engineering Connection**

This activity allows students to understand the concepts of force, elasticity, and linear springs. Mechanical Engineers require a sound understanding of these basic concepts when designing cars, robots, or other dynamic systems. Moreover, engineers of various disciplines also employ these fundamental concepts when making measurements in laboratories that are analogous to the single degree of freedom elastic systems.

**Engineering Category**

1. Relates science concepts to engineering: the activity allows students to engage themselves in basic scientific concepts and understand their application to a variety of engineering problems.

**Keywords**

Linear springs, force, thrust, elasticity, mechanics

**Educational Standards**

State science: Simple machines include: The lever, the pulley, the wheel and axle, and the inclined plane. PS 5.2g

State math: Measurement, Uncertainty, Standard 3.

**Pre-Requisite Knowledge**

Fundamental understanding of measurement and displacement

**Learning Objectives**

After this activity, students should be able to:

- Describe the fundamental concept of force
- Where we see forces in everyday life
- How can we measure force

**Materials List**

Each group needs:

- Lego Mindstorms NXT© kit if the teacher opts for group mode
- Ruler
- Linear spring
- Reference plane

To share with the entire class:

- A computer
- Lego Mindstorms NXT© kit

**Introduction / Motivation**

Did you ever wonder why a larger car seems to be able to tow more than a small car? Or why larger planes can carry more passengers than smaller ones? It is not just because they are larger, but it is primarily due to the size of their engines and the force or “thrust” that these engines may produce. What we are going to study today through a couple of simple experiments is how measuring force can be easy and useful.

We will also see that there is an interesting relationship between rotations per minute, meaning how fast the wheels spin and the torque. Torque, is the tendency for an object to be able to pivot about its axis. If you think of a door, would it be easier to open the door by pushing on the door handle? Or by pushing a few inches away from its hinges? Clearly, it is easier by pushing on the door handle and this is because while pushing just as hard in both cases, you will get more “torque” by pushing on the handle. This is because you are further away from the hinges!

This experiment also delineates the relationship between power and force. We will see that there is a linear relationship between the two. As the power input to the Lego motors is increased, the force delivered by the robotic car to the linear spring will increase.

In this experiment we will also have a basic understanding of springs, and that (believe it or not), they have pretty fundamental applications in engineering and science. Since we will see that there is a relationship between force and springs, we can use a spring to measure the force of our robotic car. And then by adjusting the speed of the motors we can see how at different speeds, the car exerts different forces.

<u>A note for teachers:</u>

Figure 1 shows experimentally obtained rotations per minute and torque relationship. This is the typical trend that should be experienced during the experiment by increasing the power (speed) and noting the torque.

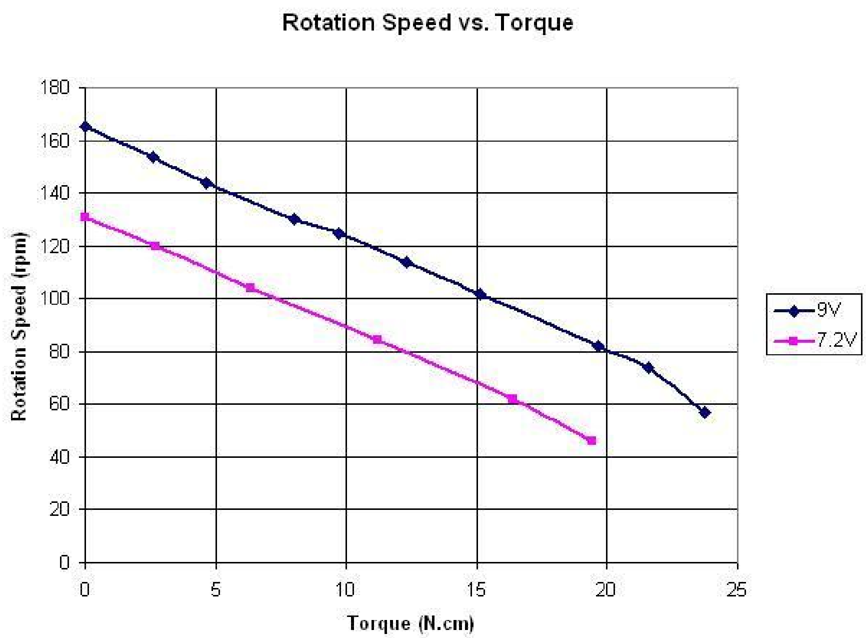


**Figure 1**
**ADA Description:** Rotations per minute and Torque relationship for a typical NXT motor
**Caption:** Figure 1: **RPM v. Torque**
**Image file name:** RPM_v_Torque.bmp
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Very fundamental to the understanding of how this experiment will develop is the following relationship between power, force, and velocity.

$$P = F \cdot v$$

The above equation illustrates that power (*P*) is equal to the product of force (*F*) and velocity (*v*). Therefore, by increasing the power delivered to the Lego motors we would expect that the speed as well as the force produced by those motors will linearly increase. Thus the ultimate expectation is that by increasing the power, the robotic car will displace the spring by a larger amount and therefore deliver a higher force.

The final fundamental concept which should be thoroughly understood is the workings of a linear elastic spring. In mechanics, a branch of physics, it is known that the elongation of a linear spring is directly proportional to the load placed on that spring so long that the load does not exceed the elastic limit. The stiffness of the spring is characterized by its spring constant (*k*). A higher spring constant correlates to a stiffer spring while a smaller spring constant correlates to a more compliant spring. The spring constant can be easily measured as described in the procedure section below. The relationship between force and displacement for a linear spring can be easily described by Hooke's Law which states:

$$F = k \cdot \Delta x$$

The equation shows that the force exerted on the spring is proportional to its spring constant and the linear displacement ($\Delta x$) of the spring in its longitudinal direction see Figure 2.

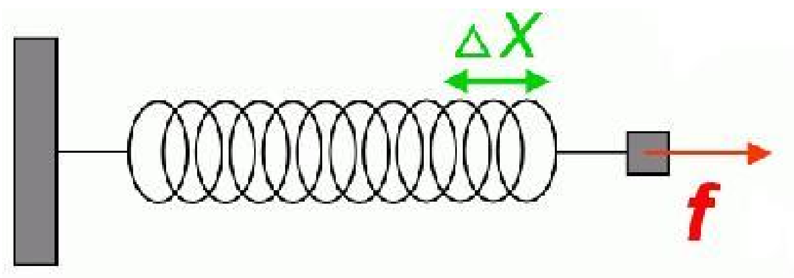


**Figure 2**
**ADA Description:** Displacement of a linear spring due to an applied force (f)
**Caption:** Figure 2: **Linear Spring Deflection**
**Image file name:** RPM_v_Torque.bmp
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### Vocabulary / Definitions

| Word | Definition |
|---|---|
| Torque | The tendency for an object to pivot about its axis |
| Force | An external event that causes a change in the motion of a body |
| Spring | A mechanical device that stores energy |
| Power | The product of force and velocity |

**Procedure**

The procedure for the activity is as follows. The items are numbered and the timeline for this process is as described above.

1. Construct the Lego Mindstorms robot as seen in catalog 9797 of the standard Lego Mindstorms kit. The robot should be constructed up to step 28.
2. Once the robot is constructed a simple RobotC program may be created that allows the vehicle to move forward at different power levels. It is suggested that the user increments the power ratings from 30-100 in increments of 10. At each increment the user should use the data logging software from Lego to determine the displacement of the robot from its reference position. An example of the code is seen below:

```
Task main ()
{
        motor [motorA]=30;
        motor[motorB]=30;
        wait1Msec(2000);
}
```

3. Once the robot can move forward, the next step is to determine the spring constant of your linear spring. This may be done by simply hanging a mass from the linear spring and noting the deflection. The force or load you are placing on your spring is simply the product of the mass itself, and the acceleration due to gravity of 9.81 m/s$^2$. See Figure 3.

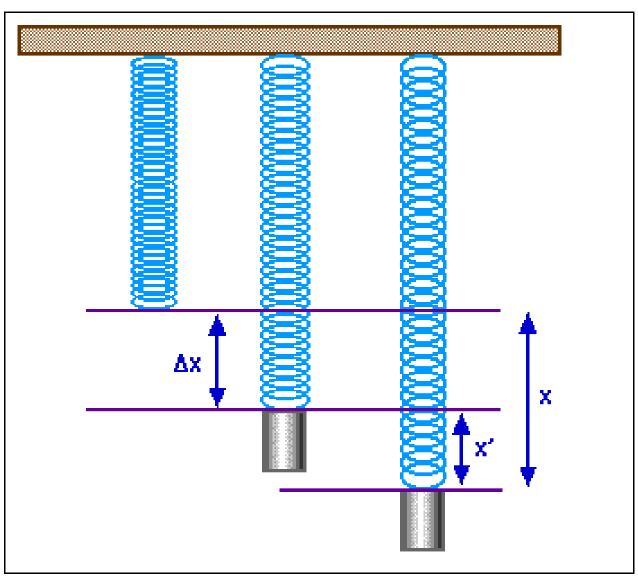


**Figure 3**
**ADA Description:** Displacement of linear spring due to force of gravity
**Caption:** Figure 3: **Linear Spring with applied force of gravity (g)**
**Image file name:** spring_gravity.bmp
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4. The linear spring should then be affixed to the rear of the robot and with a reference position as shown in Figure 4.

**Figure 4**
**ADA Description:** Experimental setup depicting robotic car displacing a linear spring. The Ultrasonic sensor is shown as well with the reference position to its left.
**Caption:** Figure 4: **Experimental Setup**
**Image file name:** experimental_setup.bmp


5. Connect the ultrasonic sensor to port 3 of the NXT module.

6. Initiate the robot C program and using the data logger record the displacement of the linear spring at the different power ratings.

7. The simplest way to view the information is to access the ultrasonic sensor from the NXT bricks menu. This is simpler than using the data logger because it only

requires the user to press -> view -> more programs -> ultrasonic sensor -> port3.

8. The value read on the sensor correlates to the displacement of the NXT robot, since the robot reaches a steady state displacement shortly after the power is altered from the provided program the values are easiest read off the screen.

It should be observed that the displacement increases as the power increases. Therefore the force exerted on the spring should increase as the power increases.

**Background**

In order to understand the fundamentals of the experiment, time should be devoted to explain the concepts of linear springs, forces, and power. There is sufficient background information on these topics in the (A note for teachers) section.

**Before the Activity**

- If the teacher chooses a demo style presentation then before the activity the robot should be built and set up as detailed in the procedure section. The sample code from the procedure section can be used to vary the power setting of the motor. The time and power may be further varied from the supplied sample code.

**With the Students**

If the students are in an interactive lesson then they should follow the procedure steps from step 1. If the students are being showed the experiment then the teacher should engage hands on with them from step 3.


**Image 2**
**ADA Description:** Students building Lego robot with given specifications for construction
**Caption:** Figure 1: **Students constructing**
**Image file name:** spring_gravity.bmp


### Safety Issues

- None

### Troubleshooting Tips

- Make sure that the ultrasonic sensor is connected to serial port 4. The ultrasonic sensor has a high communication bandwidth and therefore will only operate properly on the digital serial connection given by port 4 on the NXT module.
- Check to make sure all programming syntax is correct.
- If the spring displaces too much, you have gone beyond its elastic limit and should use a lower power setting. Additionally the spring should be replaced because at that point it has been plasticized.

### Assessment

- We know the relationship between force and displacement for springs. We also know the relationship between force and power. Is there a limit by which this experiment is no longer operable why?
- Is there a floor limit, that is, is there a power setting too low that will make this experiment inoperable? Why? (Hint: think of the elastic limit of springs, and the spring constant (k))
- How can this be applied to a real life analogy? Do tractor trailers produce more or less force then sport cars?

**Pre-Activity Assessment**

*Title:* What is Force? How do we measure it?

- Why can trucks pull more weight than cars?
- What do you think this is a function of?
- What is a Force?
- How would you measure it?
- Can you exert a force? Do you always exert a force?

**Activity Embedded Assessment**

*Title:* Force and springs

- How do you expect the spring to deflect as we increase the power?

**Post-Activity Assessment**

*Title:* What conclusions can we make?

- How do you conclude the relationship between force, power, springs, and the car
- For another assignment, do you think how fast we accelerate the car will have an impact on the force? Why or why not?

**References**

Lego Mindstorms Educational Package #9797

**Redirect URL**

http://GK12.poly.edu

**Owner**

Karl Abdelnour, AMPS Program, Polytechnic Institute of NYU

**Contributors**

Karl Abdelnour

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**Assessment Exercise**

**Name:**____________________________________________

1. **Describe, the purpose of the robotics project:**

2. **How would you define power?**

   **Hint (what is the equation and how do you interpret it?)**

3. **If the power is increased to 25%, 50%, 75%, 100% what do you observe?**

4. **What equation describes the relationship between force and spring displacement?**

5. **Does this equation always work? Why or why not?**

6. **In engineering, linear springs are used to model and approximate real world phenomena. Can you think of three phenomena in the real world that a spring could be used to describe its behavior (partially)?**

**Hint: Automobiles, Aircraft, shock absorbers….**