# Force Analysis of a Moving Vehicle (activity)

**Subject Area(s)** Physics, Science and Technology

**Associated Unit** None

**Lesson Title** Force Analysis of a Moving Vehicle

**Header** Insert Image 1 here, right justified so text wraps around it

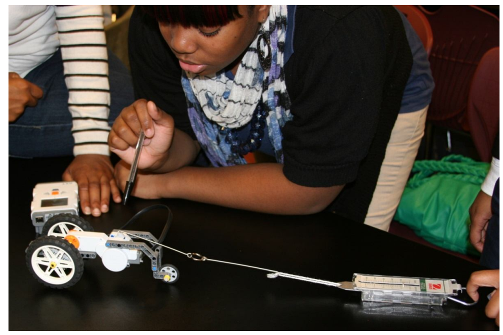
**Image 1**

**ADA Description:** Students measuring the pulling force of the LEGO car.

**Caption:** Students measuring the pulling force of the LEGO car.

**Image file:** TE_img1.jpeg

**Source/Rights:** Copyright © Polytechnic Institute of NYU



**Grade Level** 10 (9-12)

**Lesson #** 1of 1

**Lesson Dependency** None

**Time Required** 45- 90 minutes


## Summary

This LEGO Mindstorms-based activity is geared for Regents or AP Physics students. In this activity students practice to measure and analyze various forces that act on the vehicle that is moving at a constant speed on the frictional surface. During this activity students identify, measure and calculate forces that act on a moving object, i.e., weight, normal force, force of friction, force generated by the motor, tension in the string. Students use scales to measure the weight and the pulling force of the car and calculate the other forces using formulae.


## Engineering Connection

Everyday world is full of devices that interact or exert forces on one another. Using the properties of these forces mechanical engineers are able to create devices that can pull, push and transport objects in all kind of circumstances. For example, a crane that is used to construct a tall building has to be designed to be stable and be able manage various types of weights and external forces. In this activity students learn the engineering aspect and importance of the force of friction during vehicle's motion. They will also learn to see motion as caused by forces.

## Engineering Category = #1,2.

1. Relating science and/or math concept(s) to engineering
2. Engineering analysis or partial design
3. Engineering design process

## Keywords

Force of friction, Free body diagram, LEGO Mindstorms, Normal force, Pulling force of a car, Weight.

## Educational Standards

NYS science: 5.1e, 5.1j, 5.1o, 5.1q.
NYS math: A.R.4, A.R.6, A2.CN.6.

## Pre-Requisite Knowledge

A basic understanding of forces and motion. Knowledge of vector notation.

## Learning Objectives

After this lesson, students should be able to:

- Fluently identify and draw forces in free body diagram format.
- Understand the connection between force of friction and the weight of the object.
- Understand the difference between the pulling force and the force generated by the motor.

## Introduction / Motivation

**Image** Insert Image 2 here, left justified so text wraps around it

**Image 2**

**ADA Description:** Visual aid for the problem given in the Introduction/Motivation section

**Caption:** John Massis pulling two railroad passenger cars totaling 80 tons with a thick rope in 1974.

**Image file:** TE_img2.jpeg

**Source/Rights:** Copyright © Halliday, D., Resnick, R., Walker, J., "Fundamental of physics" 6$^{th}$ ed, John Wiley & Sons, 2001

How do engineers know what is the minimum power needed to move a heavy object from rest? For example, what is the best vehicle for the job to move a heavy package in the storage facility? Also, let's take a look at the following problem. "On April 4, 1974, John Massis pulled two New York Long Island railroad passenger cars totaling 80 tons with a thick rope, with a small bit attached, using only his teeth, [1]" see Image 2. Do you think physics can explain Massis achievement or this story can't take place in the universe that we live in? We will need to learn dynamics to answer these questions.

Dynamics is a study of causes of motion, namely forces that cause objects to start or to continue moving. To engineer and control such dynamics, we need to understand what a stationary or a moving object is "feeling" when it interacts with the environment. We need to understand forces: their magnitudes and direction. We need to understand how forces act on objects, how they superimpose, and how they cancel out. To try to answer above question about "superhuman" Massis who moved several train cars with his teeth. Let's say that Massis was replaced by a vehicle that had enough power to pull the train cars, See Image 3. Looking at the problem from this perspective you will understand the problem as an engineer and conduct the experiment as a scientist. In this activity, you will analyze the dynamics of the moving vehicle, and you will try to understand what kind of forces are acting on the vehicle in motion. You will relate the force of friction to the weight of the vehicle and you will also see Newton's third law in practice. This activity is about visualizing motion using mathematics and seeing it as it is caused by combination of *many* forces.

## Lesson Background & Concepts for Teachers

### Background

- Fluent answering questions about free body diagrams, Third Newton's law and vector manipulation.
- Reference table with coefficients of static and kinetic friction.
- Knowledge and experience operating NXT intelligent brick and building with NXT Mindstorms.

## Vocabulary / Definitions

| Word | Definition |
|---|---|
| Coefficient of friction | Dimensionless quantity whose value depends on the material properties of two body placed in contact with one another [1]. |
| Free body diagram | A stripped-down diagram in which only one body is considered. That body is represented by a sketch or simply a dot. The external forces on the body are drawn, and a coordinate system is superimposed, oriented so as to simplify the solution [1]. |
| Vector | Mathematical tool to represent quantities that have direction and magnitude. |

| | |
|---|---|
| | Vector is graphically represented by an arrow. |

## Materials

- For each set-up: NXT (1), motor (1), building blocks from NXT Mindstorms kit
- For each set-up: Newton's scale (1), weight scale (1)
- NXT Mindstorms and LEGO Digital Designer software
- Robot building instructions in LEGO Digital Designer, see attached as *BattleBot_robot (ldd)*

## Before the activity

- Build LEGO-based vehicle shown in Image 3 using LEGO Digital *BattleBot_robot (ldd)instructions.*
- Using LEGO Mindstorms, download *Move_forward (rbt)* program to NXT, see Image 4.
- For each team prepare Newton scale and weight scale.
- Prepare a copy for each student of *Worksheet_Force_analysis_of_a_moving_vehicle (doc)*.
- Bring a computer with Microsoft PowerPoint installed on it.

**Image** Insert Image 3 here, left justified so text wraps around it

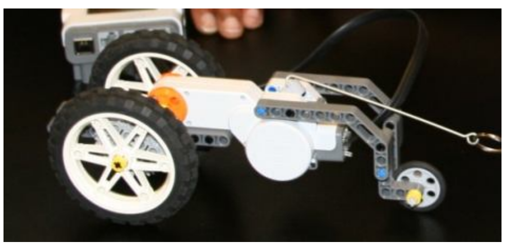


**Image 3**

**ADA Description:** Design of a LEGO Mindstorms-based car used during the activity.

**Caption:** Design of a LEGO Mindstorms-based car used during the activity.

**Image file:** TE_img3.jpeg

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**Image** Insert Image 4 here, right justified so text wraps around it

**Image 4**

**ADA Description:** LEGO Mindstorms program that drives the car during the experiment.

**Caption:** LEGO Mindstorms program that drives the car during the experiment.

**Image file:** TE_img4.jpeg

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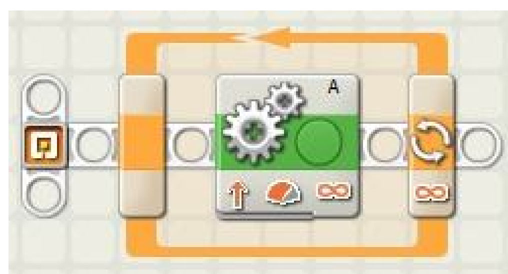


## With the students

## Before the activity

- Have a discussion with students about vehicles that are used to pull heavy objects. Ask them to give examples of such vehicles and the circumstances of their use.
- Discuss with students Massis's record problem, as mentioned in Introduction section.
- Have students fill out Pre-lesson assessment where they analyze forces acting on a system, shown in Image 5(top).
- Go over physics concepts necessary for the activity. Go over the answers to pre-lesson evaluation, as shown in *Presentation_Force_analysis_of_a_moving_vehicle (ppt)*.
- Have students discuss the relation between the forces acting on the system in Image 5(top) and force acting on the system in Image 5 (bottom). Note that, the scale in stationary and is being held firmly by the student. This discussion will transition into the activity.

**Image** Insert Image 5 here, left justified so text wraps around it

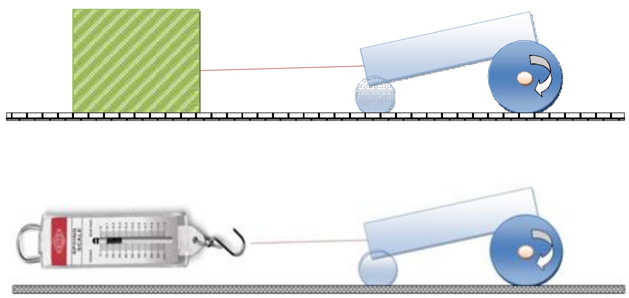

**Image 5**

**ADA Description:** Figures that are given to students to draw free body diagrams during the activity.

**Caption:** A figure of a car pulling on a heavy object (top). A figure of a car pulling on the Newton's scale, as done in the activity (bottom)

**Image file:** TE_img5.jpeg

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## During the activity

- Start the activity by dividing the class into teams and distributing the equipments necessary for each group.
- Ask students to measure the mass of the LEGO car in kg. Note: Encourage students to write units next to their measurements.
- Have students calculate weight and normal force of the LEGO car using formulae, i.e.,

$$W_{car} = m_{car} \cdot g_{earth} \text{ and } F_{normal} = W_{car}.$$

  Challenge students to be inquisitive about the origin of these forces. Where is the Normal force coming from? How does the Newton's 3rd law explain the phenomenon?
- Ask students turn NXT on and test run the "move forward" program on the LEGO car to familiarize themselves with the set up.
- Have students analyze if the car tends to slow down due to the force of friction on the surface (table, floor, etc). Let students choose the surface on which they prefer to run their experiment.
- Have students look up kinetic coefficient of friction, $\mu_{kinetic}$, between the rubber of the wheels and the chosen surface.
- Have students calculate the force of friction experienced by the moving car on the chosen surface, i.e.,

$$F_{friction} = \mu_{kinetic} \cdot F_{normal}.$$

- Encourage students to discuss how the force of friction, $F_{friction}$, is related to the weight, $W_{car}$, of the car, i.e.,

$$F_{friction} = \mu_{kinetic} \cdot F_{normal} = \mu_{kinetic} \cdot W_{car}.$$

  How can you, as engineer, use this property to design a race car? How about a tractor?
- Connect the Newton's scale to the LEGO car and ask students to measure the pulling force, see Image 6.

**Image** Insert Image 6 here, right justified so text wraps around it

**Image 6**

**ADA Description:** Students taking measurements of the pulling force of the LEGO car.

**Caption:** Students taking measurements of the pulling force of the LEGO car.

**Image file:** TE_img6.jpeg

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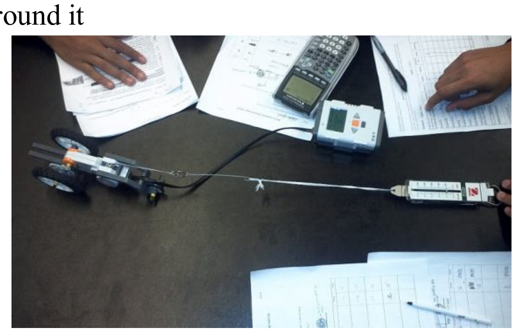

- Have students analyze a free body diagram of the set up and determine the difference between the pulling force and the force generated by the motor. The diagram should help them understand the direction of motion and the magnitude of the pulling force.

- Have students derive the relation between pulling force, force generated by the motor, $F_{motor}$, and the force of friction, $F_{friction}$ , i.e.,

$$F_{pull} = F_{motor} - F_{friction}.$$

- Have students calculate the force generated by the motor, $F_{motor}$.

### Safety Issues

None

### Associated Activities

Have students analyze the relation between mass, force of friction and the pulling force by measuring pulling force of the same cars but with different weights.

### Lesson Closure

Have students discuss the types of forces that cars need to overcome to move itself from rest? What kind of forces does the car need to overcome to move a heavy object from rest? Ask students to ponder about the problem about Massis that was given in the Introduction section. What types of forces did Massis have to overcome to move the train car from rest?

### Pre-lesson Assessment

*Do Now in Worksheet_Force_analysis_of_a_moving_vehicle(doc).*

### Post-lesson Assessment

Post-questions in the *Worksheet_Force_analysis_of_a_moving_vehicle(doc)* or have students do "Battle Bots" by Zachary Nishino (submitted to teachengineering.org)

### Lesson Extension Activities

"Battle Bots" by Zachary Nishino (submitted to teachengineering.org)

### Additional Multimedia Support

None

### References

[1] Halliday, D., Resnick, R., Walker, J., "Fundamental of physics" 6th ed, John Wiley & Sons, 2001.

### Attachments

Worksheet_Force_analysis_of_a_moving_vehicle (doc)

Presentation_Force_analysis_of_a_moving_vehicle (ppt)

BattleBot_robot (ldd)

### Other

None

### Redirect URL

None

### Contributors

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### Supporting Program

AMPS/CBRI, Department of Mechanical Engineering at Polytechnic Institute of NYU

**Version: November 2011**