Materials and Manufacturing, Agricultural Engineering

Tires or Tracks

Grade Level(s): 3 - 5

Academic Content Areas: Science, Technology, and Mathematics

Topics: Physical Science; Science and Technology; Scientific Inquiry; Design; Patterns, Functions and Algebra; and Data Analysis and Probability

Designates a recommended area of co-teaching for an AFRL Engineer or Scientist

Main Problem / Essential Question

Which is better for moving across different types of terrain, tires or tracks?

Summary

The goal of this investigation is to evaluate the performance of tires and tracks using a Mindstorm Lego robotic vehicle. The performance of the robotic vehicles will be evaluated by testing how they move over various types of terrain and inclines.

For this investigation, students will be asked to modify a robotic vehicle with tires that can move in a straight line over various courses with different types of terrain and inclines. The students will make measurements of the time it takes for their robotic vehicles to travel a fixed distance from starting line to finish line for each of the four courses. The robotic vehicle should not be modified until it has been tested three times on each of the four courses. At least one of the obstacles should be large enough that a robotic vehicle with tires cannot pass over it (examples provided in Appendix G).

1. The first course will be smooth and flat.
2. The second course will be smooth and have a steep incline of approximately 30 degrees. The angle of the incline should be large enough that most of the students' robotic vehicles with tires cannot travel up the incline without slipping.

3. The third course will have obstacles such as trenches or speed bumps that the robotic vehicle must travel over to reach the finish line.
4. The fourth course will be flat a littered many small objects such as dry beans strewn across it. The quantity, size and shape of the objects should be chosen to cause slippage of robotic vehicles with tires.

Following tire terrain trials, students should now have a discussion about the performance of their robotic vehicles with tires over the four courses. From this discussion, the students should create a list of criteria for a "better" robotic vehicle. Some possible criteria include: finishes the race, speed, and travels in a straight line.

The students should now modify their robotic vehicles so that they have tracks instead of tires. The design of the new robotic vehicles with tracks should take into account the students' criteria for a "better" robotic vehicle. The students should then test their new robotic vehicle three times on each of the four courses, measuring the time from start to finish for each test.

In conclusion the teacher will lead a post activity discussion to address critical thought questions such as; which design is faster, which design affords the robot most success with obstacles, which design is most reliable, how does the engineering design process help you to explore and solve this problem, why was it important to identify variables and conditions and not modify the throughout testing.

Big Ideas / Focus

Exploring basic principles of vehicular design, this lesson presents several potential connections to industry. There is a connection to the agricultural industry with robotic vehicles that can work in the fields. Mechanized solutions to agricultural production and processing problems require careful engineering of underlying tread systems to maximize versatility and maneuverability. There is a connection to the police and the military with the design of Unmanned Ground Vehicles (UGVs) for Explosive Ordinance Disposal (EOD). These robots keep people safe by keeping them far away from the explosives. They typically operate in rugged environments, necessitating a design that can easily traverse obstacles. There is a connection to the automotive industry, which is focused on improving the stability and safety of passenger vehicles while driving on dangerous road surfaces. There is a connection to both civilian and military aviation with the design of landing gear appropriate to an aircraft's size, momentum, and typical runway conditions.

In this lesson, students are presented with courses for their robotic vehicles that are difficult for a robotic vehicle with tires to complete. The students should come away from this lesson with an understanding that it is easier to complete a course that has difficult terrain or a steep incline when they use a robotic vehicle with tracks. The higher friction of the tracks is better at preventing slipping under these conditions.

Each group of students will investigate how the force of friction on a robotic vehicle changes its motion over a straight course. The students will identify one or two variables and evaluate them in a series of simple experiments to predict how those variables affect the motion.

After determining the variables to be tested, students will design an experiment and create a data table to organize and record their results. This data table should make it easier to compare and analyze results with other groups. Students will identify and select the appropriate measurements and tools needed to determine the distance and time it takes a robot to travel down the course. Students will use the data collected to practice converting their original results to an equivalent unit in the same measurement system. For example: inches to feet, millimeters to centimeters, and centimeters to meters. Other calculations students can determine are the ranges of data collected, the speed of the vehicles using the formula s=d/t (speed = distance divided by time), and the mean speed for each variable. Students can create graphs of their results to help them explain their results to the other groups.

After completing their calculations, students will evaluate their observations and measurements made by themselves and others and then identify possible reasons for any discrepancies.

Not only does this lesson address items in the Academic Content Standards; it utilizes higher level thinking skills. Students will use the engineering design process to design and build a robotic vehicle to travel over different terrains and inclines. They will observe and re-design to make improvements. All of this will be done in a cooperative learning environment, allowing the students to gain an understanding of the "TEAM" concept by working in groups.

Prerequisite Knowledge

The students should have a basic understanding of how to use a stop watch to measure time and how to use a yard/meter stick to measure distance. They should then know how to convert original results to an equivalent unit in the same measurement system. For example: inches to feet. A demonstration can be done to explain how to determine the speed of a vehicle using the formula Speed=Distance/Time (s = d/t).

Students should be able to do basic mathematical computations (add/subtract/multiply/divide). A demonstration can be done to show students how to take the data collected from an experiment to find the mean, median, mode and range.

Students should be able to record and organize data collected in a data table. They should also know how to graph the results of an experiment.

The students should be able to use the scientific method when conducting an experiment. They should understand how to make predictions and be able to support their predictions with scientific reasoning.

The students should be able to make and carefully record scientific observations.

Students should understand the force of friction as a resisting force.

Standards Connections

Content Area: Science

Physical Science Standard: Students demonstrate an understanding of the composition of physical systems and the concepts and principles that describe and predict physical interactions and events in the natural world. This includes demonstrating an understanding of the structure and properties of matter. In addition, it includes understanding the nature, transfer and conservation of energy; motion and the forces affecting motion; and the nature of waves and interactions of matter and energy. Students demonstrate an understanding of the historical perspectives, scientific approaches and emerging scientific issues associated with the physical sciences.

Grade band 3-5 – Benchmark C: Describe the forces that directly affect objects and their motion.	1. Describe an objects motion by tracing and measuring its position over time. (grade 3) 2. Identify contact/noncontact forces that affect motion of an object (e.g., gravity,

	magnetism, and collision). (grade 3) 3. Predict the changes when an object experiences a force (e.g., a push or pull, weight and friction). (grade 3)

Science and Technology Standard: Students recognize that science and technology are interconnected and that using technology involves assessment of the benefits, risks and costs. Students should build scientific and technological knowledge, as well as the skill required to design and construct devices. In addition, they should develop the processes to solve problems and understand that problems may be solved in several ways.

Grade band 3-5 – Benchmark B: Describe and illustrate the design process.	1. Use a simple design process to solve a problem (e.g., identify a problem, identify possible solutions and design a solution). (grade 3) 2. Describe, illustrate and evaluate the design process used to solve a problem. (grade 4)

Scientific Inquiry Standard: Students develop habits of mind as they use the processes of scientific inquiry to ask valid questions and to gather and analyze information. They understand how to develop hypotheses and make predictions. They are able to reflect on scientific practices as they develop plans of action to create and evaluate a variety of conclusions. Students are also able to demonstrate the ability to communicate their findings to others.

Grade band 3-5 – Benchmark B: Organize and evaluate observations, measurements and other data to formulate inferences and conclusions.	1. Discuss observations and measurements made by other people. (grade 3) 2. Record and organize observations (e.g., journals, charts and tables). (grade 3)
Grade band 3-5 – Benchmark C: Develop, design and safely conduct scientific investigations and communicate the results.	1. Develop, design and conduct safe, simple investigations or experiments to answer questions. (grade 4) 2. Explain the importance of keeping conditions the same in an experiment. (grade 4) 3. Describe how comparisons may not be fair when some conditions are not kept the same between experiments. (grade 4) 4. Identify one or two variables in a simple experiment. (grade 5)

Content Area: Technology

Design Standard: Students apply a number of problem-solving strategies demonstrating the nature of design, the role of engineering and the role of assessment.

Grade band 3-5 – Benchmark A: Describe and apply a design process to solve a problem.	1. Apply the design process to purposefully solve a problem (e.g., how to improve recycling at school and home). (grade 4) 2. Recognize when changes to a solution are needed to meet the requirements. (grade 4) 3. Use data to test and evaluate the prototype solution. (grade 5) 4. Analyze the requirements for a design including such factors as the desired elements and features of a product or system and limits that are placed on the design. (grade 5)
Grade band 3-5 – Benchmark B: Describe how engineers and designers define a problem, creatively solve it and evaluate the solution.	1. Demonstrate steps used in the engineering design process including defining the problem, generating ideas, selecting a solution, testing the solution, making the item, evaluating the solution, and presenting the results. (grade 5)
Grade band 3-5 – Benchmark C: Understand the role of troubleshooting in problem-solving.	1. Apply the process of experimentation to solve a technological problem (e.g., test which glue works best for a given material). (grade 4)

Content Area: Mathematics

Patterns, Functions and Algebra Standard: Students use patterns, relations and functions to model, represent and analyze problem situations that involve variable quantities. Students analyze, model and solve problems using various representations such as tables, graphs and equations.

Grade band 3-4 – Benchmark G: Describe how a change in one variable affects the value of a related variable.	1. Describe how change in one variable affects the value of a related variable (e.g., as one increases the other increases or as one increases the other decreases). (grade 4)
Grade band 5-7 – Benchmark J: Use a formula in problem-solving situations.	2. Model problems with physical materials and visual representations, and use models, graphs and table to draw conclusions and make predictions. (grade 5)

Data Analysis and Probability Standard: Students pose questions and collect, organize, represent, interpret and analyze data to answer those questions. Students develop and evaluate inferences, predictions and arguments that are based on data.

Grade band 3-4 – Benchmark A: Gather and organize data from surveys and classroom experiments, including data collected over a period of time.	1. Collect and organize data from an experiment, such as recording and classifying observations or measurements, in response to a question posed. (grade 3) 2. Represent and interpret data using tables, bar graphs, line plots and line graphs. (grade 4)
Grade band 5-7 – Benchmark E: Collect, organize, display and interpret data for a specific purpose or need.	1. Determine appropriate data to be collected to answer questions posed by students or teacher, collect and display data, and clearly communicate findings. (grade 5) 2. Modify initial conclusions, propose and justify new interpretations and predictions as additional data are collected. (grade 5)

Preparation for activity

Day 1: Pre-Activity:

1. Pre-test (Appendix A)
2. Shipping box from The Air Force Research Laboratory (AFRL) that contains
    a. Manila envelope enclosing Request for Proposal (RFP) letters (Appendix B)

       Optional: Arrange for an AFRL engineer to deliver the RFP and discuss engineering challenge.
    b. Constructed robot base with tires and tracks (Separate lesson document: Build guide).
    c. Bubble wrap and /or packing peanuts
3. Assign students to engineering teams (reference instructional tips section)
4. Engineering Design Process Handout (Appendix C)
5. Sample Data Chart (Appendix D)
6. Pre/ post- test Rubric (Appendix E)
7. Pre/ post- test answer key (Appendix F)

Day 2:

1. Constructed robot base for each team
2. A set of four tires and two tracks for each team
3. Team role guidelines (suggestions provided in Student roles section)

Optional: Arrange for an AFRL engineer to participate in students engineering challenge.

Day 3:

1. Test courses 1 through 4 (Appendix G: Course Design Primer)
2. Stop watch for each group
3. Meter stick for each group
4. Data charts and/or science journal

Optional: Arrange for an AFRL engineer to participate in students engineering challenge.

Day 4 & 5:

1. Challenge course
2. Class set of Engineering Performance Assessment Rubrics (Appendix H)
3. Data charts and/or science journal

Day 6: Post-Activity:

1. Post-test (Appendix A)
2. Post-test Rubric (Appendix F)

Critical Vocabulary

Data - individual facts, statistics, or items of information

Friction - a resistant force that can slow movement

Incline - The degree to which a straight line varies either vertically or horizontally.

Measurement - A method of determining quantity, capacity, or dimension.

Robot - A machine or mechanical device that is capable of performing tasks on its own.

Stability - The ability of a vehicle to remain upright or return to its original position when in motion.

Terrain - an area of land or ground

Tires - A ring or band of rubber placed over the rim of a wheel to provide traction.

Tracks - A continuous band of linked plates passing over two or more wheels.

Variables - The part of an experiment that changes while everything else remains the same.

Wheels - A circular frame or disk arranged to revolve on an axis.

Timeframe
Identify the daily breakdown of the lesson activities. Include time allotments for each activity as well as scheduled time for the administration of the Pre-Test and Post-Test.

Day	***Time Allotment***	***Activities***
1	45 - 60 min.	Pre-Test and Hook
2	45 min	Assign student roles, familiarize teams with materials for investigation of problem, teams design experiments
3	60 - 80 min	Student teams investigate and collect data
4 & 5	45 min	Student teams analyze and report results to class
6	45 min.	Post-Test and Problem Reflection

Materials & Equipment
<u>Handouts / Assessments / Paperwork</u>

Pre-tests	1 per student
Pre-activity RFP letters	1 per student
Data charts and/or Science journal	1 per student
Grading rubrics	1 per student
Post-tests	1 per student
Engineering Performance Assessment Rubric	1 per student

<u>General supplies</u>

Stopwatches	2 per team
Protractors	2 per team
Meter Sticks	1 per team
Calculators (optional)	1 per team
Shipping Box (AFRL Hook)	1 per class
Large Envelope (to hold RFP's: Appendix B)	1 per class
Bubble Wrap or packing peanuts	(Enough for shipping box)

A large, wheeled tote to carry all equipment is helpful

Courses (Appendix G)

Masking Tape	1 to 2 rolls
Ramp material, (3 ft. shelving board 12 in wide)	1 for each set of courses set up or 1 for every four groups
Textbooks (about 1-2 in thick, wood, pencils)	2 to 3 for every four groups
Jump rope	1 for every four groups
Dry beans, cereal, sand	25 lbs. for every four groups

Teacher's Note: Ramps may be prefabricated

Robots

Base robot with wheels	1 per group
Four tires	1 per group
Two tracks	1 per group

Teachers Note: For each robot, you will need **1 LEGO® MINDSTORMS® Education NXT Base Set kit and 1 NXT Education Resource Kit**. The NXT kits will contain the parts necessary to build the base robot with wheels and have four tires and twotracks, see Appendix L,to build.

Classroom cleanup

Dust pan and broom	Optional: 1 per class
Large tarp (to set courses on)	Optional: 1 per class

Safety & Disposal

There are no hazardous materials that require specific disposal instructions. Please refer to instructional tips to view set-up suggestions that will aid in clean-up and disposal.

Pre-Activity Discussion

The teacher picks up a large shipping box (prepared ahead of time with bubble wrap, peanuts etc.) and begins to open it at the beginning of class. As she/he is doing this, they explain to the class that they received this package from AFRL before work today. The first thing the teacher pulls out of the box is a large manila envelope which contains a class set of the RFP (request for proposal) letters (Appendix B). The teacher then passes out a letter to each of the students and they read it as a class. This letter explains to the class what they will be doing. The box also contains a pre-built "base" robot, a set of four tires, and two tracks that can be pulled out of the box as they read the letter.

After reading the letter, the teacher will need to guide the discussion using questions to help the students determine what information they will need to collect, to set up data charts, to write up a materials list for the equipment they would need to use, etc.

Possible Questions:

- Can you think of examples in real life where similar vehicles have different tires? *Ex: Racing tires vs. mountain bike tires.*

- What is the letter asking us to do? *Answers will vary. Acceptable answers include: design a test, test tracks and tires three times, and record results.*
- What is the difference between wheels, tires and tracks? Answers will vary. *See definitions provided in vocabulary for appropriate response, photographs, webquests may be helpful for understanding the difference.*
- How can we determine speed? *Acceptable answers include: speedometer on a car, calculate by determining the amount of time it took to go a certain distance (s = d/t) .*
- How are we going to test each performance standard? *Answers will vary. Acceptable discussion should focus on a test course and the modified robot design.*
- What information do we need to keep collect? *3 trials for each robot design including the time, distance, and speed, as well as observations and average speed of the robot.*
- How are we going to organize the data collected? *Students should recognize that data should be collected in a written format in tables, charts, and notes.*
- What equipment are we going to need? *Robot, tires, tracks, measurement devices such as stop watches and yard sticks, course setup supplies such as glue, tape scissors, etc.*
- How can using the Engineering Design Process (EDP) help students discover a solution?

  Problem: Provided in the RFP

  Question: How can I gather this information?

  Think: Class should brainstorm that they need to build a test course

  Design: Students will modify the robot to gather the effect of the variables (tires versus tracks).

  Test: Students should conduct their experiment

  Solution: Determine the answer based on their tests.

Teacher Instructions

Day 1

Objective: Students will be able to describe how vehicles move and predict results for the engineering challenge.

1. Administer pre-test
2. Conduct pre-activity discussion
3. Form engineering teams (refer to Student roles and Instructional tips)
4. Introduce the Tires or Tracks challenge by showing the NASA video at the website and the “prompt” below: http://www.jpl.nasa.gov/video/index.cfm?id=795

   Prompt: AFRL is looking for a design for their newest vehicle to be deployed to moon in 2015. One of the key components of the vehicle is the “tires.” You will be testing tracks and tires to determine which is better.

5. Distribute Engineering Performance Assessment Rubric (Appendix H) and sample data chart (*optional*-Appendix D, alternative Appendix K).

6. Discuss Engineering Performance Assessment Rubric (Appendix H) and have students develop a data chart in their science journals to gather the data, do the necessary calculations and interpret the results. If time allows, the class should brainstorm data charts and agree on one that the entire class will use.

   An AFRL engineer or scientist could deliver the package and share the design challenge. They can also lead/ help students in the pre-activity discussion and explore the benefits of the Engineering Design Process (Appendix C).

Day 2

Objective: Students will use their knowledge and collaborate with peers to brainstorm conditions for tires and tracks.

Teacher's Note: Tracks should be setup for students to reference and prepare for day 3.

1. Use think-pair-share to brainstorm all conditions and types of tires and/or tracks that would be best. See website for helpful hints on think-pair-share strategy http://www.youtube.com/watch?v=ykSZdq2kpwg
2. As a team, define what "better" or "best" means in this robotic challenge.
3. Introduce the robot chassis and basic controls of the robot.

An AFRL engineer or scientist can help students brainstorm on robotic design and scenarios in which that robot will be appropriate. This volunteer can relate this design challenge to real world scenarios.

Day 3

Objective: Students will test the four courses, collect data, and analyze data.

1. Test robot chassis on the four courses provided, see Appendix G.
2. All students record all data and observations in data chart provided.
3. Have students critically analyze data to determine whether tires or tracks would be better based on knowledge gained to this point.

4. The students should now modify their robotic vehicles so that they have tracks instead of tires.

   Teacher's Note: The design of the new robotic vehicles with tracks should take into account the students' criteria for a "better" robotic vehicle. The students should then test their new robotic vehicle three times on each of the four courses, measuring the time from start to finish for each test.

5. As a class, discuss the role of friction on the tires and tracks. Because there is less robotic material touching the surface of the course when the tires are being used there is less friction. Since the tracks are in constant contact with the surface of the course they experience more rolling friction.

6. Lead a brief discussion on the effects of different variables (tires, tracks, courses). Establish terminology of variables.

   An AFRL engineer or scientist can help students throughout their robotic challenge and data collection. This volunteer can relate this design challenge to real world scenarios and discuss how engineers use the Engineering Design Process to solve different problems.

Day 4 & 5

Objective: Students will use prior knowledge to demonstrate their choice of "best" treads and discuss the outcomes with the class.

1. Introduce the "Challenge Course." (Appendix G). This will be used as an assessment tool.
2. Predict whether tires or tracks will be better for this course based on prior knowledge.
3. Have the robot complete the course with tires and tracks.
4. Collect data and record observations.
5. Determine final recommendation based on evidence, peer evaluations and observations.
6. Conduct wrap-up session/discussion according to the post activity discussion section.

Have an Air Force Engineer come to your class and propose a "challenge course"(of which you and the Engineer predetermine) to the students, explain AFRL's interest in determining whether tires or tracks are appropriate for the represented terrain This course should not require a definitive answer, but allow students to explain the trade-offs inherent in each design.

Day 6

Objective: Students will demonstrate knowledge and mastery of skills and content knowledge.

1. Administer post-test (Appendix A).

Background Information

With the development of any specialized vehicle, the question, "Which is better: a vehicle that has tires or one that has tracks ?" surfaces again and again. In order to answer this question, the U.S. Army has tested and studied the benefits and shortfalls of vehicles having tires and tracks for combat platforms for the past 30 years. Results indicate that no single criterion can be applied that will answer the tires-versus-track issue for all situations and missions. In fact, the underlying premise in resolving the tires-versus-track dilemma is deeply rooted in the complex variables regarding the vehicle's role, terrain profile, and specific vehicular characteristics such as weight. A general summary of where one design excels over the other is shown in the following table.

Table 1.Results of Prior Study on the Performance of Vehicles with Tracks versus Tires

Study Results	Tracks	Tires
Route Flexibility	X	
Cross Country Mobility	X	
Traction on Slopes	X	
Road Speed		X
Logistics		X
O&S Costs		X
GVW, Volume and Payload	X	
Maneuverability/Turning Radius	X	
Transportability	X	
Weight Growth Potential	X	
Gap and Obstacle Crossing	X	

From a mobility perspective, vehicles having tires tend to have a considerably higher ground pressure than that of their tracked counterparts. This implies inferior performance for vehicles that have tires when used on soft ground. Tracked vehicles offer the best solution for a versatile platform that is required to operate over diverse terrain, including extremely difficult ground, because tracks inherently provide a greater surface area than tires, resulting in better traction.

On roads, the average rolling resistance of tracked vehicles equals four percent of their weight, while that of their counterparts fitted with cross-country tires equals only two percent their weight. Because tires have half the rolling resistance of tracks, vehicles with tires need less fuel and can cover longer distances by road before they need to be refueled. These longer distances are also accomplished at a much faster speed. These advantages of wheeled vehicles disappear, however, when they move off-road. Then their fuel consumption may be at least as high as that of tracked vehicles of equal weight, and their speeds must drop considerably as well.

Agility is harder to measure to award a clear winner. Compared to a tracked counterpart of equivalent weight and engine output, we can expect a vehicle having tires to have higher speed and better acceleration. When it comes to zigzagging, both types of wheels are comparable. Tracked vehicles can pivot in place, while vehicles having tires have more responsive steering over even terrain.

Vehicles having tires are also generally less expensive to design and build than their tracked counterparts since their designs are simpler. They also tend to be less expensive to operate. As noted above, they travel farther than tracked vehicles for the same quantity of fuel, and maintenance requirements also are less burdensome.

Clearly, there is no single right answer to this lesson. It is up to the students to experiment and observe where one design excels over the other. As with most engineering problems, the performance in one area may come at the cost of another design variable. It is left up to the young engineers to decide for themselves what are the most important design variables to meet the goals of the individual courses.

References:
Paul Hornback, “The Wheel Versus Track Dilemma”, Armor Magazine, March-April 1998, http://www.globalsecurity.org/military/library/news/1998/03/2wheels98.pdf

Lutz Unterseher, “Wheels or Tracks? On the 'Lightness' of Military Expeditions”, Project on Defense Alternatives, *Briefing Memo* #16, July 2000 (revised December 2001), http://www.comw.org/pda/0007wheels.html

Instructional tips
To make this lesson more successful, instructors should give careful consideration to grouping of the students. Choose students who work well together. Four students per robotics kit is recommended. If you have to use bigger groups, be sure that roles and responsibilities are clearly defined, as discussed in the student roles and responsibilities section.

Assignment of Student Roles and Responsibilities:

Students will all assume different roles:

Role Name	***Brief Description***
Mechanical Engineer	Responsible changing the NXT Lego Robotics base tires and tracks assembly.
Timer	Responsible for operating the stop watch during the experiments.
Operations Manager	Responsible for setting up the experiment and running the NXT Lego Robotics base through a variety of different courses.
Recorder/Technical Writer	Record the observations of team members and data collection tools throughout the experiment.

Student Instructions
Located in Appendix I.

Formative Assessments
Students will be administered a pre-and post-test.

Students will also be assessed using the Engineering Performance Assessment Rubric (Appendix H) on their ability to organize and accurately record data, calculation of the mean speed of their robot designs, and analyzing and interpreting their results. After analyzing their results the student groups will decide on the best prototype robot to use for the final obstacle course.

Post-Activity Discussion

1. Which modification made for a faster robot – tires or tracks? Why? *Answers will vary; students should support their answers with evidence.*
2. Which allows the robot to move over obstacles the best – tires or tracks? Why? *Students should support their answers with evidence and determine that tracks allow for more maneuverability.*
3. Which is the most reliable – tires or tracks? Why? *Students should support their answers with evidence and determine that tracks are more reliable for course completion.*
4. Which would you recommend to AFRL for the new vehicle– tires or tracks? Why? *Answers will vary; students should support their answers with evidence.*
5. Discuss the role of the Engineering Design Process in the student's decision making process.
6. Discuss why it is important to keep conditions the same in any experiment.

An AFRL Engineer can encourage and provide positive feedback as students present their findings. They can ask questions that require students to draw conclusions from their collected observations and measurements exemplifying the importance of reliable data collection.

Technology Connection

Use the **ADISC** Model created by ITEL to plan the use of technology in this lesson/activity. (Reference your handbook for more information on the ADISC model.)

Integration Model	***Application Description***
Technology that supports students and teachers in **dealing effectively with data**, including data management, manipulation, and display	Protractor may be used to measure angles of inclines. Calculators may be used to help students check their equations. Stop watches will be used to time trials.
Technology that supports students and teachers in conducting **inquiry**, including the effective use of Internet research methods	Tires and Tracks will serve as variables for experimentation. LEGO® MINDSTORMS® Robot is the vehicle required for students to conduct investigation. Protractor may be used for students to measure the angles of incline for various courses. Stop watches will allow student to record amount of time necessary for trials.

Technology that supports students and teachers in **simulating** real world phenomena including the modeling of physical, social, economic, and mathematical relationships	Students may view videos of examples of various vehicles operating in rugged environments such as police, military, space, or agricultural vehicles that are provided in the references section. LEGO® MINDSTORMS® robot simulates a life size vehicle.

Interdisciplinary Connection

Social Studies: Using Time for Kids or Newsweek for kids, find articles that explain how robotics are being used in the department of defense, for public safety, and more.

Social Studies: Using online research, students should construct a timeline of the history of robotics, identifying the time in which the first robot was created and how it was used up to the present.

Language Arts: Once students have tested the robot and identified how it is most effective, they can write a paragraph that explains one application for the robot.

Language Arts: Students can take the point of view of the robot and use figurative language such as personification to write a narrative of the robot's adventures in a day.

Propose big-picture technical challenges that face the DOD and our nation, emphasizing the need for professionals with particular skill sets and backgrounds. Explain how students can start acquiring these skills both in and out of school.

Home Connection

Students and parents can explore different types of vehicles that use tires and tracks and report back to the class on their performance and specific functions as they move over various types of terrains and inclines (parents can help their child differentiate the pros and cons to each type).

Students and parents can visit a construction site or farm where various vehicles are used that have tires and tracks to be able to further understand their function.

Students can sign out a small LEGO® MINDSTORMS® kit to bring home. This kit should contain enough pieces to create a chassis with tires so students can further explore the differences between tires and tracks. With their personalized vehicle, students can demonstrate for family members how the vehicle moves over various terrains. Students can have family members help them design other "vehicles" propelled by tires or tracks.

Students can estimate the speed of an activity (running –track, baseball throw, bicycle by timing the event for a known distance).Students can also estimate how long it will take to travel to grandma's, the store, etc, based on the average speed during the trip.

Differentiated Instruction

Inquiry can be more or less teacher-guided

Students can be challenged to create program on the computer for their vehicle.

Students can be challenged to create another vehicle to be used for testing

Students can construct mathematically accurate “blue prints” of their vehicle or use Google sketch-up to create their design.

Assessment can be group based versus individually measured

Students who need more structure can be given more constraints for their vehicle, such as: vehicle can be preassembled or preprogrammed.

Extension

There are many additional ways to provide challenges to your students based on their needs within this lesson. Below are listed a few, arranged by category.

TIME: Expand the number of days for the lesson to provide additional time for testing.

COURSES: The types of courses listed are simply suggestions. You can add additional courses using commonly found items or even combine multiple “textures” to one course. Students could suggest and/or create courses for other students to test. Students could create the “Challenge Course.” The length of the course could vary depending on time and space.

MOTION OF ROBOT: The current motion of the robot is straight forward. If time allows and you have the flexibility to allow students to change the motion, then the possibilities to expand this lesson grow exponentially. The basic robot comes with space to “program” up to five steps. Teaching the students how to program the robot using the NXT-G programming software would enhance this lesson and provide opportunities to program much more complex actions to be completed on the courses.

ROBOT DESIGN: The design for the robot is standardized to keep the lesson simple. However, there are endless possibilities for robot design. The only limitations are the number of robots, amount of LEGOs available, and time. The focus of this lesson is on the tires and tracks, not so much on design. You could easily modify this lesson to allow for more creativity in the robot design. You could also let the students build the robots by following the set of directions included in this lesson.

TESTING: The number of tests for each course could be increased to provide a better data trend. It would also provide students with more opportunities to make observations, analyze the information gathered, and make a more solid conclusion.

Additional Math standards can be addressed through this lesson if time allows. An optional math worksheet is provided in Appendix K (Data Analysis and Probability, Patterns, Functions and Algebra, Number, Number Sense and Operations).

Career Connection

The design of tire and tread systems is a complicated endeavor requiring specialists from across engineering disciplines. Engineers take into account functional and performance requirements of a vehicle such as maneuverability or safety, define key performance parameters, and conduct extensive evaluations of their designs to meet these specifications. Oftentimes, these evaluations are supported by computer-aided design (CAD) packages or modeling and simulation (M&S) toolkits that facilitate virtual testing. Because of this emphasis on computer-aided analysis, important career connections can also be made to software engineering and the computer sciences.

Mechanical engineers in the Armed Forces design vehicles for multiple uses including civilian, police, and the military uses. For example: mechanical engineers design Unmanned Ground Vehicles (UGVs) for Explosive Ordinance Disposal (EOD). These robots keep people safe by keeping them far away from the explosives. They typically operate in rugged environments, necessitating a design that can easily traverse obstacles. Additionally mechanical and materials engineer study wheel design for military vehicles such as transport vehicles and tanks that may need to operate in various types of terrain.

Engineers in the automotive industry, study wheel and tire design with the focus of improving the stability and safety of passenger vehicles while driving on dangerous road surfaces.

Agricultural Engineers: Often times focus on increasing efficiency of agricultural practices.These practices rely heavily on machinery properly designed for the environment it is meant to be used in. Manufacturing companies must study the issues such as tires or tracks when designing new farm machinery for multiple goals such as planting preparation and harvesting. Mechanized solutions to agricultural production and processing problems require careful engineering of underlying tread systems to maximize versatility and maneuverability.

Additional Resources

Additional Resources	*Purpose and Application*
http://www.lego.com/eng/education/mindstorms/default.asp	Lego Education is a good starting point for teachers to find basic information about designing and programming a LEGO® MINDSTORMS® Robot.
http://www.teachervision.fen.com/group-work/cooperative-learning/48547.html	This website will further explain how to use the Think Pair Share strategy.
http://edtech.kennesaw.edu/intech/cooperativelearning.htm	This website will further explain how to use cooperative learning in the classroom
http://www.theworks.org/fb/teachers/engineering_design_process.html	This is a website that explains how to implement the Engineering Design Process in your classroom. It gives cooperative learning activities that use the EDP.

Cited Sources

Lutz Unterseher, “Wheels or Tracks? On the 'Lightness' of Military Expeditions”, Project on Defense Alternatives, *Briefing Memo* #16, July 2000 (revised December 2001), http://www.comw.org/pda/0007wheels.html

Paul Hornback, “The Wheel Versus Track Dilemma”, Armor Magazine, March-April 1998, http://www.globalsecurity.org/military/library/news/1998/03/2wheels98.pdf

Credits

Ann Drake - Contributing author
Laurie Hawkins - Contributing author
Kim Hemmelgarn - Contributing author
1st Lt Matt Lenzo - Contributing author
Bruce Preiss - Contributing author
Wendy Shelton - Contributing author
Todd Smith - Contributing author
Bev Stambaugh - Contributing author
Kim Puckett - Contributing author, Editor
Sandra Preiss – Administrative Editor
Dr. Margie Pinnell – Administrative Editor

Teacher Reflections

- Were students focused and on task throughout the lesson? *Insert answer here.*
- If not, what improvements could be made the next time this lesson is used? *Insert answer here.*
- Were the students led too much in the lesson or did they need more guidance? *Insert answer here.*
- Did the students learn what they were supposed to learn? *Insert answer here.*
- How do you know? *Insert answer here.*
- How did students demonstrate that they were actively learning? *Insert answer here.*
- Did you find it necessary to make any adjustments during the lesson? *Insert answer here.*
- What were they? *Insert answer here.*
- Did the materials that the students were using affect classroom behavior or management? *Insert answer here.*
- What were some of the problems students encountered when using the …? *Insert answer here.*
- Are there better items that can be used next time? *Insert answer here.*

Appendix A: Pre/Post-test

Name________________________________

1. During a lab the distance a toy car traveled was 1.5 meters in 5 seconds.

   A. How many cm (centimeters) did the car travel? Please show your work.

   B. How many mm (millimeters) did the car travel? Please show your work.

   C. Calculate the speed of the toy car. Please show your work. Use the formula s=d/t or speed = distance / time.

Use the following description of an investigation to answer questions 2-4

You have been asked to design a robot that can move quickly over a course with a varied surface. The surface is partially flat and smooth, bumpy with obstacles to climb over, and has a 45 degree incline or slope. The robot kit contains two assembly options that can be used to finish the robot.

A. You can use 4 wheels hubs with tires.
B. You can use 4 wheel hubs with two tracks mounted on them.

2. Which assembly option A or B would you use if you wanted the robot to go as fast as possible over the varied surface described above? Explain your reasoning.

3. Describe the specific materials and information you would need to collect in order to determine which assembly option (A or B) would work the best.

A. List **at least 4 materials** needed for this investigation:

C. List of Information to record during the investigation. Include **at least 7 pieces** of data that should be collected.

4. Use the specific information you listed in question #3 above to create a sample data chart that you could use to record your investigation results.

   <u>Draw the data chart on the back of this paper.</u>

   Include **at least 7 pieces** of data that should be collected.

Appendix B: AFRL Request for Proposal (RFP)

Dear Engineering Teams:

The Air Force Research Lab is looking for a design for their newest vehicle to be deployed in 2015. This land based vehicle must be able to withstand varied terrain including on and off road environments. One of the key components of this vehicle is the choice in tires or tracks which will afford the vehicle its mobility. You will be testing tracks and tires on the prototype robots to determine which would be better to use on the vehicle. We have sent you samples of our pre-assembled “base” robot. Each robot also has a set of 4 tires and a set of 2tracks. These robots have been programmed to travel in a straight line.

Our design needs and performance standards:

We need you to build and test several prototype robots using the tires and the tracks to determine the following:

1. Which design is the fastest?
2. Which design allows the robot to move over obstacles the best?
3. Which design is the most reliable?

Use the following list to make sure your data collection is complete for each of the prototype robot designs you test.

Each design team needs to test their “base” robot designs for each of the 3 performance standards listed above.

Design #1:

- Design description of prototype design of the “base” robot (tires or tracks)
- Observations: (This includes a general description of what your robot could or could not do on the test course.)
- Performance Standard passed:

  ____ Goes fast (include the mean speed and the data collected)

  ____Goes over obstacles: (Description of what it could or could not go over.)

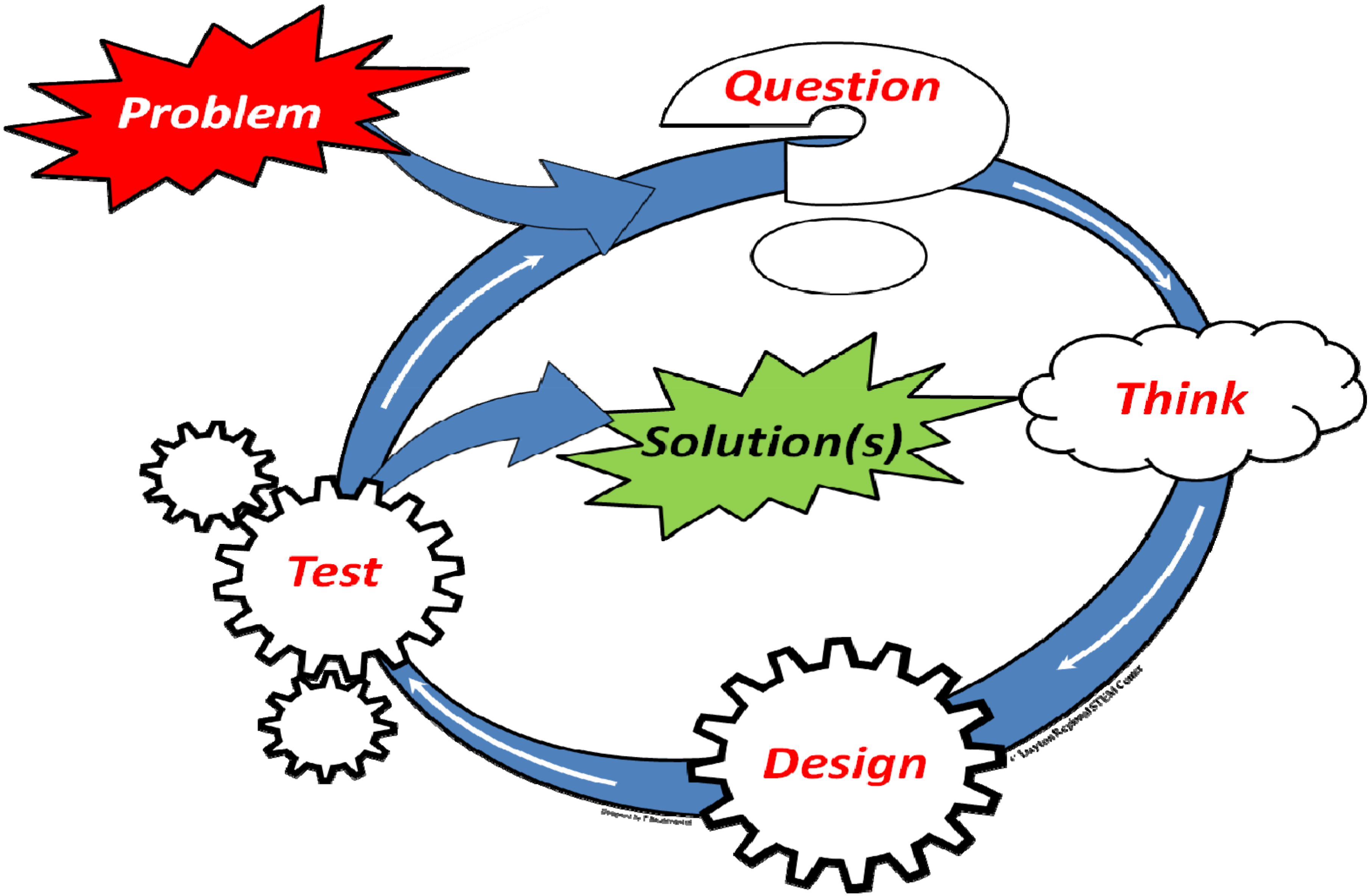
  ____ Shows reliability (The design finishes the testing course)

Thank you very much for helping to collect this information. We look forward to hearing about your results. Your valuable results will help us design a faster, more flexible and reliable vehicle.

Sincerely,

AFRL Representative

Appendix C: Engineering Design Process



Appendix D: Sample Data Charts

Name__________________________________

Data Charts

Tires versus Tracks

Tire results

Robot with tires	**Time (s)**	**Distance (cm)**	**Speed (cm/s)**	**Observations and description of course**
Trial #1				
Trial #2				
Trial #3				
Average Speed calculated (show your work):				Overall comments:

Track Results

Robot with tracks	**Time (s)**	**Distance (cm)**	**Speed (cm/s)**	**Observations and description of course**
Trial #1				
Trial #2				
Trial #3				
Average Speed calculated (show your work):				Overall comments:

Appendix E: Pre/Post Test Rubric

If the student does not respond to any of the questions then they receive a score of zero score for that portion of the test.

Question	4 points	3 points	2 points	1 points
Question 1 A. How many cm did the car travel? Show your work.	Answer is correct. Student shows their work. 1.5m x100cm =150cm The student demonstrates that there is 100 cm in every meter and labeled their answer correctly.	Numerical answer is correct. The student shows their work, however the measurement unit is incorrect or missing.	Numerical answer is incorrect. The student shows their work however they made a calculation error however the measurement unit is correct.	Numerical answer is incorrect. The student did not show any work and the measurement unit is either incorrect or missing.
Question 1 B. How many mm did the car travel? Show your work.	Answer is correct. Student shows their work. 1000mm x1.5m=1500 mm. The student demonstrates that there is 1000 mm in every meter and labeled their answer correctly.	Numerical answer is correct. The student shows their work, however the measurement unit is incorrect or missing.	Numerical answer is incorrect. The student shows their work however they made a calculation error however the measurement unit is correct.	Numerical answer is incorrect. The student did not show any work and the measurement unit is either incorrect or missing.
Question 1 C. Calculate the speed of the toy car. Please show your work. Use the formula s= d/t or speed = distance/time.	Answer is correct. Student shows their work. 1.5 meters divided by 5 seconds equals .3m/sec The student demonstrates how to put the correct data into the formula provided and calculate the correct	Numerical answer is correct. The student shows their work, however the measurement unit is incorrect or missing. The student was able to insert the correct data into the formula provided.	Numerical answer is incorrect. The student shows their work however they made a calculation error. OR the student incorrectly inserted the data into the formula provided.	Numerical answer is incorrect. The student did not show any work and the measurement unit is either incorrect or missing.

	answer labeling it accurately.		The measurement unit is correct = m/s	
Question 2 Which assembly option would you use if you wanted the robot to go as fast as possible over the varied surface described above? Explain your reasoning. A. You can use 4 hubs with tires. B. You can use 4 hubs with 2 tracks mounted on them.	Answer B is chosen. The student explains how tires have less friction than tracks on a smooth surface and would be the better choice if the course was smooth and flat. However, the course is varied so in this case the tracks would be more successful traveling over rough surfaces and up a steep incline.	The student selects answer B. The student either explains how tires have less rolling friction than tracks on a smooth surface and would be the better choice if the course was smooth and flat. OR The student discusses how the course is varied so in this case the tracks would be more successful traveling over rough surfaces and up a steep incline. The student does not give both lines of reasoning to support their choice.	The student selects Answer A as a choice and explains that tires would be faster on the smooth flat surface however they fail to address the need for the car to travel over a varied surface and up an incline.	The student does not make a selection of either option A or B. **OR** The student gives incorrect reasoning about how to make the car move on the course. **OR** The student gives a partially correct reasoning but does not identify which option they are addressing.

Question 3 Describe the specific materials and information you would need to collect in order to determine which assembly option (A or B) would work the best. A. List the materials needed for this investigation.	The student answers the question by listing at least 4 materials needed to complete the investigation. Response could include: robot kit, meter stick, stop watch, protractor, data chart, paper, pencil or pen, a surface course that includes a smooth flat surface, a bumpy section and an incline. The student did not include any unnecessary materials on their list.	The student answers the question by listing at least 3 materials needed to complete the investigation. Response could include: robot kit, meter stick, stop watch, protractor, data chart, paper, pencil or pen, a surface course that includes a smooth flat surface, a bumpy section and an incline. The student did not include any unnecessary materials on their list.	The student answers the question by listing at least 2 materials needed to complete the investigation. Response could include: robot kit, meter stick, stop watch, protractor, data chart, paper, pencil or pen, a surface course that includes a smooth flat surface, a bumpy section and an incline. Student may have included 1 or more supplies that would not be required.	The student answers the question by listing only 1 material needed to complete the investigation. Response could include: robot kit, meter stick, stop watch, protractor, data chart, paper, pencil or pen, a surface course that includes a smooth flat surface, a bumpy section and an incline. Student may have included 1 or more supplies that would not be required.
Question 3 Describe the specific materials and information you would need to collect in order to determine which assembly option (A or B) would work the best.	The student answers the question by listing at least 7 possible pieces of information they would need to write down in their notes in the investigation. The list could include the following: 1. How fast did the robot	The student answers the question by listing at least 5-6possible pieces of information they would need to write down in their notes in the investigation. <u>NOTE</u> refer to the list under a score of 4 points. The student may write down 2 or less unnecessary or	The student answers the question by listing at least 3-4 possible pieces of information they would need to write down in their notes in the investigation. <u>NOTE</u> refer to the list under a score of 4 points. The student	The student answers the question by listing at least 1-2 possible pieces of information they would need to write down in their notes on the investigation. <u>NOTE</u> refer to the list under a score of 4 points. The student may write down 4 or more

B. List the information you would need to record during the investigation.	go/ speed? 2. Time measurement in seconds. 3. The distance the robot traveled. 4. The number of trials for each test robot. 5. Observations: Such as: what obstacles the robot can successfully go over, and what obstacles the robot cannot go over. 6. Can the robot go up a 30 degree incline? 7. Results for varying inclines 8. Can the robot finish the entire course? 9. What variables will be tested? 10. What controls need to be determined? 11. Description of the course or measured	irrelevant items on the list.	may write down 3 or less unnecessary or irrelevant items on the list.	unnecessary or irrelevant items on the list.

	distance of the course. The student did not include any unnecessary or irrelevant items.			
Question 4 Use your specific information you listed in question #3 above to create a sample data chart that you could use to record your investigation results.	The student answers the question by neatly and accurately drawing a data chart that includes 7 of the pieces provided in Question 3 B. NOTE an example data chart provided in the Pre-Test /Post-Test document KEY (Appendix F). The student could rearrange the information included. The student does not include any information in the data chart that is irrelevant or unnecessary.	The student answers the question by neatly and accurately drawing a data chart that includes 5-6 of the pieces provided in Question 3 B. The student could rearrange the information included. The student does include 1 or 2 pieces of information in the data chart that is irrelevant or unnecessary.	The student answers the question by neatly and accurately drawing a data chart that includes 3-4 of the pieces provided in Question 3 B. The student could rearrange the information included. The student may include up to 3 pieces of information in the data chart that is irrelevant or unnecessary.	The student answers the question by neatly and accurately drawing a data chart that includes 3-4 of the pieces provided in Question 3 B. **HOWEVER,** the data chart is unorganized or difficult to read due to neatness. The student could rearrange the information included. The student may include up to 4 pieces of information in the data chart that is irrelevant or unnecessary.

Appendix F: Pre/Post Test Answers

1. During a lab the distance a toy car traveled was 1.5 meters in 5 seconds.

A. How many cm (centimeters) did the car travel? Please show your work.

100 cm = 1meter.The car traveled 1.5m x $\frac{100cm}{1m}$ =150cm.

B. How many mm (millimeters) did the car travel? Please show your work.

1000 mm = 1 meter. The car traveled 1.5m x $\frac{1000mm}{1m}$ =1500mm.

C. Calculate the speed of the toy car. Please show your work. Use the formula s=d/t or speed = distance / time.

$\frac{1.5m}{5 sec}$ = .3 meters/ second

Use the following description of an investigation to answer questions 2-4

You have been asked to design a robot that can move quickly over a course with a varied surface. The surface is partially flat and smooth, bumpy with obstacles to climb over, and has a 45 degree incline or slope. The robot kit contains two assembly options that can be used to finish the robot.

B. You can use 4 hubs with tires.
C. You can use 4 hubs with two tracks mounted on them.

2. Which assembly option A or B would you use if you wanted the robot to go as fast as possible over the varied surface described above? Explain your reasoning.

Answers will vary but students should either select A or B option above and provide at least 2 or 3 reasons why they made their choice. In general, tires have less rolling friction than tracks, which enables them to travel at higher rates of speed on smooth horizontal surfaces. For surfaces that are not smooth, or are not horizontal, the additional friction provided by the tracks can prevent slipping. Tracks are generally better than tires for robotic vehicles that will travel over rough surfaces and up steep inclines.

3. Describe the specific materials and information you would need to collect in order to determine which assembly option (A or B) would work the best.

A. List the materials needed for this investigation:

Possible answers may include:

Robotic kit
Meter stick
Protractor
Stop watch
Data chart
A course with a varied surface as described in the problem.
Paper
Pencil/Pencil

B. List of Information you would need to record during the investigation:
Possible answers may include:

How fast the robot goes (Mean speed)
Time measurement
Distance measurement
Number of trials
Observations
List of the obstacles the robot can successfully go over.
List of obstacles the robot cannot successfully go over.
Can the robot go up the 30/45 degree incline?
(Yes, no, or partially)
Can the robot finish the entire course?
What variables will be tested?
What controls will need to be determined?
Description of the course possibly including measured distance

4. Use your specific information you listed in question #3 above to create a sample data chart that you could use to record your investigation results. <u>Draw your data chart on the back of this paper.</u>

Possible Answer:

Robot with tires	*Time(s)*	*Distance (cm)*	*Speed (cm/s)*	*Observations and description of course*
Trial #1				

Trial #2				
Trial #3				
Average Speed calculated:				*Overall comments:*

OR

Robot with tracks	*Time (s)*	*Distance (cm)*	*Speed (cm/s)*	*Observations and description of course*
Trial #1				
Trial #2				
Trial #3				
Average Speed calculated:				*Overall comments:*

Appendix G: Course Design Primer

The robots will be traveling on four different courses. You will need to build at least one of each of the four different types of courses. It is recommended that you have more courses than you have robots so that the students will not have to wait to test their robot on a course. For example, if you have eight robots, you should build two of each of the four courses.

Designing good challenge courses for your LEGO vehicles will require some trial and error, but the following guidelines should help you select appropriate and accessible materials.

Material Type	Tracks	Tires
Inclines less than 25 degrees	OK	OK
Inclines approx. 30 degrees	OK	TROUBLE
Inclines greater than 30 degrees	TROUBLE	TROUBLE
Scattered pebbles	OK	OK
Bubble wrap	OK	OK
Aquarium gravel mound	OK	TROUBLE
Large rocks	TROUBLE	TROUBLE
Textbooks approx. 1” thick	OK	TROUBLE
Binders approx. 1” thick	OK	TROUBLE
Fixed pencil speed bumps	OK	OK
Loose pencil speed bumps	OK	TROUBLE

Course 1 – Smooth & Flat

Although not much of a challenge for either tires or tracks, students should be able to observe differences in speed. To create this course, simply mark the start and finish lines on the floor with tape approximately 1 ftapart.

Course 2 – Ramp

Tracks should fare better than tires on a steep incline, but the ramp’s grade and material will factor into the exact angle of failure. In general, both tires and tracks fair similarly on inclines less than 25 degrees. If the incline is greater than 30 degrees, the robot’s center of gravity may cause it to tumble. A wide piece of wood, metal, or plastic propped on LEGO NXT part bins should provide an adequate test ramp. At 30 degrees, the high end of a 3 foot ramp should be about 18 inches above the floor. Place a start and a finish line on the ramp. To achieve the desired results it might be necessary to adjust the angle of the incline slightly more than 30 degrees to be just a little bit more than a base robot with tires can climb.

Course 3 – Obstacles

The obstacle course can be made using items typically found in the classroom. Stay away from obstacles that are bigger than the vehicle's clearance. For example, large rocks will stop both a wheeled or tracked vehicle. Favor wide, yet short obstacles like blocks of wood, pencils, Styrofoam trays, and books. Tires have difficulty crossing over 1" thick textbooks or binders. Choose obstacles that are tall enough to prevent the tires from climbing over them, but not so tall that the tracks cannot climb over them. The obstacles should be between 1-2 " thick. Place a start and a finish line on the floor about one meter apart and distribute the obstacles on the course. Experiment with both fixed and loose obstacles. Tracks will effortlessly roll over loose obstacles, whereas tires will drag them along.

Course 4 – Slip and Slide

The goal of this course is to cause traction problems. This is a bumpy road laid out on the floor. Place a start line and a finish line about one meter apart. Between the start and finish line tape a jump rope to the floor to create a "pit" area. Fill the "pit" area with mounds of sand, cereal or dry beans. The jump rope will help to keep the "terrain" in the middle of the course. There is no limit to how much mess can be made!

Challenge Course: Design a course of your choosing that is a combination of the above course challenges.

Appendix H: Engineering Performance Assessment Rubric: Tires or Tracks

If the student does not include the information listed in the rubric in their investigation notes the score is a zero for the sections that are missing.

Category	4	3	2	1
Problem/Question and Idea	The student states the problem as a need for a test to determine what is a better choice for the vehicle and identifies the two options. The question provides specific focus and information which would allow someone else to repeat the investigation.	The student states that they are to determine which is better tires or tracks.	The student states they are to choose an option for the vehicle but does not discuss options.	The student's statement does not make full sense but includes the terms test, vehicle, tires, tracks, and better/ best choice.
Materials and Supplies needed to Test Prototype Robot	The student lists at least 4 materials needed to complete the investigation in their data chart. The list could include: robot kit, tires, tracks, meter stick, stop watch, data chart, paper and pencil or pen, a surface course that includes a smooth flat surface, a bumpy section and an	The student lists at least 3 materials needed to complete the investigation in their data chart. The list could include: robot kit, tires, tracks, meter stick, stop watch, data chart, paper and pencil or pen, a surface course that includes a smooth flat surface, a	The student lists at least 2 materials needed to complete the investigation in their data chart. The list could include: robot kit, tires, tracks, meter stick, stop watch, data chart, paper and pencil or pen, a surface course that includes a smooth flat surface, a bumpy section and an	The student lists only 1 material needed to complete the investigation in their data chart. The list could include: robot kit, tires, tracks, meter stick, stop watch, data chart, paper and pencil or pen, a surface course that includes a smooth flat surface, a

	incline. The student did not include any unnecessary materials on their list.	bumpy section and an incline. The student did not include any unnecessary materials on their list.	incline. Student may have included 1 or more supplies that would not be required.	bumpy section and an incline. Student may have included 1 or more supplies that would not be required.
Data Collection, Measurement &	Student correctly fills in 20 of the data entry and calculation sections on the data charts. (Time, distance, speed, and average speed for all three trials for both tires and tracks)	Student correctly fills in 16-19 of the data entry and calculation sections on the data charts. (Time, distance, speed, and average speed for all three trials for both tires and tracks)	Student correctly fills in 12-15 of the data entry and calculation sections on the data charts. (Time, distance, speed, and average speed for all three trials for both tires and tracks)	Student correctly fills in at least 11 of the data entry and calculation sections on the data charts. (Time, distance, speed, and average speed for all three trials for both tires and tracks)
Observations	Student records accurate observations for all 8 observation sections.	Student records observations for at least 6 observation sections.	Student records observations for at least 4 observation sections.	Student records observations for at least 2 observation sections.
Data Analysis	The student forms conclusions based on their experiments and explains: How tires have less rolling friction than tracks on a smooth surface and would be the better choice if the course was smooth and flat.	The student forms conclusions based on their experiments and explains: that because the vehicle has to be able to maneuver on and off road the tracks are necessary for traveling over rough surfaces and up a steep incline.	The student forms conclusions based on their experiments and explains but only states that tracks are the best solution and does not elaborate why.	The student gives incorrect reasoning and states that tires are the best solution.

	However, because the vehicle has to be able to maneuver on and off road the tracks are necessary for traveling over rough surfaces and up a steep incline.	The student does not address the tires in their answer.		
Modification and production of final prototype robot.	Using the results of their data analysis the students will modify and build their final prototype robot. This robot will be tested on the final obstacle course designed by the teacher or the class. The prototype performs with the following levels of proficiency during the testing on the obstacle course: 100% of the Performance standards are met: <u>Goes fast</u> The mean speed after three time trials is faster than 10 seconds. The prototype <u>goes over 100% of the obstacles</u>	Using the results of their data analysis the students will modify and build their final prototype robot. This robot will be tested on the final obstacle course designed by the teacher or the class. The prototype performs with the following levels of proficiency during the testing on the obstacle course: Performance standard: <u>Goes fast</u> The mean speed after three time trials is between (11-20 seconds). The prototype <u>goes over</u>	The students modify and build their final prototype robot without any indication that they considered the data collected during the testing phase. This robot will be tested on the final obstacle course designed by the teacher or the class. The prototype performs with the following levels of proficiency during the testing on the obstacle course: Performance standard: <u>Goes fast</u> The mean speed after three time trials is between 21 and 30 seconds. The prototype <u>goes over</u>	The students <u>do not</u> modify and build their final prototype robot. This robot will be tested on the final obstacle course designed by the teacher or the class. The prototype performs with the following levels of proficiency during the testing on the obstacle course: Performance standard: <u>Goes fast</u> The mean speed after three time trials between 31 and 60 seconds. The prototype <u>goes over 50% of the obstacles and 1/3 of the way up</u>

	and completely up the incline. The prototype completes the entire course 100% of the time.	90% of the obstacles and at least 2/3 of the way up the incline. The prototype completes the entire course 100% of the time trials.	80% of the obstacles and ½ of the way up the incline. The prototype completes the entire course 2 of the 3 time trials.	the incline. The prototype completes the entire course 1 of the 3 time trials.

Appendix I: Student Instructions

Name______________________________

Which is better for moving across different types of terrain, tires or tracks?

Your robot is already designed to move in a straight line over the various courses. Your job is to decide the standards you will use to measure the robots success: for example, is it stable? Is it fast?

STEP # 1: Assign roles and responsibilities in your team as described by your teacher.

My role is ____

My responsibilities are

____

____

____

____

STEP # 2: Complete the assembly of your robot by attaching the tires first.

STEP # 3: Gather your group at the assigned course.

STEP # 4: Measure the amount of the time it takes for your robotic vehicle to travel a fixed distance from the start line to the finish line for one of the provided courses. **Remember to record all observations for the trial.**

- ✓ Record information on your data chart.

STEP # 5: Repeat your trial a total of three times.

STEP # 6: Repeat step 4 and 5 for each of the other courses provided.

- ✓ Record information on your data chart.

STEP # 7: Once you have run the four courses three times each with your robot, discuss with your team the performance of your robotic vehicles with tires over the four courses. From this discussion, you should create a list of criteria for a "better" robotic vehicle.

STEP # 8: Create a list or standards for a "better" robotic vehicle.

Standards

____

____

____

____

STEP 9: Modify your robotic vehicle by replacing the tires with the provided tracks.

STEP 10: Repeat Steps 4 and 5 with your modified robotic vehicle.

- ✓ Record information in your science journal
- ✓ Once you have completed the experimentation steps with both tires and tracks, you will need to analyze the data to determine when tires outperform tracks and when tracks outperform tires. Write a summary of your conclusions in your science journal.
- ✓ Review your science journal and answer/ fill in any remaining sections.

Appendix J: Cooperative Group Rubric: Tires or Tracks

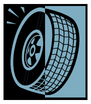
Category	4	3	2	1
Contributions and Team work	The student or group is observed being on-task and working with their group 95-100% of the time. Behaviors observed may include: The discussion is about the project, the students are listening to other members of the group, and all members are recording the data or are doing their assigned job for the day.	The student or group is observed being on-task and working with their group 80-94% of the time. Behaviors observed may include: The discussion is about the project, the students are listening to other members of the group, and all members are recording the data or are doing their assigned job for the day. At this level the teacher may observe a few minor instances where the students are off task but quickly get back on task when asked to do so or refocused by the teacher.	The student or group is observed being on-task and working with their group 70-79% of the time. Behaviors observed may include: The discussion is about the project 2 out of 4 times the teacher observes the group. 2 out of 4 times the members of the group are listening to other members of the group. The teacher observes members recording the data or they are doing their assigned job for the day 2 out 4 times. At this level the teacher may observe instances where the students are off-task 2 out of 4 times that they observe the group. The group requires time by the teacher to get back on- task when	The student or group is observed being on-task and working with their group 50-69% of the time. Behaviors observed may include: The discussion is about the project 1 out of 4 times the teacher observes the group. 1 out of 4 times the members of the group are listening to other members of the group. The teacher observes members recording the data or they are doing their assigned job for the day 1out 4 times. At this level the teacher may observe instances where the students are off-task 1 out of 4 times that they observe the group. The group requires time by the teacher to get back on- task

			asked to do so.	when asked to do so.
Preparedness	The student is observed as having 100% of the materials needed to do their job. Student is not searching for writing utensils, data charts, or previously distributed materials.	The student is observed as being mostly prepared. Minimal time is spent acquiring supplies (this is witnessed only 1 or 2 times).	The student is observed as on 3 to 4 occasions acquiring supplies at the interruption of the assigned task.	On more than 4 occasions the student has been witnessed as being off task in an attempt to acquire necessary materials that have been previously acquired or distributed.

Appendix K: Optional Math Worksheet/Alternate Data Collection Sheets

Tires or Tracks

I. SMOOTH & FLAT COURSE / Data Collecting Form

TIRES 

	Distance	Time	*Speed
Trail # 1			
Trail # 2			
Trail # 3			
Trail # 4			

SPEED!

Median:___________

Mode: __________

Mean: ___________

Range: ___________

Tires or Tracks

I. SMOOTH & FLAT COURSE / Data Collecting Form

TRACKS 

	Distance	Time	*Speed
Trail # 1			
Trail # 2			
Trail # 3			
Trail # 4			

SPEED!

Median:___________

Mode: __________

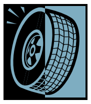
Mean: ___________

Range: ___________

Data Analysis/ Conclusions

Tires or Tracks

II. INCLINE COURSE/ Data Collecting Form

TIRES 

	Distance	Time	*Speed
Trail # 1			
Trail # 2			
Trail # 3			
Trail # 4			

SPEED!

Median:___________

Mode: __________

Mean: ___________

Range: ___________

Tires or Tracks

II. INCLINE COURSE/ Data Collecting Form

TRACKS 

	Distance	Time	*Speed
Trail # 1			
Trail # 2			
Trail # 3			
Trail # 4			

SPEED!

Median:___________

Mode: __________

Mean: ___________

Range: ___________

Data Analysis/ Conclusions

Tires or Tracks

III. TRENCHES COURSE/ Data Collecting Form

TIRES 

	Distance	Time	*Speed
Trail # 1			
Trail # 2			
Trail # 3			
Trail # 4			

SPEED!

Median:___________

Mode: __________

Mean: ___________

Range: ___________

Tires or Tracks

III. TRENCHES COURSE/ Data Collecting Form

TRACKS 

	Distance	Time	*Speed
Trail # 1			
Trail # 2			
Trail # 3			
Trail # 4			

SPEED!

Median:___________

Mode: __________

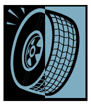
Mean: ___________

Range: ___________

Data Analysis/ Conclusions

Tires or Tracks

IV. FLAT WITH OBJECTS/ Data Collecting Form

TIRES 

	Distance	Time	*Speed
Trail # 1			
Trail # 2			
Trail # 3			
Trail # 4			

SPEED!

Median:___________

Mode: __________

Mean: ___________

Range: ___________

Tires or Tracks

IV. FLAT WITH OBJECTS/ Data Collecting Form

TRACKS 

	Distance	Time	*Speed
Trail # 1			
Trail # 2			
Trail # 3			
Trail # 4			

SPEED!

Median:___________

Mode: __________

Mean: ___________

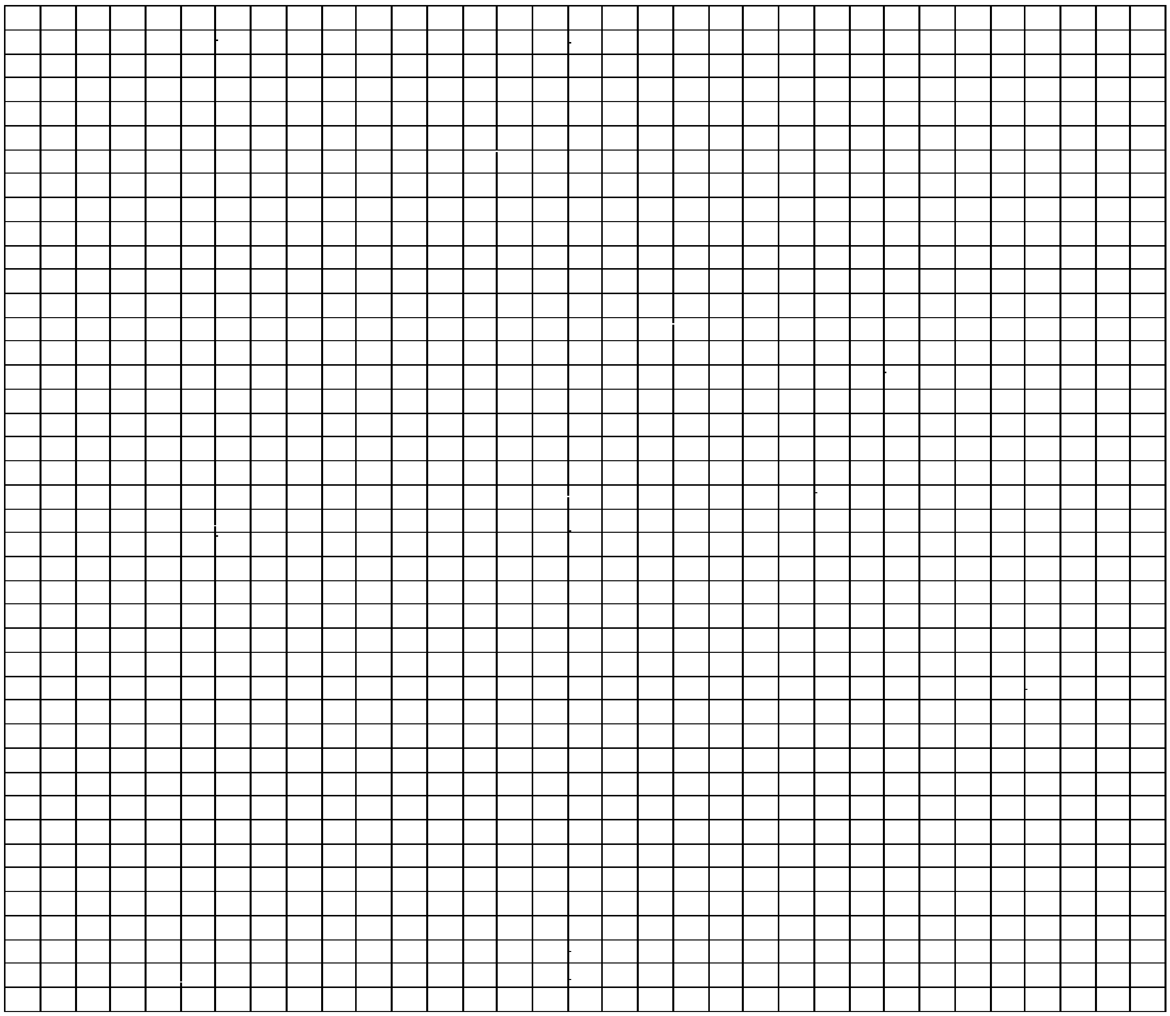
Range: ___________

Data Analysis/ Conclusions

Tires or Tracks  ***DOUBLE BAR GRAPH!***

Average __________Speed

Course ______



KEY:

Tires color:______

Tracks color:______