Lesson Focus
In this lesson, students build spinning tops out of everyday materials. Their challenge is to design a spinning top that can spin for at least 10 seconds within a circle 30 cm in diameter.

Lesson Synopsis
The "Tinkering with Tops" lesson explores the history, design and motion of spinning tops. Students work in teams of "engineers" to design and build their own tops out of everyday items. They test their tops, evaluate their results, and present to the class.

Age Levels
8-18

Objectives
During this lesson, students will:
- Design and build a spinning top
- Test and refine their designs
- Communicate their design process and results

Anticipated Learner Outcomes
As a result of this lesson students will have:
- Designed and built a spinning top
- Tested and refined their designs
- Communicated their design process and results

Lesson Activities
Students work in teams to design and build their own spinning top out of everyday materials. Their top must be able to spin for at least 10 seconds within an area 30 cm in diameter. Student teams review their own designs, the designs of other teams, and present their findings to the class.

Resources/Materials
- Teacher Resource Documents (attached)
- Student Worksheets (attached)
- Student Resource Sheets (attached)

Alignment to Curriculum Frameworks
See attached curriculum alignment sheet.
**Internet Connections**

- Spinning Top & Yo-Yo Museum (www.topmuseum.org)
- TryEngineering (www.tryengineering.org)
- ITEA Standards for Technological Literacy: Content for the Study of Technology (www.iteaconnect.org/TAA)
- National Science Education Standards (www.nsta.org/publications/nses.aspx)

**Recommended Reading**

- Tops: Making the Universal Toy (ISBN: 978-1933502175)

**Optional Writing Activity**

- Write a paragraph or essay describing how engineering is applied in the toy industry.
**Lesson Goal**
The goal of this lesson is for students to design their own spinning top that can spin for at least 10 seconds within a circle 30 cm in diameter. Student teams design their spinning tops out of everyday materials and then test their designs. Students then evaluate the effectiveness of their spinning tops and those of other teams, and present their findings to the class.

**Lesson Objectives**
During this lesson students will:
- Design and build a spinning top
- Test and refine their designs
- Communicate their design process and results

**Materials**
- One set of materials for each group of students:
  - sharpened pencils
  - pens
  - toothpicks
  - cds
  - coffee stirrers
  - marbles
  - paper plates
  - plastic lids
  - pennies
  - metal washers
  - tape
  - string
  - clay
  - scissors
  - stopwatches
  - ruler

**Procedure**
1. Show students the various Student Reference Sheets. These may be read in class, or provided as reading material for the prior night's homework.
2. Divide students into groups of 2-3 students, providing a set of materials per group.
3. Explain that students must develop a spinning top from everyday items. The top needs to spin for at least 10 seconds within a circle that is 30 cm in diameter. Students can mark this area with tape or string on the floor. The top that can spin the longest within the circle is the winner.
4. Students meet and develop a plan for their spinning top. They agree on materials they will need, write or draw their plan, and then present their plan to the class.
5. Student teams may also trade unlimited materials with other teams to develop their ideal parts list.
6. Student groups next execute their plans. They may need to rethink their plan, request other materials, trade with other teams, or start over.
7. Next...teams will test their spinning tops. Their object is to design a spinning top that can spin for at least 10 seconds within a 30 cm circle.
8. Teams then complete an evaluation/reflection worksheet, and present their findings to the class.

**Time Needed**
- One to two 45 minute class periods
History of the Top
Tops have been in existence for thousands of years. The first top was most likely a rock or acorn spun by a child. Tops have been used for entertainment, gambling, or even spiritual purposes. Tops have been discovered throughout history all over the world. Clay tops have been found dating back to 3500 BC in the Middle East. Wooden tops found in Egypt are believed to date back to 2000 – 1400 BC. Tops have been found in Greece from as early as 500 BC. In Rome, tops made of bone dating from 27 BC have been discovered.

Anatomy of a Top
A top is made up of four basic elements, the tip or point, the shoulder, the crown and the body. The top spins on its tip or point. At the opposite end of the top is what is known as the crown. The crown is sometimes used to spin the top using one’s fingers. Below the crown is what is known as the shoulder. Between the shoulder and the point is the body of the top. Tops can be made out of all different kinds of materials such as clay, wood, ceramic, or plastic.

Types of Tops
There are many different varieties of tops.

Twirling top - A twirling top is spun by manually twisting the crown. A dreidel is a common example of a twirling top.

Supported top – A top which is spun with a string while the top is held upright by a support.

Whip top - A whip top is set into motion and kept spinning by whipping it with a whip.

Throwing top - A throwing top has a string wrapped around its body which is attached to a stick. When the top is thrown causing the string to be rapidly released from its body, the top spins.

Pump top - A pump top has a crown that is pushed down or pumped several times to create the spin.
Here are a few science concepts to keep in mind while you are developing and testing your spinning top.

◆ **Why a Top Stays Upright**
Once a top is set spinning, it tends to keep upright, no matter what happens. Given that it is in fact balanced on a very small, sharp point, this may seem surprising. No way will you ever get a pencil to stand upright like that. Why should this be? It is because of what is known as the “Gyroscopic Effect”.

◆ **The Gyroscopic Effect or Gyroscopic “Precession”**
Assume you have a smooth circular disc mounted on an axle (or axis). See the diagram at right. The best practical example of this is a bicycle wheel. To see the “gyroscopic effect” in action, try the following activity. Stand with both arms out straight in front of you, and hold one end of the bicycle axle in each hand, so that the wheel is vertical. (Use a front wheel because you will get less greasy!). Have a friend spin the wheel reasonably fast.

Now try and push forward with your **right** hand. You may be surprised to find that instead of the wheel moving towards the **left**, the **top** of the wheel will in fact try to tip over towards the **right**. If you try and push your **left** hand forward, you will find that instead of the wheel turning to the **right**, the **top** of the wheel will try and tip over towards the **left**. You will be quite surprised to find just how strong these forces are. The “gyroscopic effect” can best be visualized by remembering the “Quarter-turn rule”. This says that if you try and move the axis of a spinning disc in any given direction, the disc will in fact tilt in a direction which is 90° **forward in the direction of rotation of the wheel, and** in a direction **opposite** to that in which you are trying to turn. In other words, if you try to turn left, it will tilt to the right, and vice versa. It is this gyroscopic effect which enables you to stay upright while riding a bicycle – i.e. if you turn the handlebars to the left, the bicycle will want to tip over to the left. But the gyroscopic effect of the front wheel counteracts this tendency, with the result that you remain upright. Put another way, as you weave your way down the road, the bicycle will rock gently from side to side but on average will remain upright. If it were not for this effect, riding a bicycle would be much more difficult! With very small wheels, this effect is much less, which is why scooters are so much less stable.

Insofar as tops are concerned, the principle is the same. Any slight disturbance of the top as it spins, automatically produces a self-correcting effect in the opposite direction.

◆ **Energy**
Energy is the ability to do work. All forms of energy fall into two basic categories: potential energy and kinetic energy. Potential energy is mechanical energy which is due to
a body’s position. It is also known as stored energy. A top at rest has potential energy. Kinetic energy is mechanical energy that is due to a body’s motion. When a top is spun, whipped, or pumped its potential energy is transformed into kinetic energy.

◆ Angular Momentum
Angular momentum is a measure of the motion of mass around a center of rotation. It is the product of the mass, velocity and radius of a rotating body. The formula for angular momentum is: \( L = m \times v \times r \), where \( m \) = the mass of the wheel in grams, \( v \) = velocity of the rim in meters/ second, and \( r \) = the radius of the rotating mass.

Angular momentum is conserved unless acted on by an outside force. The mass of the top and the distribution of that mass affects the angular momentum of the top. A top will slow down when it is acted on by the forces of friction or gravity. These two forces will eventually cause a top to slow down, wobble and fall over.

◆ Real World Applications
The Gyro-compass - After riding a bicycle, probably the most common application of a gyroscope is in what are known as “gyro-compasses”. Ships and aircraft all have several. A gyro-compass senses the rotation of the earth and if left to itself will gradually settle down to face true north. (Not magnetic north, which, as you may know moves about gradually and almost never coincides with “true north”.) Once set, in that direction, a gyro-compas will very consistently continue that way, no matter which way the ship or plane may turn. Ships’ gyros are usually quite large. Flywheels can weigh 20 lbs or more, and are driven by an electric motor. Aircraft gyros are quite small and are often driven by air pressure caused by the forward motion of the plane. Gyro-compasses are almost always enclosed in a hermetically sealed case under vacuum, to minimize losses due to air friction.

A limitation however, is that gyro-compasses do not function very well when they get too close to the North or South Poles. Why should this be? Because when you are within a few degrees of the pole, the angular displacement is too small for most compasses to detect. In such situations, a modern GPS is required.

Space Satellites - For much the same reason, space satellites use gyros to maintain their orientation with respect to the Earth. The two primary methods for orienting satellites include spin stabilization and three-axis stabilization. In spin stabilization, the satellite spins around its axis like a top, which keeps it stable and oriented in a particular direction. Spin stabilization has been used in the design of several NASA spacecraft including the Pioneer 10 and 11 spacecraft, the Lunar Prospector, and the Galileo Jupiter orbiter. In three axis stabilization, satellites are designed with small wheels that spin to keep them pointing in the right direction. These wheels either speed up or slow down to correct the orientation of the satellite. Three-axis stabilization was used in the design of Voyagers 1 and 2.

Tropical Storms - Although not strictly an “application”, gyroscopic effects also determine which way round tropical storms rotate – anti-clockwise in the northern hemisphere and clockwise in the southern hemisphere.
You are a team of engineers who have been given the challenge to design a spinning top out of everyday items. The top needs to be able to spin for at least 10 seconds within a circle that is 30 cm in diameter. The top that can spin the longest in the circle is the winner.

**Planning Stage**
Meet as a team and discuss the problem you need to solve. Then develop and agree on a design for your spinning top. You'll need to determine what materials you want to use.

Draw your design in the box below, and be sure to indicate the description and number of parts you plan to use. Present your design to the class.

Design:

Materials Needed:

You may choose to revise your teams' plan after you receive feedback from class.

**Construction Phase**
Build your top. Tips: You may want to experiment with different quantities of weights and the placement of those weights, as well as the distance between the body of the top and the point. During construction you may decide you need additional materials or that your design needs to change. This is ok – just make a new sketch and revise your materials list.
Testing Phase
Each team will test their top. You'll need to time your test to make sure your top can spin for at least 10 seconds within a circle that is 30 cm in diameter. Be sure to watch the tests of the other teams and observe how their different designs worked.

<table>
<thead>
<tr>
<th>Test</th>
<th>Time Spun within 30 cm Circle</th>
<th>Total Time Spun</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test 1</td>
<td></td>
<td></td>
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<tr>
<td>Test 2</td>
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<td>Test 3</td>
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<td>Test 4</td>
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<tr>
<td>Average</td>
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</tbody>
</table>

Evaluation Phase
Evaluate your teams' results, complete the evaluation worksheet, and present your findings to the class.

Use this worksheet to evaluate your team's results in the Tinkering with Tops lesson:

1. Did you succeed in creating a top that spun for at least 10 seconds within the 30 cm circle? If so, what was the maximum time it spun? If not, why did it fail?

2. Did you decide to revise your original design or request additional materials while in the construction phase? Why?

3. Did you negotiate any material trades with other teams? How did that process work for you?
4. If you could have had access to materials that were different than those provided, what would your team have requested? Why?

5. Do you think that engineers have to adapt their original plans during the construction of systems or products? Why might they?

6. If you had to do it all over again, how would your planned design change? Why?

7. What designs or methods did you see other teams try that you thought worked well?

8. Do you think you would have been able to complete this project easier if you were working alone? Explain...

9. Can you devise a way to calculate the number of rotations your top made in 10 seconds? If so how?

10. Why do you think the spinning top has been such a universal toy?
For Teachers: Alignment to Curriculum Frameworks

Note: Lesson plans in this series are aligned to one or more of the following sets of standards:
- U.S. Science Education Standards (http://www.nap.edu/catalog.php?record_id=4962)
- U.S. Next Generation Science Standards (http://www.nextgenscience.org/)
- International Technology Education Association's Standards for Technological Literacy (http://www.iteea.org/TAAPDFs/xstnd.pdf)
- U.S. Common Core State Standards for Mathematics (http://www.corestandards.org/Math)
- Computer Science Teachers Association K-12 Computer Science Standards (http://csta.acm.org/Curriculum/sub/K12Standards.html)

◆ National Science Education Standards Grades K-4 (ages 4 - 9)
  CONTENT STANDARD A: Science as Inquiry
  As a result of activities, all students should develop
  ✦ Abilities necessary to do scientific inquiry
  CONTENT STANDARD B: Physical Science
  As a result of the activities, all students should develop an understanding of
  ✦ Properties of objects and materials
  CONTENT STANDARD G: History and Nature of Science
  As a result of activities, all students should develop understanding of
  ✦ Science as a human endeavor

◆ National Science Education Standards Grades 5-8 (ages 10 - 14)
  CONTENT STANDARD A: Science as Inquiry
  As a result of activities, all students should develop
  ✦ Abilities necessary to do scientific inquiry
  CONTENT STANDARD B: Physical Science
  As a result of their activities, all students should develop an understanding of
  ✦ Motions and forces
  CONTENT STANDARD G: History and Nature of Science
  As a result of activities, all students should develop understanding of
  ✦ History of science

◆ National Science Education Standards Grades 9-12 (ages 14-18)
  CONTENT STANDARD A: Science as Inquiry
  As a result of activities, all students should develop
  ✦ Abilities necessary to do scientific inquiry
  CONTENT STANDARD B: Physical Science
  As a result of their activities, all students should develop understanding of
  ✦ Motions and forces
  CONTENT STANDARD E: Science and Technology
  As a result of activities, all students should develop
  ✦ Abilities of technological design
  ✦ Understandings about science and technology
Tinkering with Tops

For Teachers:
Alignment to Curriculum Frameworks
(continued)

◆ National Science Education Standards Grades 9-12 (ages 14-18)

CONTENT STANDARD F: Science in Personal and Social Perspectives
As a result of activities, all students should develop understanding of

- Science and technology in local, national, and global challenges

CONTENT STANDARD G: History and Nature of Science
As a result of activities, all students should develop understanding of

- Historical perspectives

◆ Next Generation Science Standards Grades 2-5 (Ages 7-11)

Matter and its Interactions
- 2-PS1-2. Analyze data obtained from testing different materials to determine which materials have the properties that are best suited for an intended purpose.

Motion and Stability: Forces and Interactions
Students who demonstrate understanding can:

- 3-PS2-1. Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.

Engineering Design
Students who demonstrate understanding can:

- 3-5-ETS1-1. Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
- 3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.
- 3-5-ETS1-3. Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

◆ Next Generation Science Standards Grades 6-8 (Ages 11-14)

Engineering Design
Students who demonstrate understanding can:

- MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

◆ Principles and Standards for School Mathematics (ages 11 - 14)

Measurement Standard
- Apply appropriate techniques, tools, and formulas to determine measurements.
- solve simple problems involving rates and derived measurements for such attributes as velocity and density.
For Teachers: Alignment to Curriculum Frameworks (continued)

◆ Principles and Standards for School Mathematics (ages 14 - 18)
  Measurement Standard
  - Apply appropriate techniques, tools, and formulas to determine measurements.
  + analyze precision, accuracy, and approximate error in measurement situations.

◆ Common Core State Standards for School Mathematics Grades 3-8 (ages 8-14)
  Measurement and data
  - Measure and estimate lengths in standard units.
  + CCSS.Math.Content.2.MD.A.1 Measure the length of an object by selecting and using appropriate tools such as rulers, yardsticks, meter sticks, and measuring tapes.
  + CCSS.Math.Content.2.MD.A.3 Estimate lengths using units of inches, feet, centimeters, and meters.

◆ Standards for Technological Literacy - All Ages
  Design
  + Standard 8: Students will develop an understanding of the attributes of design.
  + Standard 9: Students will develop an understanding of engineering design.
  + Standard 10: Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.