<u>SCIENCE</u>

By Val Oliver

The Physics of Yo (and more!)

Physical science is all around us. It explains how everything we see in our world works. The yo-yo involves many of these aspects of physics, and analyzing each of these as it relates to the yo-yo, can help students understand the concept easily and enjoyably. Ultimately, they can generalize this understanding to the other things they view in the world around them.

Yo-Yos can be used to demonstrate the basic concepts of inertia, motion, mass, velocity, force, and gravity. The specific concepts of physics which will be discussed and demonstrated with a yo-yo as they relate to these general ideas are:

1. **Gyroscopic Stability**
2. **Distribution of Mass**
3. **Planes of Spin**
4. **Friction**
5. **Gravity**
6. **Levers**
7. **Air Resistance or Drag**
8. **Potential and Kinetic Energy**
9. **Precession – (introduction to)**

Once these ideas are conceptualized within our world, we will review the Toys in Space project and ask students to project these concepts and how they will or will not be valid in the non-gravitational world of space.

Each of these concepts will be explained, followed by suggested exercises to challenge the mind and demonstrate the principle. Students should be encouraged to develop a theory, or hypothesis, as to what the results of the experiment will be, perform the exercise, and summarize the results, explaining whether or not their hypothesis was correct, and why. This approach demonstrates the lesson with hands-on experimentation which encourages the use of the scientific method and less on the memorizing of scientific facts.

Additional concepts related, but not discussed at this time are:

7. **Rotational inertia (spinning energy)**
8. **Conservation of Angular Momentum**

- Suggested grade levels: 4-8
- Standards of Learning used:

5. Conduct research and communicate findings
6. Understand and apply scientific concepts
8. Use information to make decisions

GYROSCOPIC STABILITY

Grade Levels: 4-8

Definition: Once a wheel is spinning in a particular plane, it does not want to change its plane of spin, as long as it has rotational inertia, or spinning energy.
Newton's First Law of Motion: **Every object in a state of uniform motion tends to remain in that state of motion unless an external force is applied to it.**
Galeileo's Law of Inertia: A**n object in a state of motion possesses an ``inertia'' that causes it to remain in that state of motion unless an external force acts on it.**

Gyroscopic stability has to do with mass and inertia. Once mass is set in motion, it continues on that line until acted on by some other force. In the case of a yo-yo, this motion is rotational inertia, because it is moving around a central axis in a particular plane, i.e. horizontal, vertical or diagonal. Therefore, once the yo-yo is spinning in a particular plane, usually vertically, it will stay spinning on that plane unless acted on by some other force. A spinning top is typically standing vertically, yet spinning horizontally on a surface.

Activities:

1. Discussion Review:

1. Why a bicycle is easier to balance when the wheels are spinning than when they are not spinning.
2. What keeps a Frisbee™ straight when it is flying?
3. How can a spinning top balance on its point?
4. Why is it better to put "spiral" or spin on a football when thrown?
5. Think of others.

Challenge question:

Question: Why did the "spitball" become an illegal pitch?
Answer: The saliva decreased the friction between the ball and the fingers as the ball was thrown, resulting in less spin. A ball thrown without spin will travel unpredictably as the air hits it in various ways and will be more difficult to hit.

Question: Think of other sports where spin becomes important in the effectiveness of the game?
Sample answers:

- Bowling (curve into pins driving them into others)
- Basketball (backspin causing the ball to hit the rim and bounce down into the basket)
- Tennis (a spinning ball hitting the ground will bounce in different ways to trick the opponent)

- Football (spin gives a thrown ball stability in flight resulting in faster, longer and more accurate passes.)

2. Research gyroscopes.
Grade levels: 7-8

a. Explore where and how gyroscopes are used. Use the library and/or internet to search on sources for "gyroscope."

Examples:

1. Hubble telescope - for alignment and stability
2. Ocean liners - for stability of ship, avoidance of seasickness
3. Guidance and Navigational Systems - for stability and alignment

3. Research the Hubble telescope. Use the library and/or internet to search on sources for "Hubble."

a. Identify ways the Hubble uses the gyroscope.

1. stability
2. alignment, to turn or change direction.
   (How would it then stop turning?)

4. Spin a dime on its edge and watch it stand. Can you stand a dime on its edge?

5. Challenge students to think of as many objects as they can that use the gyroscopic stability of spin.

6. Identify a yo-yo trick and how the fact that the yo-yo is spinning helps to make the trick easier.

Examples:

1. Man on the Flying Trapeze - thrown and remaining still causes the yo-yo to swing around the other finger in a straight line and land on the string.
2. Rock the Baby - a spinning yo-yo will spin vertically inside of the cradle, whereas a non-spinning yo-yo will turn and many times, hit and twist around the cradle string, which can ultimately cause unwanted knots in the string!

7. Why is it important for the yo-yo to roll straight off of your fingers when doing the Power Throw or Sleeper?
Answer: Because of gyroscopic stability, the yo-yo will maintain the angle with which it leaves you hand. Therefore, if it leaves your hand straight, it will remain straight. However, if it leaves your hand crooked, it will remain crooked and the string will rub against the side of the yo-yo, causing friction, and slowing the yo-yo down more quickly. Test this.

8. Spin Tops. Can you balance a spinning top on your hand if it's not spinning? Why or why not?
Answer: Once again, once something is spinning, it is stable (it doesn't care!) and will remain spinning in the same plane until it runs out of spinning energy. A spin top which

is not spinning will be affected by gravity and fall over. However, once the top is spinning, the force of the spin is actually stronger than the force of gravity to pull it over, until the spin is slowed by some outside force. In this case, the outside force would be mostly from the friction with the spinning surface and somewhat with the air resistance from the air on the top itself.

9. What about a ball-bearing spin top? Why will it spin longer than a standard fixed tip spin top?
Answer: On a ball-bearing spinning top, the tip if the top is not spinning, but is stationary…only the body of the top is spinning. Therefore, there is no friction between the point itself and the surface. The air resistance still exists, and there is some amount of friction within the ball-bearing itself, however, with reduced friction, the top will spin longer. This is more noticeable on a soft surface such as a hand or carpet rather than a hard floor surface since these surfaces have a greater contact surface between the point and the top than does a hard surface where only a very small point of the tip is touching the spinning surface. Try it!

DISTRIBUTION OF MASS

Grade Levels: 4-8
(Suggestion: Set up lab stations to perform these tests. Then move into discussion.)

Definition: Where the weight of an object is placed.

The higher the percentage of the mass distributed to the outside circumference of a spinning object, the longer it will spin.   This assumes that other factors are equal, such as friction, weight, and velocity of spin.

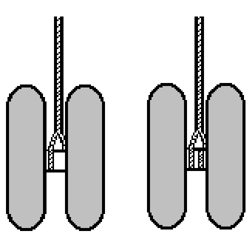
Activities:

1. Discussion Review:

1. Why a hollow spinning top will spin longer than a solid one.
2. Why an Aerobie™ or flying ring will fly longer than a Frisbee™ or other solid flying disk.
3. Think of others.

String mechanics

Yo-yos of different designs can be used to demonstrate the concept of distribution of mass. The following exercises require the basic knowledge of attaching a string to a fixed-axle yo-yo. There are two ways to attach the string: double-looped or single-looped around the axle.



A fixed-axle yo-yo with a double-looped string (string wrapped around the axle twice) will not spin or "sleep" at the bottom of the string when dropped, but will instead climb a distance back up the string once it reaches the bottom. A yo-yo which has been single-looped will spin or "sleep" at the bottom of the string once dropped.

Single-looped   Double-looped

Find two yo-yos of similar size and weight, one which is solid and one which is rim-weighted (i.e. the percentage of weight is greater toward the outside circumference).

Examples of regular yo-yos: Wooden yo-yos, Duncan Imperial.
Examples of rim-weighted yo-yos: Technic by Spintastics and ProYoII by Duncan.

2. Drop-Return.

Equipment:

1. 2 yo-yos listed above, <u>double-looped</u> so that they will try to climb back up the string when dropped. Use strings of equal lengths.
2. Yardstick or other measuring device.

Project which yo-yo will climb further up the string.
Perform test.
Procedure:
Drop each yo-yo from a fixed point and measure the height to which each yo-yo climbs back up the string. Repeat the exercise several times (average) to qualify your discoveries.
Record your answers in inches and convert to metric.
Make a B<u>ar Graph</u> for each yo-yo.
Summarize your results.

3. Drop-Spin.

Equipment:

1. 2 fixed axle yo-yos, as listed above, <u>single-looped</u> so that when dropped, they will spin at the bottom of the string OR 2 ball-bearing transaxle yo-yos (for longer spin times).
   Examples of transaxle yo-yos: Tornado or TigerShark by Spintastics, Duncan Throw Monkey, Yo-Yo Jam Dragon Jam and Yomega Raider (all rim weighted) and Duncan Speed Beetle (non rim-weighted).
2. Stop watch or other timing device.

Project which yo-yo will spin at the bottom of the string longer.
Perform test.
Procedure:
Drop each yo-yo from a fixed point and measure the duration of the spin by starting the time when the yo-yo reaches the <u>bottom</u> of the string. Stop the timer when the yo-yo stops spinning. Repeat the exercise several times (average) to qualify your discoveries.
Record your answers.
Make a Bar Graph for each yo-yo.
Summarize results.

Exercises #2 and #3 should have visually displayed the effectiveness of the distribution of mass on a spinning object.

4. Hypothesize what would happen to one particular rim-weighted yo-yo as you increase or decrease the percentage of mass on the outside circumference. Predict which yo-yo will spin longest and which will spin the shortest length of time. Perform the test.

SUGGESTION: The TigerShark yo-yo by Spintastics Skill Toys, Inc. is an excellent yo-yo to use for this experiment. The reason is that it comes with "speed rings" to intentionally increase the rim weight of the yo-yo. These "speed rings" are removable. Use one TigerShark with speed rings, and another with the speed rings removed. (To remove them, pop off the holographic side disk on each side of the yo-yo and remove the metal rings you find inside by lifting up from under them with a screwdriver or other such tool.) For the yo-yo without the rings, weigh the "speed rings" and use the same weight of molding clay molded around the central hub on each side of the yo-yo. That way the total mass of the yo-yo will be the same and only the distribution of the mass varies.

Procedure:

Use or the TigerShark as suggested above or one of the yo-yos listed earlier. Perform any or all of the exercises in #2 and #3 with the following modifications using a small amount of molding clay. Note: Use the same piece of material in each case so that the variables other than the placement remain constant. (Rubber bands can also be used to weight the outside of the yo-yo.) (Exercise #2 must be done with a double-looped fixed axle yo-yo OR a quadruple-looped Tornado or TigerShark by Spintastics so that it will return up the string.)

1. Add weight to all areas of the yo-yo.
2. Add weight to the rim only. (TigerShark perfect for this.)
3. Add weight to the center only.

How did your hypothesis compare to the actual results?

5. Rolling and Flying

Equipment:

Take a Frisbeetm and an Aerobietm as close to the same size as possible.

a. Roll them down a plane, or incline, simultaneously so that the velocity is the same to see which will travel further before falling over.

b. Throw the Frisbee™ and Aerobie™ together with one hand to see which flies further. (Repeat three times and average your results.)

Does distribution of mass have anything to do with the results?

SPIN TOPS

6. Spin tops. Experiment with a plastic spin top which is hollow.

a. Spin the top "as is." Then spin it with the following modifications.

b. Fill the inside with molding clay.

b. Put various amounts of molding clay only around the outside rim.

c. Put molding clay only at the center/lower portion of the top.

What affect does the position of the clay have on the length of the spin?

Answer: While it is difficult to spin the top with the exact same amount of force without some sort of spinning device (which can be made), in general the spin configuration with the highest amount of weight, or mass distribution, at the outside edge will always spin longer.

7. Make your own spinning top out of a plastic plate or margarine tub with a pencil or other sharp object pierced through the center. (Rubber bands can help hold the this pencil "shaft" in place but wrapping the bands around the pencil tightly at the base of the pencil/plate's center. You can also put a thread spool at the top and bottom of the plate or tub in order to hold the pencil "axle" straight.

Compare spin times as you spin heavier or lighter tops.
Compare spin times as you spin tops that are wider or narrower in diameter.
Compare spin times as you spin tops which have more weight to the outside surface or to the center surface close to the pencil axle.

Optional Exercise:

It is also fun to make patterns on your plate or tub and to view them when they are stationary vs. when they are spinning.

1. What if you color ½ of your plate blue and ½ of your plate yellow? What color would you see? What about ½ blue and ½ red? ½ red and ½ yellow?

2. Have you ever seen the optical illusion of seeing multiple colors as an object spins when it is painted in a specific pattern of only black and white? Whoa! Black and white contains all colors and in specific patterns, when spun or combined, your eye actually sees ALL colors. Find that optical illusion online or in an optical illusion book. That's pretty cool…science and art together!

CHALLENGE QUESTIONS:

Assume that you have two flying disks or rings that have different weights, but the percentage of weight distribution to the outside of the disks are the same. Which will spin the longest?

Answer: Once spinning with the same velocity, the mass of the heavier object will keep it spinning longer than the lighter object if the weight distribution is the same.
Explanation: Have you ever played or seen the game played called "Crack the Whip?" In this game, participants put on their ice skates, stand in a line on the ice holding hands or with their arms around each others shoulders. At some point, everyone starts turning. Of course, the center person is only turning around in a stationary position. The person next to them is traveling in a slightly larger circle…and on and on, until the last person is reached. "Who's the whip?" It is, of course, that last person on each end of the line! They have much, much further distance to go in the same amount of time in order to keep

the line straight. Yikes! This proves that the outside of a circle is spinning faster than the inside. When something is spinning then, you want to put as much of the mass, or weight, on the outside, which is spinning much faster, avoiding placing it in the slower moving area toward the center.

PRECESSION – Introduction to:

Grade Levels: 6-8

1. Yo-Yos. First, perform the following experiment with a ball-bearing TigerShark yo-yo (by Spintastics).

a. Throw a hard Spinner. Watch it spin.

a. Does it stay in the same plane of spin while it is spinning?

b. Throw it multiple times. Notice that even though a throw may be somewhat crooked, the spin stays in the plane from which it was throw (at least until the spin dies).

c. Now remove ONE of the "speed rings" from one side of the yo-yo. (To remove it, pop off the holographic side disk on one side of the yo-yo and remove the metal ring you find inside by lifting up from under it with a screwdriver or other such tool.)

d. The yo-yo is now OBVIOUSLY out of balance. If you were to throw a Spinner again, what do you predict will happen? Do you think it will tip over on the heavy side? Why or why not?

e. TRY IT! Throw a hard Spinner and watch the yo-yo spin. What happens?

What you should see happen is that the yo-yo will begin to turn toward the weighted side, but will not tip over, as you may expect. This is called precession. It will stay spinning in the plane from which it was thrown, due to gyroscopic stability.

This proves that when a yo-yo is spinning in a crooked manner, it is NOT due to the yo-yo being out of balance. It is because the player is not throwing the yo-yo straight. (Sorry!)

6. Gyroscopes.

A simple visual to show precession is a gyroscope. Pull the string in a gyroscope to spin the wheel inside of it. Loop the string around one end of the gyroscope and let go of the other side. Does it fall? No! Would it fall if it were not spinning? Yes!

However, how is it spinning? It isn't just spinning as it is stationary on the string. It is actually turning around the string axis. Why? This is precession, as explained below.

7. Spin Top.

A Spin top is another form of a gyroscope, and therefore will precess in the same way as a gyroscope when spun and hung on a string.

Gyroscopic Precession says that a spinning object tends to react to a disturbing force by rotating in a direction at right angles to the direction of the force. In this case, the disturbing force is the weight of the heavier side of the yo-yo. Thus, instead of falling the direction of the weight, precession causes the yo-yo to rotate at right angles to that pull, or toward the side of the yo-yo which is the heaviest.

What demonstrations in the **Science of Spin** assembly showed **precession?**

- Gyroscope hanging on the string was turning.
- Spinning top hanging on the string doing Rock the Baby was turning.

AIR RESISTANCE OR DRAG

Grade Levels: 4-8

Drag is created by the outside surface of an object moving against the air. More surface and/or uneven surface equates to more air resistance or drag.

Activities:

1. Discussion Review:

1. Why an Aerobie$_{tm}$ will fly longer than a Frisbee$_{tm}$ when thrown together.

When thrown together from one hand, which will result in the same velocity of spin, the Aerobie$_{tm}$ will fly further because it is thinner and has less overall surface area, resulting in fewer air molecules hitting it, and therefore, has less air resistance or drag to slow it down. This is in addition to the fact that the distribution of mass around the rim of the Aerobie$_{tm}$ results in longer spin.

2. Compare and predict:

1. Given two yo-yos, one that has protuberances or spokes and one that has smooth sides. Which yo-yo will spin longer? Why?

If you have a Technic by Spintastics or a Pro-YoII, you can remove the side disks which will expose uneven surfaces. Will they spin longer with or without the side disks?

(Any uneven surface will increase drag and deplete spinning energy.)

2. Given two yo-yos, one that has holes in it causing it to whistle and one which does not. Will the whistling yo-yo spin faster, slower, or the same as the one that does not whistle? Why?

(Whistle making noise increases the amount of drag, therefore it will spin slower.)

FRICTION

Grade Levels: 4-8

Definition: The rubbing of two surfaces together. The resistance to relative motion between two surfaces in contact.

Yo-Yos

The traditional, standard spinning yo-yo is spinning on a string around the axle, therefore, friction exists between the string and the spinning axle. Transaxle yo-yos have the yo-yo spinning on some type of bearing to which the string is attached. The purpose of the bearing is to reduce the amount of friction, so that the yo-yo spins longer. The amount of surface that is in contact with the spinning shaft creates friction.

The yo-yo returns up the string when an upward jerk on the string introduces slack into the spinning yo-yo. The friction between the inside of the yo-yo and the slack string causes the yo-yo to "eat " the string and wind the yo-yo back to the hand.

<u>String adjustment</u>

A yo-yo string is one long string, doubled over and twisted, resulting in a loop at the bottom of the yo-yo string through which the yo-yo is placed. Each time you wind the string around the yo-yo (if right-handed), it puts an additional twist in the string. Eventually, the string becomes so tight around the axle that it no longer can spin or sleep at the end of the string. Untwisting the string counter-clockwise will do the reverse, or loosen the string.

Types of axles:

1. **Standard wood or metal axle** - The string spins against the axle.
   Example: Technic by Spintastics, ProYoII by Duncan, Duncan Imperial, wooden yo-yos.
2. **Sleeve bearing** - The shaft through the center of the bearing spins on the length of the sleeve bearing, while the string remains stationary on the outside of the sleeve.
   Example: Yomega PowerSpin, Fireball and Brain yo-yos.
3. **Ball Bearing -** The shaft through the center of the bearing spins with the inside race against the balls in the bearing, while the string remains stationary on the outside race of the bearing.
   Example: Tornado and TigerShark by Spintastics, Yomega Raider, Duncan Throw Monkey.

<u>Activities:</u>

1. Experiment with a standard axle yo-yo, varying the string tightness. Will a yo-yo having a tight string sleep more or less than one with a loose string? Why?

Summary Answer: In general, a standard yo-yo with a loose string will sleep, while a standard yo-yo with a tight string will not. The tighter the string squeezes the axle, the more friction is created. You can experience the same thing directly by putting your finger instead of the yo-yo in the string and rotating the string around the finger or rotating the finger in the string while tightening and loosening the wind of the string.

2. Summarize the three types of yo-yo axles. Look inside of each type of yo-yo. Explain where the friction occurs in each case and predict which yo-yo will spin the longest. Prove your results by performing the experiment. Make a drawing of each showing where the point of friction occurs. (Since it would be impossible to throw each yo-yo with the same force, perform the experiment using the Drop-Spin technique in Exercise Distribution of Mass #3.)

Summary Answer:

1. Standard axle - Friction is between the axle and the string itself. The surface for friction is the width of the string for over half the circumference of the axle. The materials are string against wood or metal.
2. Sleeve bearing - Friction exists between the inner shaft and the inside of the sleeve bearing, for the length of the bearing. The materials are steel against teflon.
3. Ball bearing - The point of contact or friction is between the steel balls and the race of the bearing itself. (This results in the smallest surface of friction.)

3. Will the tightness of the string wind affect how well a transaxle yo-yo spins?

(Since the transaxle yo-yo spins on the bearing, the string has little effect. The string on a transaxle is usually double or triple looped around the bearing.)

4. Questions on reducing friction.

What happens if you use lubrication, such as Vaseline or Slick50 on a spinning yo-yo? On a sleeve bearing? Ball Bearing?

Can you use too much lubrication? Would the yo-yo work if you could completely eliminate friction?

5. Give examples of things we use friction for.

6. Give examples of things we couldn't do without friction.

Spin Tops

Experiment with a standard fixed tip spin top and a ball-bearing spin top.

Fixed Tip Spin Top

A fixed tip top has a tip which is press fit into the spin top body or is an actual part of the top body, and therefore spins with the body of the top.

1. Where is the friction when a fixed tip top is spinning?

Answer: The majority of the friction is at the point of contact with the spinning surface. There also is a certain amount of "air friction," called air resistance, or drag, but this would remain constant for the following experiments.

2. What difference occurs on a firm surface, such as wood or tile, vs. a softer surface, such as a hand or carpet?

Answer: A top spinning on a softer surface would have more surface contact, resulting in more friction and less spin time than a hard surface.

3. What difference occurs when the point is sharp vs. when the point is rounded or dulled?
Answer: Again, the difference is the amount of surface area contacting the top's point. A sharper point would result in less contact and therefore, less friction, resulting in a longer spin.

4. Where is the friction if you were to hang a fixed tip top on the string?
Answer: Again, mostly on the tip where the string is in contact with the top and some with the air on the entire surface of the top.

Ball-Bearing Spin Top

On a ball-bearing spin top, the tip of the top does not spin….only the body of the top spins.

1. Where is the friction when a ball-bearing top is spinning?
Answer: Friction occurs in 2 main areas. There is the same amount of "air friction," called air resistance, or drag, around the surface of the top as with the fixed tip top (assuming they are the same size). There is also some amount of friction within the ball-bearing itself. But the total amount of friction is much reduced from the fixed tip top.

2. What difference occurs on a firm surface vs. a softer surface as in question 2 above with a fixed tip top?
Answer: There is no difference since the point is not spinning.

3. Where is the friction if you were to hand a ball-bearing top on the string?
Answer: Again, air resistance, or drag on the surface of the top and friction within the bearing itself, but none at the point of string contact.

CHALLENGE QUESTION:
1. What difference would you see if the ball-bearing had added grease inside of it? What if you completely cleaned all of the grease out by soaking the bearing with mineral spirits?
Answer: Grease inside of a bearing aids the bearing by providing a coating around the balls of the bearing and therefore shielding it from eventual rust. However, it provides more friction, or drag, within the bearing itself, causing the bearing to slow more quickly than a "clean" (non-greased) bearing. Removing the grease from a bearing, reduces or removes that shielded protection around the bearing, allowing it to spin more freely and therefore LONGER than a typical greased, or "shielded," bearing.

POTENTIAL AND KINETIC ENERGY

Grade Levels: 5-8

Energy. It always exists and is never lost. Energy is simply transferred from one place to another. The yo-yo can display this in a number of ways.

Potential energy is the energy that is stored and waiting to be released.
Kinetic energy is the energy that is in objects that are moving.

When a yo-yo is wound up, it has potential energy. As the yo-yo rolls down the string, that potential energy is being converted into kinetic (motion) energy. That kinetic energy is again converted into potential energy as the yo-yo winds back up the string. Gravity provides the force for the conversion and some of the energy is lost through friction, in the form of heat. The potential energy in the muscles of your arm can be added to that wound up yo-yo and that energy too, can be converted into kinetic energy by the spinning yo-yo.

Throwing the yo-yo so that it spins down the string uses some of that potential energy, whereas simply dropping a yo-yo to the ground, string and all, does not. Therefore, a spinning yo-yo will fall more slowly than one that is dropped (as long as the other end of the string is held).

As the yo-yo travels down the string, the string is unwinding from around the axle, and so, the size of the axle is continually decreasing. (At this point, the string still wound around the axle is part of the axle. With each turn, there is less string around the axle so the axle grows smaller.) This is significant because it means that the yo-yo is spinning more slowly at the top of the string than it is as it moves down the string, where it picks up speed. Liken it to a bicycle wheel. The larger the wheel, the less revolutions it takes to travel a certain distance. The energy required for the yo-yo to spin increases with the speed of the spin, therefore, when the yo-yo is spinning more quickly, less energy is available for falling. This means that the yo-yo's vertical descent is slower at the bottom of the string than at the top, because it is spinning faster. This is the scientific fact that makes the often told story about the yo-yo being used as a weapon difficult to believe. A spinning yo-yo makes a very poor weapon.

Taken in reverse, the yo-yo's spin decreases more as it rolls up the string, but it's vertical velocity increases. This explains how the yo-yo can appear to snap quickly into the hand and is sometimes difficult to catch.

Kinetic to Potential Energy.

While yo-yos normally are used to demonstrate the conversion of potential energy to kinetic energy, the Skyrocket trick demonstrates the reverse in quiet a spectacular way. It is performed by first throwing a fast Spinner. The yo-yo string is then carefully taken off of the finger. The yo-yo is given a jerk so that it begins to climb back up the string.

However, just as the yo-yo reaches the top of the string, the player lets go of the string, sending the yo-yo up into the air.

Performing the Skyrocket yo-yo trick converts some of the rotational kinetic energy back into potential energy by winding back up the string. The rotational kinetic energy decreases as the yo-yo climbs up the string while the vertical velocity increases. Once the yo-yo is released, no further energy is converted. The remaining kinetic energy is expended in the yo-yo's vertical climb against gravity. The best time to release the yo-yo into flight, then, becomes the point when it is closest to the hand, where the directional (vertical) kinetic energy is at its highest. In addition, the faster the yo-yo is spinning when it starts its climb up the string, the higher the yo-yo will skyrocket or climb into the air.

Exercises:

1. A yo-yo is a flywheel used for the storage and conversion of energy. What other things can you think of that use flywheels?

Example: Pottery wheel

2. Bring to school a list of five things you used today that use spin.

Examples: Revolving door, fan, lazy susan, blender, dryer, wheels.

DIABOLOS/SPINABOLOS

A diabolo is a spinning skill toy which is like two cones attached together at their points and is spun with the use of a string attached to two sticks. You may have seen performances with diabolos in a circus as well as in the famous attraction "Cirque de Soleil."

As with both yo-yos and spinning tops, diabolos may have a standard fixed axle or in the case of the Spintastics' Spinabolo TM, a one-way bearing axle. For the concept of potential and kinetic energy, as well as that of levers, the type of axle is irrelevant.

1. When a player is using a diabolo, where is the potential and kinetic energy?

Answer: When a player is standing still, he/she has potential, or stored (lazy!) energy in the muscles of their arms. When the player begins pumping the sticks, they have converted that potential energy into kinetic (or moving) energy. The arm is connected to the sticks, therefore, the sticks also now have kinetic energy. The sticks are also connected to the string, so the string also has kinetic energy. However, the string is not CONNECTED to the diabolo itself.

2. How then, is the energy transferred from the kinetic energy of the arm/stick/string to the diabolo itself?

Answer: FRICTION! This spinning skill toy could not work without friction.

CHALLENGE QUESTIONS:

1.Can you walk without friction?
No! That's why it is more difficult to walk on ice than on another solid surface.   There is less friction on the ice.

2. What sports do you use levers in?
Answer: You may initially think of such sports as hockey (the stick), golf (the club) or tennis (the racquet). However, the correct answer is that there is NO sport which does not use levers. Your body is full of them! Your arm is a lever, used in throwing a football or basketball. Your leg is a lever, used in kicking a soccer or football. Your fingers are even levers used in playing chess!

LEVERS

The diabolo/spinabolo has the most obvious use of levers, however, levers are also a very important function in performance of a yo-yo.

Diabolos/Spinabolos

1. **What simple machine is represented by the sticks of the diabolo?**
   Answer: A lever! You could still spin the diabolo without the use of the stick, however, you would have to exert a significantly greater amount of energy to generate the same amount of spin when using the stick "levers." In addition, when you toss the diabolo up into the air, you simply use your levers. Strength is not a requirement for a higher toss. Simply separate your stick "levers" more quickly to generate a higher flight.

Yo-Yos

Levers are also very important when manipulating a yo-yo.

1. How are levers used in yo-yo play?
Answer: The proper placement for a yo-yo string on your finger is between your first and second knuckle of your middle (tall) finger. Why? It is because your finger is a lever. If you place the string at the base of your finger, you are not utilizing the lever that is your finger. In addition to that, your wrist, elbow and ultimately, your shoulder result in consecutively longer levers. So what? Well, the beauty of levers is that the longer the lever you use, the more power you have! Therefore, the greater length of the lever that you use when you release your yo-yo, the greater power (or length of spin) that you have. You don't have to be strong to have a long spinning yo-yo, which is why yo-yo play does not require strength or prowess. Yay! In other words, you use "leverage," which means the length of your lever. The greater the leverage, a longer spin will result.   Wow! That's why you always end up with that "dead dog" when trying to do 'Walk the Dog.'' You simply weren't using enough leverage to get a longer spin!

TOYS IN SPACE

1. Discuss how you believe a yo-yo would behave in the non-gravitational world of space.

> **a. Would it be able to "sleep."**
> **b. Is gravity necessary for the yo-yo to perform standard tricks?**
> **c. Could you do Walk the Dog? Rock the Baby? Around the World?**

Summary: On April 12, 1985, the yo-yo was first taken into space by NASA on the Space Shuttle Discovery as part of the Toys in Space project. A basic spinning yo-yo was used to see what effect microgravity would have on it. What they discovered was that a yo-yo could be released at slow speeds and gracefully move along the string. However, the yo-yo refused to "sleep," so tricks like "Rock the Baby" or "Walk the Dog" were impossible. Without the downward force of gravity, the yo-yo could not spin against the loop at the end of the string and so, rebounded up the string. Around the World was the only spinning trick which was even close to possible, since the forces involved in the circular motion would keep the yo-yo pushing at the end of the string. It was also found that the yo-yo must be thrown, not dropped, as there was no gravity to pull it down. The yo-yo worked in all directions equally, whereas on earth, the speed is affected by the direction of the yo-yo. For example, "Shoot the Moon" became much easier in space, without the effects of gravity.

A YO-YO WITH A BRAIN?

In 1986, the Yomega Corporation introduced a new type of yo-yo named "The Brain." Its patented design demonstrated yet one more concept of physics, that of centrifugal force. The yo-yo contains two clutch arms with ball bearings used for weight. When the yo-yo is thrown lightly, the yo-yo returns easily, similar to a double-looped standard axled yo-yo. However, when thrown hard, the weighted ball bearings on the clutch arms are forced to the outside rim of the yo-yo, disengaging a mechanism allowing the side disks and center shaft to spin freely while the Teflon axle and string remain stationary. This allows the yo-yo to spin or "sleep" easily. When the yo-yo slows down to the point where the centrifugal force can no longer hold the clutch arms extended, the return mechanism is reengaged and the yo-yo winds up the string automatically.

The Spintastics' "Magic" uses the same technology to produce an auto-return yo-yo. The difference is that the plastic sleeve is around a ball-bearing, rather than just sitting on the center steel shaft itself. This allows even longer spins than the previously designed auto-return yo-yos.

Activities:

1. **Show the "Brain" or "Magic" to students. Have them try it. Have them take one apart. Ask them to explain to you how it works!**

LED LIGHTED YO-YOS

Some yo-yos also have light and sound, many generated through the use of centrifugal force. These yo-yos have a battery operated circuit, which when still, does not complete the electric circuit in order for the light or sound to function. Once the yo-yo is spun however, centrifugal force causes movement of a contact bar on the circuit itself to make contact and complete the electric circuit. The result is light….or sound…or both! The Spintastics' "Magic" is similar, and has a clear body so that the LED light will show through. The only difference is that instead of centrifugal motion creating a closed circuit, any motion will do so due to a motion detector switch.

Activities:

2. **Show the "Magic" to students. Have them try it. Have them take one apart. Ask them to explain to you how it works! Why does it create light patterns when it is spinning?**

CONCLUSION EXERCISES

We have seen how yo-yos respond to various physical properties. With what you have learned, we will now look at the yo-yo to project what would happen if certain properties of the yo-yo itself were changed.

Parts of a yo-yo:

1. sides
2. shaft
3. axle
4. string
5. groove or gap

These parts interact with one another in various ways resulting in the performance quality of the yo-yo. Use what you have learned about gyroscopic stability, distribution of mass, air resistance, friction and energy to predict the outcomes of the following experiments. If possible, perform the experiment to prove your answer. Remember that it is important to change only one variable at a time, in order to prove the true effect of that one variable.

CHALLENGE QUESTIONS:

By manipulating the physical makeup of the yo-yo, many things about the science of mechanics can be learned.

What if?:

1. Different materials are used for the yo-yo and/or string? Harder/softer, heavier/lighter, rougher/smoother ?

(Materials that would increase friction would decrease function. More mass would increase inertia for longer spins, but would be harder to handle and hurt the finger.)

2. What happens when you change the shape of the yo-yo? Is a triangle a good shape for a yo-yo? A square? A ball?

(A disk shape has less drag. Other shapes would increase drag.)

3. What happens when you change the sizes? Of the yo-yo, of the string, of the axle, of the string groove?

(a yo-yo [normally 2 1/8" in diameter] between 1 ½" and 3" will work well. Outside those dimensions, problems occur.) (See summary on string groove.)

4. What enables the yo-yo to climb the string?

(Rotational inertia and friction.)

5. Is it the balance of the yo-yo that keeps it straight when it is spinning?

(No. It is gyroscopic stability.)

7. Why doesn't the yo-yo climb all the way back up the string when dropped (double-looped)?

(Some of the energy is lost to friction during the conversion from potential to kinetic and back to potential.)

Summary Answers:

Axle:

The diameter of the axle is important for a spinning yo-yo because the larger the diameter of the axle, the greater the amount of friction and faster it will slow down. The optimum diameter size of a yo-yo is thought to be 0.58 cm. A smaller axle than that begins to create problems in getting the yo-yo to climb back up the string.

String/Groove:

The thickness of the string and the width of the groove act together. A thin string needs a thin groove while a thick string needs a thick groove. A thick string in a thin groove will cause the string to fill the groove and create too much friction. A thin string in a thick groove will result in too wide of a space and the yo-yo will not return well, as it has nothing to rub on to start it climbing up the string when jerked.

Sides:

Assuming the same weight, the sides can be solid, rim-weighted or center-weighted. The rim-weighted yo-yo will spin the longest, then the solid and lastly, the center-weighted.

Shape:

The shape of the yo-yo is also significant. Novelty yo-yos have been made in the shape of balls and footballs. These shapes, while interesting, are not as efficient because there is more surface for drag and they also change the distribution of the mass. The rim of a spinning object is that circumference which is perpendicular to, and furthest from, the axis, or center, of spin. The further the mass gets from that rim, the more concentrated the weight becomes around the axis and slows the spinning down.

Weight:
Given the same percentage distribution of mass, a heavier yo-yo will spin longer because a yo-yo with a higher mass has more potential energy. It is harder to start and to stop a massive object. Once it starts spinning, it will spin longer. Analogy: Which is harder to stop? A rolling basketball or bowling ball?

Balance:
A well-balanced yo-yo is a valuable thing. However, it is not that which keeps the yo-yo spinning in a straight line. One might think that if the two sides of a yo-yo had differing weights, that the yo-yo would lean or tip to the heavier side when spinning. In fact, it will not lean because both sides are spinning. It would tend to precess, but would still spin in a straight plane.

STORY
The best example of this is a true story that we can leave with you.
His name was Barney Akers and he was a famous and well-loved Duncan yo-yo pro who traveled across the country demonstrating and teaching the act of yo-yoing to kids. The wooden yo-yos at that time were turned on a lathe and periodically, when the machine got to the end of the piece of wood, the process stopped wherever the wood ended. Sometimes it would result in a yo-yo side that was short (thinner than the other side). These yo-yos were to be discarded. However, Barney took those lop-sided yo-yos along with him. When a child complained that his or her yo-yo was out of balance and that was why it was not spinning straight, Barney would pull out his very obviously lop-sided yo-yo and demonstrate that it was not the yo-yo at all. The only reason that the yo-yo would not be spinning straight was due to a bad throw. The yo-yo had to be rolling off the fingers crooked for that "gyroscopic spinning machine" to be spinning crookedly. With that, there could be no argument. A science lesson that child would surely remember.

SUPER SCIENCE CHALLENGE

Invention/Innovation Challenge: Try to design an innovation that will help yo-yos spin longer or loop better, etc. Use pictures and diagrams, and, if possible, build a model and test.

References:

1. The New American Webster Dictionary, 1972
2. American Scientist, "The Yo-Yo: A Toy Flywheel", March-April 1984, Wolfgang Burger
3. Science magazine

4. Science and Sports, Robert Gardner , 1988
5. Toys in Space, Dr. Carolyn Sumners, 1992
6. Tops: Building and Experimenting with Spinning Toys, Bernie Zubrowski, 1989

<u>Videos:</u>

1. “Spinning Things,” with Bill Nye the Science Guy.
   Award Winning show:
      1996 Silver Apple - National Educational Film Festival
      1996 Silver Screen U.S. - International Film and Video Festival
      1996 Golden Apple - CINE

Frequently on Cable-TV channels or can be ordered from various video suppliers.

2. “Yo-Yos in Space,” NASA.