Science Circus Learning Guide

Director's Statement

Early in my professional career I was delighted to realize that my high school physics studies could be applied to the juggling problems I encountered later in life. The "Science Circus" was created to demonstrate that many of the effects of juggling performance are achieved by applying simple concepts of Newtonian physics to the tools of the circus. It is my hope that the audience will leave with their eyes opened to the physics at play in their hobbies, jobs, and entertainments and that they will take with them a beginning vocabulary for describing the kinetic world around them. More idealistically, I hope they recognize that art and science are not exclusive sets, but interacting subsets of creative human endeavor.

Pre- or Post-Show Discussion Questions

Q: How does science influence the arts?

A: Chemistry helps to create paints, sculptable plastics, casting compounds and molding materials; it's no coincidence that Monet's landscape painting innovations came about soon after the creation of paints that were easily traveled with... Biology and medicine help us to understand how our bodies move and work so we can dance better and see better, train for more intensive performances and heal from accidents... Physics studies sound and resonance and allows us to record music and design better instruments and better theaters... without optical physics and electronics, there'd be no video art... Microscopes and telescopes open our eyes to new shapes that later appear in our visual vocabulary...; etc.

Q: How do the arts impact/influence science?

A: Biological drawings are a way artists aid anatomists and the paintings of Audubon still aid naturalists; architectural drafting combines mathematics with art; typography of elements, graphs and other organizational charts rely on aesthetics to better present scientific relationships; rendering of digital data into pictures, ... (hard question)

Q: What in your life demonstrates some of the physics concepts you observed today?

A: Gravity affects all you do on this planet. Gyroscopics helps stabilize airplanes & your bike. Centripetal force is used in your washing machine during the spin cycle, when you throw a discus, when you swing a bat, when a girl twirls her skirt. Inertia allows you to coast on your bike and makes brakes necessary on your car. Inertia snaps your head back when you stomp on the gas and makes you feel lighter when the elevator starts down. Center of mass allows a figure skater to spin smoothly and not wobble and makes a coin easier to spin than a drumstick. Etc.

Vocabulary

physics, force, gravity, gyroscopic, gyroscope, rotation, angle, centrifugal, centripetal, inertia, momentum, mass, weight, volume (physical), motion, resistance, friction, center, balance, equilibrium, horizontal, vertical

Performance Recap & Follow-up Activities
[Brackets surround descriptions of tricks used to illustrate ideas in show]

I. Gravity is the first concept explored. Gravity is a mysterious force that attracts matter to matter. Scientists can describe its effects, but they still don't know how it works - some even think it travels through a different dimension. For jugglers, gravity is our constant foe, but also our ally. If there was no gravity there would be no juggling as we know it, yet gravity limits juggling. The juggler loves to compete against gravity. *[Ball Juggling]*

A. On Earth, gravity pulls toward the center of the planet at a constant rate of 32 feet per second squared (9.8 meters/sec squared). What does this mean to a juggler?

1. It means gravity is constant, never changing, and thus reliable. We don't have to worry about a ball falling faster today than it did yesterday or falling in fits and starts. This makes juggling rhythmical. It also means that the longer something falls, the faster it goes. [Ball dropped from 1 foot off ground hits more quietly than ball that falls farther]

2. It also means that a ball thrown high takes longer to return to the juggler than a ball thrown low even though it picks up more speed on the way down. So, you can juggle higher and slower or lower and faster. If you want to juggle more objects, throw higher to give yourself more time to squeeze in the extra balls. A bad high throw is harder to catch, however, than a bad lower throw. *[5 Ball Routine starting with low 3 ball juggle then juggling higher to gain enough time between throws to add two more balls]*.

B. Gravity pulls at the same rate of acceleration on a heavy object as on a light object. This is weird, but Galileo proved it about 400 years ago. You'd think that a ping-pong ball would fall slower than a bowling ball, but air resistance aside, it doesn't. *[A feather and a wooden box fall at very different rates of acceleration, but when the feather is put on the box so the box can push air aside for the feather they fall at the same rate]*. Jugglers use this fact to juggle combinations of odd weights and sizes using the same rhythms as they use with three equal objects. *[Bowling ball, ping-pong ball and juggling ball are juggled at the same height as three balls that weigh the same amount and 'lo the rhythm is the same]*.

C. (Not in all shows) Air resistance is a great concept to use if you wish to slow juggling. Air has density and a falling object must push through the air to reach the ground just like you have to push through water to reach the bottom of a swimming pool. If the falling object has a large surface area, but little mass, the air can really slow its fall. DaVinci used this concept to design the first parachute. Juggling is often taught with scarves because they catch lots of air and so fall more slowly than balls. *[Scarf juggling].*

Gravity and Air-Resistance Activities

A. Inclined plane experiments - roll balls of different weights down a ramp and time their descents as Galileo did. Graph the outcomes. Can you show that gravity pulls at the same rate on balls of different weight? How does friction factor in? Air resistance?

B. Balloons - drop an uninflated balloon from a specific height. Drop the same balloon inflated from that height. Why does it fall so much slower when inflated? Air resistance! Weigh the balloon uninflated and inflated. Is there a difference? Why? Air does have mass, so it will add to the weight of the balloon – can you detect this?

C. Garbags - Inflate a garbage bag using a hairdryer then twist the end closed and secure it with a rubberband so air won't escape. Swish it through the air. Why is it harder to push it through the air than to swish your empty hand through the air? What part of the garbag hits the ground first after it's thrown? Why?

D. Juggle - plastic produce bags can be juggled just like juggling scarves. This is a cheap prop, as grocers will usually give them away. Learn the "X-shaped" juggling pattern. Begin by holding two bags in your right hand and one in your left. Lift your right hand up to the left and drop one bag. As the first bag falls, lift the left hand up to the right and drop the bag from your left hand. Catch the first bag in your left hand. Lift your right hand up to the left and drop its other bag. Catch the second bag. Continue in this manner. Always throw right to left and left to right. NEVER hand across, ALWAYS throw at about the same height as your hand is when you reach up to ask a question. If you can juggle three bags or scarves in an X pattern, try juggling with "dead" (bounceless) tennis balls (which tennis clubs will usually give away). The pattern is the same. Start with the hand with two in it and make exchanges.

E. Time and graph a basketball dropped from different heights.

II. Gyroscopic Stability is one of my favorite concepts. It's fairly complex to understand, but even without a full understanding, you can appreciate the fact that a spinning object can be more stable than a stationary object in some positions.

A. A common oil funnel is a great example. If you stand it on narrow end on your palm and try to balance it, it's very difficult to keep it upright. But if you spin it like a top it balances itself on your palm. *[Funnel Spin Demo]* When it slows down, it looses the gyroscopic stability and gravity pulls it over.

B. Jugglers use gyroscopic stability when juggling rings.

1. A ring thrown haphazardly is floppy and difficult to catch. A ring thrown with a wheel-like spin is much more stable and predictable *[3, 4 & 5 ring juggle].*

2. It's like a bicycle: standing still with its kickstand up the bike falls over *[set two rings on ground standing up and let go – they fall],* but rolling with its kickstand up your bike balances more easily *[backspin rings and they roll and balance].*

C. My favorite of the gyroscopic juggling toys is the diabolo, or Chinese Yo-Yo. If not spinning, it falls off its string when lifted. Spinning, it stays on its string and can be guided through numerous nifty tricks - as long as it's kept spinning. *[Diabolo demo].*

D. The same is true with a ball. *[I try to balance a still ball on my finger and cannot. I spin the ball with its equator parallel to the ground, catch it on my finger at the center of spin and it balances no problem].* Notice, however, that as the spin of the ball slows, the gyroscopic stability diminishes and gravity eventually pulls the ball down. *[Spin and place 3 balls on volunteer wearing a pointy hat and holding a knitting needle in each hand].*

Gyroscopic Activities

A. Coin Spinning - Spin pennies and observe gyroscopic stability. Try to balance one not spinning. Which is easier? Roll the penny. Why does it wobble in a circular, drunken way as it slows down?

B. Jacks - a dollar buys several kids jacks. Spin them like tops.

C. Gyroscope - the old 19th century toy is still a hit among kids and readily available at any progressive toy store (often with a teaching booklet).

III. Centripetal Force is another concept difficult to fully understand, but fun to observe and useful to jugglers. Most of us have heard of the fictitious "centrifugal" force that pulls outward on an object swung or spun around a center point. This outward motion is actually just acceleration in a straight line. The water is thrown from your clothes because it keeps going in a straight line as the machine drum turns. This is just outward motion. Why don't the clothes keep going outward? Because they are pushed to the side by the spinning drum – we call that push "centripetal force." In another example, if you tie a leash on an object swung or spun around a center point, the leash pulls inward keeping the object from accelerating away (if you let go of the leash the object will go away). This inward pull along the leash is called "centripetal" force.

A. Trackball - pushes a loose ball inward when swung around the track. Works in all directions and is stronger than gravity until it slows down. *[Trackball trick].*

B. Meteor Bowls – Centripetal force can push inward at the same time it's pulling inward. When swung around, the ropes pull the bowls inward with centripetal force and the bowls push the water inward with centripetal force. The water wants to keep going outward, but it can't because the bowls are in the way. *[Meteors with water in them].*
C. The cowboy lariat is an excellent example of centripetal force in circus arts. The outward throw is balanced by the "spoke's" inward centripetal pull. Done right, the inward and outward forces balance creating a circle you can jump through. *[Lariat "Texas Skip"].*
D. Another centripetal trick is the "Flying Pizza" which has a continuous "leash" pulling inward at all points along the circle rather than just the one point where the lariat's "spoke" meets its wheel. Every thread of the cloth pizza is a "leash." *[Spin the floppy cloth circle and it's outward motion lifts the weighted edge while the inward centripetal pull of the threads keeps it from flying apart - it opens to reveal a giant pizza-like disk].*

Centripetal Activities

A. Swing a weight (such as a small stuffed toy animal) tied to the end of a string and let go; observe that it very much wants to fly away in a straight line from the center of rotation (an arc once gravity drags it downward). Note that the string is all that holds it back. We need a name for this force that pulls it back...centripetal force! The harder you swing it around, the more you are throwing it outward so the centripetal force must be greater to keep it from flying away.

B. Now put some wads of paper or some water in a bucket and take turns swinging the bucket around at arms length in a vertical circle. Why doesn't it fall out? What part of the bucket is exerting centripetal force?

C. The moon is flying around us in a circle. Why doesn't it fly off in a straight line? Is gravity acting as a centripetal force? (Good question)

IV. Center of Gravity/Balance - In the circus people are always balancing things. They balance themselves on tightwires and such and they balance objects on their chins and even people on people. To balance something you must support it under its center of gravity.

A. Center of gravity is different from its measured middle. The middle is the spot equally distant from each end. The center of gravity is the spot you must support it under to balance it.

1. You can't balance a rose by putting your finger under its middle. When you balance something you must support it under the spot where gravity is pulling just as much on one side as the other … whether balancing it horizontally *[Balance rose on finger with rose parallel to ground]* or vertically.

2. To balance the rose vertically, the stem end must be directly under the center of mass of the flower. Gravity constantly tries to pull it down so you must keep moving your nose under that point of balance. *[Balance rose on nose standing it up]*.

B. The same is true not only when balancing something on you, but when balancing yourself on something e.g.

1. (Not in all shows) Rola Bola = board on cylinder - the cylinder must be under your center of gravity for you to stay on the board. If you move, the cylinder must move to support you under your center of gravity or you will fall. *[Rola-Bola balance demo]*.

2. 6' tall unicycle - As with the vertical rose, you must keep the support (wheel) under the center of mass (you). You have to get on the seat and get the tire under your center of gravity before gravity pulls you down. Not easy. Once on it, you rock the tire back and forth so it crosses under your center of gravity as often as possible giving you an average of support. *[Mount uni and juggle 3 clubs on it while spinning a ball to gyroscopically balance on a mouthstick]*.

Center of Gravity Activities

A. Hold a yardstick on your forward pointed index fingers, one finger under each end. Slide your fingers toward center. You should end up at the balance point - the center of mass. Try it again with one finger at the end and the other 1/4 of the way toward center. What happens? Why? Hint: more weight makes more friction on the supporting finger.

B. Pierce a tennis ball (or use balls of clay) and thread it on a dowel - move the ball and find the center of gravity of the object. Try to balance the dowel vertically without the ball on it then try again with the dowel at the top. Is it easier with the ball on the top? Jugglers think so. Why? Hint: inertia makes the more massive top harder to move compared to the less massive bottom, so the bottom is easy to move under the center of gravity without also moving the top as much.

C. Balance on one foot and/or hop. Notice how different body positions (hunched over, arms to one side, head back) affect the balance. If you stand on one foot with your hands at your sides what happens if you reach the other foot and your arms to the right? Your center of gravity changes, depending on the shape of your body.

V. Inertia is one of the most basic concepts in the universe. Sir Isaac Newton made it his first law of motion. Inertia says two things: something moving wants to keep moving (like a speeding cement truck with no brakes) and something at rest (still) wants to stay at rest (like getting out of bed on a Monday morning). In other words, things try to not change the way they are moving.

A. (Not in all shows) Jugglers use inertia to perform the "9 Box Slap Stack." Nine plain wooden blocks can be converted from a vertical stack to a horizontal stack by moving faster than gravity. With a block in each hand you can accelerate them leftward and let go with the right hand - for a moment the unheld right box tries to stay moving to the left even though the right hand is not pushing it. Tada, inertia! The right box stays next to the left box moving to the left as gravity pulls it downward. While it's still next to the left box, you can use the right hand to grab another box off the vertical stack and catch all three in a horizontal stack before gravity gets a point. *[Demo with all 9 boxes].*

B. Inertia also says objects at rest tend to stay at rest. The old tablecloth pull is my favorite demo of this aspect of inertia *[demo, but combine with another gyroscopic trick by spinning 9 ceramic bowls on 9 poles attached to a table and then pulling the table's cloth - and, hopefully, catch all the bowls].* Notice that the plates, vase, etc. on the table are at rest and try to stay at rest when the tablecloth is suddenly pulled out from under them.

C. This last trick demonstrates everything we've covered: **gravity** tries to pull the bowls down so we use **gyroscopic stability** to keep the bowls up by rotating them. The bowls are supported by the sticks on the average under their **centers of gravity** and so they balance. To accelerate the bowl rotation, we swirl the sticks around so they push against the rims of the bowls and the rims push back with **centripetal force**. Once in a spinning motion, the bowls try to keep moving because of **inertia**. **Inertia** also keeps the plates and stuff at rest when the tablecloth is pulled out from under them.

Inertia Activities

A. Something at rest tries to stay at rest - put a page on a table with about 3 inches hanging off the edge. Put a heavy book on the page. Pull the page out from under the book rapidly. Why doesn't the book move? Pull the page out slowly. Why does the book move? Friction quickly defeats inertia. What are some ways to defeat friction? Try different weight of book. Try pulling other things out from under the book.

B. Something in motion tries to stay in motion - Roll a ball down a ramp and observe how it tries to keep moving, even when it encounters obstacles. Is there a difference when it rolls over a smooth surface vs. carpet vs. bumps? Friction again! Notice how an object with more mass has more inertia. A boulder is harder to get moving than a marble. A boulder is harder to stop or change it’s direction of motion than a marble.

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5000 SE Division Portland, OR 97206
1-800-584-4530

International Jugglers Association
www.juggle.org
Box 443 Davidson, NC 28036
800-367-0160

Juggling Data Base
www.jugglingdb.org

Western Arts Club (lariats and western supplies)
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Info. On Performer
Rhys Thomas has performed "acrobatic comedy juggling" as his sole profession since 1987. His career has taken him to Japan, Europe, and across North America where he performs for Fortune 500 companies, worldwide television, arts festivals, and educational institutions galore. He is the proud father of Isabel and Matilda who are just now old enough to catch, and husband to Maria (who is a wonderful catch).
For more on Rhys and his shows: WWW.JUGGLEMANIA.COM