May/June 2009 VOLUME 22 ISSUE 5

TEACHERS' INNOVATIONS IN K–8 SCIENCE, MATH, AND TECHNOLOGY

Connect™

INSIDE

THIS ISSUE'S FOCUS

Things in Motion: Newton's Laws

Get Moving with your Students!

A child rolls a ball toward a set of stairs and watches as it bounces down. Each successive bounce is higher. But sometimes the ball hits the very edge of the step, and it goes off at a shallow angle. "What if I roll it harder next time? How many steps can I make it jump at once? What if I use a smaller, bouncier ball?" the child might ask. This kind of exploration is the very basis for investigating the laws of motion in which most of us have participated and brilliant minds have articulated for thousands of years.

With screens blinking in front of our students more and more, and a prevalence of structured time, as a group, students have less experience in playing around or "messing about," with physical objects in motion. Our job as educators is to surround them with opportunities to observe, question, test, and think critically about what they see and do. The following stories do just that. They embed the explorations of motion in the study of Newtonian physics. Here, translated from the *Philosophiæ Naturalis Principia Mathematica*, are Newton's three laws of motion:

1. *Every body perseveres in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by force impressed.*
2. *The change of momentum of a body is proportional to the impulse impressed on the body, and happens along the straight line on which that impulse is impressed.*
3. *For a force there is always an equal and opposite reaction: or, the forces of two bodies on each other are always equal and are directed in opposite directions.*

We hope this issue gives you the impulse and direction to get moving with your students.

Connect™

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Roller Coaster Physics

by Jacqui Ketner

My goal for students is to have a feel for physics. I want them to realize that the physics we learn about in class is in action all around us, not just a difficult concept to master from a textbook. However, *Energy* is a difficult concept for elementary school children. The only way to help students internalize this concept is to make it hands-on and multifaceted. Many kids are fascinated with the idea, if not the reality, of roller coasters, so it is a reliable hook. Imagine a classroom filled with pipe insulation slit in half length-wise, marbles, and a vast quantity of tape. That is what our science classroom looks like.

Making things move

My students are fourth graders, so I limit our study to a few basic concepts. Our fourth-grade definition of energy is: *the stuff that makes things move*. We leave it at that. With that definition in place, we can talk about potential energy and kinetic energy with some meaning.

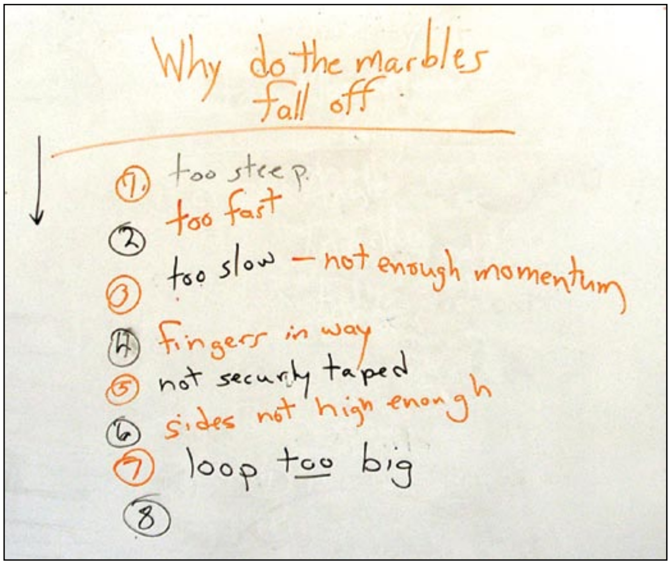
Pairing kids up in teams needs to be done with care. I find that students with similar abilities and a similar knowledge base are the best partners. They are ready to learn similar things. As my students work with their materials, taping the pipe insulation to the furniture and floor to create model roller coaster tracks, I circulate among them.

Their first challenge is to document the things that make the marble fall off the track that they have designed. Some teams of kids have to learn by trial and error that the end of the coaster needs to be lower than the beginning. They can't tape both ends to a tabletop and expect the marble to coast to the end. Clearly, this is important information that these students need to experience for themselves in order to learn.

Some teams tape the section of pipe insulation and the marble rolls down without difficulty. They generally come to me and say they are done and they don't know what to write on their paper because the marble did not fall off. I tell them they are not trying hard enough. If they try some riskier things, it will fall off.

By the end of the class period students can come to the white board and as a class, rattle off a dozen things that make the marble fall off. They have found that

Some teams of kids have to learn by trial and error that the end of the coaster needs to be lower than the beginning.



pipe insulation that goes down too steeply will make the marble fall (here I elicit what students know about gravity and how they can keep the marble on the track). They have also learned that a loop that is too big will make the marble fall off (at which point there is an opportunity to discuss speed, and the need for them to design a track that fits the speed at which the marble is traveling). Taping strategies are always right up there on the list of important skills as they strive to engineer a track that is secure, stable, and smooth.

Potential and kinetic

This project lasts for a few weeks. Each day when the students come to science class I give them a new challenge, something else to consider as they work and as their skills progress. Within a few class periods they are able to keep the marble on the track with relative ease and they push themselves to new heights.

I try to channel this energy for at least part of each period to focusing on concepts of momentum, inertia, friction, and gravity. We visit Web sites, watch a video from an old "Newton's Apple" television series and try to integrate vocabulary into our talks. Eventually I allow them to use two pieces of insulation and tape the start of the coaster as high as they can reach while they are standing on the floor.

As my students hold the marble at the top of their track, they are aware that the marble has the potential for making it down the track. For one specific lesson, I have designed a track that uses two tape measures and has a small jump at the end of the track. Students attempt to quantify both the amount of energy they give the marble, measured in inches from the floor where they release it, and the distance in inches from the end of the track to the landing point of the marble. It is pretty clear, even if the kids are imprecise at measuring, that if they give their marble more potential energy by releasing it further off the floor, the marble has greater kinetic energy as it flies off the end of the track.

As I attempt to integrate the wonders of the Internet into my teaching, I use one class period to work with a Web site called "Funderstanding," http://www.funderstanding.com/coaster. On this site, one can change many factors on a model roller coaster, but I limit the students in class to changing the sizes of the hills and loops. Allowing kids to change gravity, friction, and speed would cloud their emerging understanding. I encourage the kids who are really excited about the site to check out the Web site coaster on their own time and play with all the possible variations. Although my goal is for the kids to make the little car on the Web site get to the bottom of the track, I think they actually have more fun designing a track that makes the car fly off. But that teaches them just as much about the energy in the system.

Open exploration

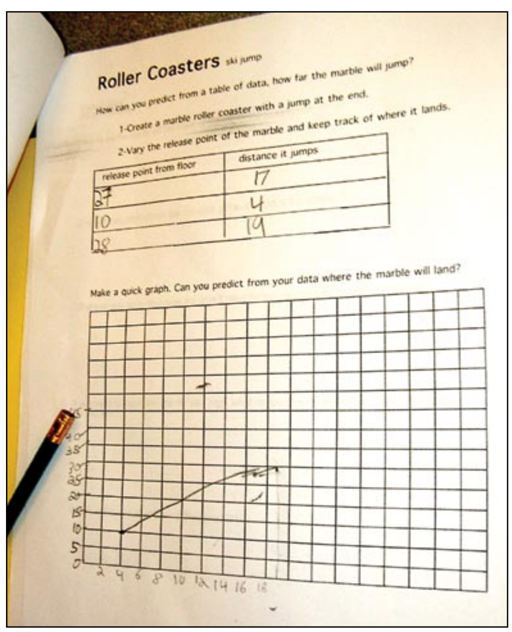
For a portion of each day, I allow my students to play and try out different things without giving them any specific challenge. This gives them the latitude to gain some experience and me some time to talk with the teams about different circumstances in which they have observed similar things happening. "I bet you have felt like that when you are swinging on a swing on the playground." "Have you ever had something on your lap in the car and it slides off when the car goes around a turn?" "When you were on a real roller coaster and went over a big bump, remember how you felt so light, you were glad you had your seat belt on?" "Have you ever swung a bucket of water around and around and not spilled any, even when the bucket is upside down?" Students need to connect what they are seeing in science class to what they experience in the world so that science makes sense.

As a culminating activity, my students design a coaster project for demonstration. We clear the center of the room for an audience. Each team designs a coaster, names the coaster, and makes a labeled diagram of their work. They try to include some of the vocabulary from the project as they demonstrate their work to the assembled audience. I have no expectation that they will articulate the classic physics terminology of objects in motion or Newton's laws, but it is clear they have gained practical knowledge of these concepts. As they progress into middle school however, they carry these visceral experiences with them and refer to them in order to augment their developing intellectual understanding.

A short slide show with student narration can be seen as a "Voice Thread" at http://voicethread.com/?#u79096b268706. I use these Voice Threads as an assessment to see what the students feel is important, what they retained over the course of the lessons, and as a way for their parents to get a window into what we

are doing in class. For instance, one girl shares her observation that if the first loop is smaller than the second loop, the marble will not complete its run down the track. She has learned through her experiences that she needs to design a track with progressively smaller hills and loops to insure that her marble will have enough energy to get to the bottom of the track.

My fourth graders didn't mention Newton's laws by name, but I noticed that my fifth graders studying rockets the next year added a slide about equal and opposite reactions as part of their explanation about why rockets are able to take off. You can check out other Voice Threads compiled by my students at the conclusion of the slide show mentioned above.



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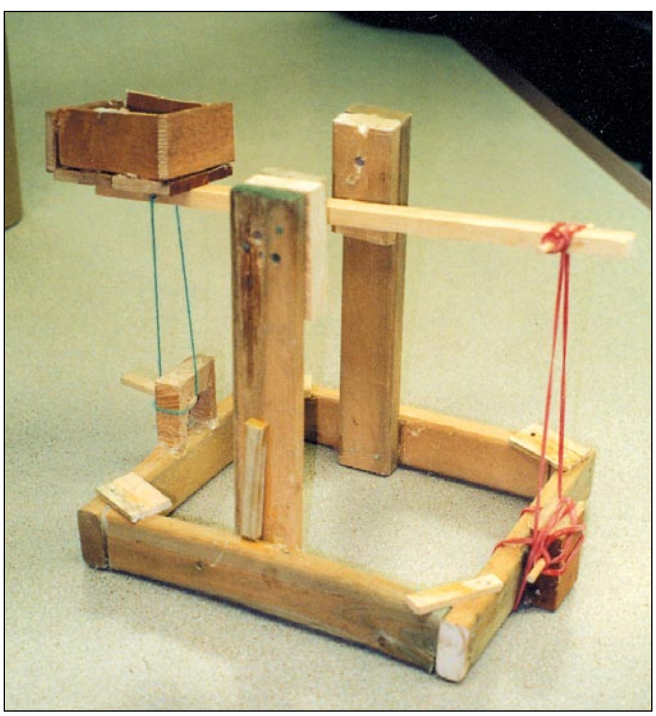
Combining Technology & Science with Catapults

by Meredith Wade

The classroom hummed with activity. The fourth-grade students talked and worked together to follow a design to build catapults. They focused their attention on measuring and cutting pieces of wood and cardboard, drilling holes, and cutting dowel pieces. Teams of students had chosen from two different catapult designs and were constructing them using the LINX tools and materials (LINX is a system of design technology and construction using real hand tools and wood). Each design had plans for the layout and steps for construction.

Why wouldn't you want to explore more with your new car or catapult?

The construction offered students the challenges of accurately measuring and cutting pieces of wood, reading plans, and following steps in joining materials. As they worked they shared their problem solving: "How did you drill that piece?" "How did you get the dowel to fit?" The students have discovered through experience that even a project with plans and directions is not perfect and often needs some modifications. I value a construction project like this one for students, because it requires them to transform a 2D plan into a 3D object with moving parts. It helps them develop a variety of science and technology skills.



Start with design, then experiment

When I first started design-and-build challenges with students, I was content to help guide students through the design process and complete a project. In the book, *Design and Technology Through Problem-Solving*, Robert Johnsey describes the design process as:

- Define a problem;
- Research it and consider multiple solutions;
- Choose a promising solution;
- Design a device or make a plan on paper;
- Make device/carry out plan;
- Test device/plan;
- Improve device/plan or begin again.

For younger kids, walking them through this process and having them complete a designed construction seemed appropriate and sufficient. The goal might be to build a vehicle that could roll with axles and wheels.

But the more I worked with older students and talked to other teachers, I realized that a built object like a car or a catapult could be the first part of an integrated project that combines technology with further investigations that incorporate science and math. Why wouldn't you want to explore more with your new car or catapult? What can it do? Why did we make these things? With the older students there were so many possibilities for other studies to flow naturally from their constructions.

Catapults and motion

We chose catapults because we wanted to construct and create a product, but we also wanted to ask questions about getting things in motion, to experiment with the catapults, and collect data.

A few of our questions were:

- How do the two designs compare?
- What is the same and different about them?
- Which catapult can throw the longest or most accurately?
- What happens if you change a part of the design, for example, if you add more tension by using more than one rubber band to the throwing mechanism?
- What happens when you throw different objects?

In the groups that I've built catapults with, there is a universal need for the students to have unstructured time to test everything, and sometimes even to test everything at once! They enjoyed having time to see how the catapults worked, how best to set them up, and how different projectiles behaved. Sometimes in their enthusiasm to take their new constructions to the limit, they would actually break the catapult. This was not a bad thing to have happen; students used the opportunity to figure out how to repair it, and what would need to happen differently to prevent further breaks. After this open experimenting time the students were ready to create and follow a more structured investigation.

Their beginning play with the catapults was valuable for determining which variables they could control. For example, some students started with lightweight projectiles (cotton balls or pom-poms), and then moved on to heavier things like wooden or plastic beads. Once the building and adjusting of the catapults was complete, the students worked to determine which question they were going to test.

Investigations began with meter tapes, a variety of rubber bands, beads, and small animals; a target, chart paper, and graph paper. Teams divided themselves into different areas of the room, depending on the question they were exploring. Many of the groups worked on either measuring distance or gauging the accuracy of the launch. They tested and collected data in a variety of ways, depending on what they were researching. Then they tested again.

The group testing for accuracy formed their investigation to track how many throws out of ten would land the projectile into a dishpan across the room. Another group played with the effect of rubber band tension on the release. They marked off one area of the room as a firing zone and tracked how tension affected the throw.

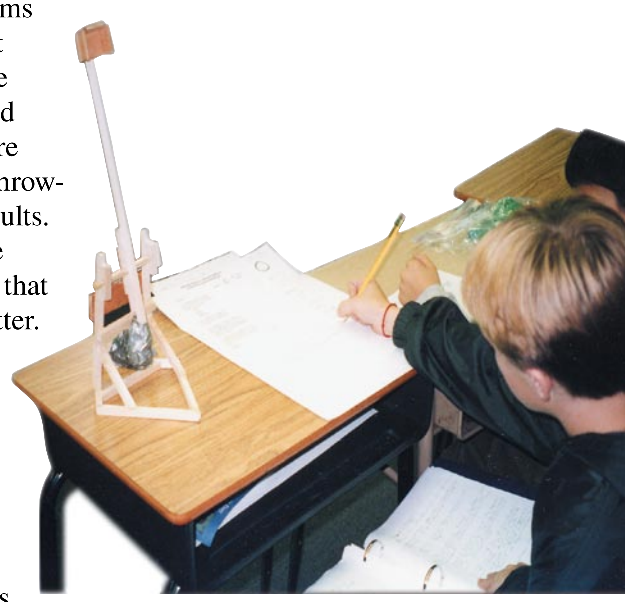
The value of discussion

There is a universal need for the students to have unstructured time to test everything.

We tried to include a discussion as part of each testing session to compare notes and summarize discoveries. Sometimes the discussions were a brief check-in with groups reporting on how they had progressed with their experiments and what they might try next. Longer discussion sessions offered wonderful opportunities for students to practice the skills of presenting clearly and being active listeners.

The students presenting were asked to talk concisely about what they were working on and use evidence from their collected data to justify any claims. They also had to answer other students' questions.

The teams had a chance to compare discoveries and see what conclusions they could make about catapults and motion. For example, two teams had different catapult designs but both were testing what happened when they added more rubber bands to the throwing arms of the catapults. The team that got the longer distances said that their catapult was better. While the numbers were greater for the actual distances, a student on the other team noticed that the overall trend of the data was the same. Data from both teams



Teams of students construct catapults.

showed that more tension on the rubber bands produced longer distances. The students could see a similar pattern in the data and thus made a more general conclusion that was not based on just one experiment.

This combination of building a product and having a chance to determine a way to test it was very satisfying and engaging for students. While it took more time to complete building, testing, and analyzing the results, the whole project gave them a rich variety of integrated learning experiences in technology, math, and science. ✎

Resources

The Linx System. Catalog online at The Science Source, http://www.thesciencesource.com.

Johnsey, Robert. *Design Technology through Problem-Solving.* Simon & Schuster, (U.K.), 1991.

Meredith Wade is a professional development consultant with Synergy Learning in Brattleboro, Vermont.

Newton on the Playground

by Meredith Wade

Kids interact with Newton's laws of motion every day: a foot meets a soccer ball, a body bounces on a trampoline, an adult pushes a child on a swing. These repeated experiences with things in motion teach us all to predict how something will behave and what to expect.

If a child has kicked a ball around, she knows from experience that kicking the ball sends it in the same direction of the kick she gives it. So she can use this experience to move a ball and determine the direction in which the ball is likely to move. However, that experience does not necessarily create an understanding of Newton's laws of motion, at least not until we describe and question the experiences and look for similarities in how things behave.

Here is an example of how discussion and demonstrations of everyday experiences on the playground can lead to developing a beginning understanding of Newton's laws of motion. This conversation is with a few eight- and nine-year-old students on a playground. The teacher (T) and students begin at the swings.

T: What happens if you sit on the swing?
Karen: Nothing. I'm not moving.
T: How do you get into motion?
Rema: You need to move your body or have someone push you.
José: You can get going like this. (Demonstrates using feet to push back and then begins to swing.) Now I can keep going by moving my body.
T: So what gets you into motion?
Karen: A push or jump—some kind of motion.
T: You need motion to make motion?
Rema: You need some energy to go.
José: Yeah, something to make it go.
T: So the swing by itself won't swing?
Karen: Nope.
T: Tell me what you noticed about the difference between a small push and a big push.

José: Well, a little push only makes you go a little and a big push makes you go more.
Rema: Yeah, my dad gives me some really big pushes and I go really high!
T: If you stop getting pushes or stop pumping your legs, what happens?
Karen: You slow down.
Rema: Slowly you lose motion power.

While the teacher and kids are talking they take time to try out the experiences they are discussing. They take turns sitting still on the swing and then comparing small pushes and big pushes. They compare how long it takes after three big pushes for the swing to slow down to stop. And they generate more interesting questions to explore: Does it make a difference who is on the swing and who is pushing? They notice that a bigger person on the swing is harder to get going. If you push a big person and smaller person the same number of times, does the bigger person swing longer?

From these very personal and physical experiences, the children are beginning to articulate Newton's first law (when they say a swing won't go by itself) and the second law (when they say and show that a bigger person needs a bigger push).

The teacher moves the group from the swings and presents a ball. Using similar questioning as with the swings the teacher leads the kids to talk about and test getting a ball into motion, comparing small kicks and big kicks, and how to stop the motion of the ball.

In these conversations and demonstrations the teacher and kids share their experiences of things in motion and generate some common understandings. The teacher helps them put their ideas together and make some statements to summarize the learning.

T: So, on the playground today, we've seen that an object like a swing or a ball needs a push or a pull to get it going. Otherwise it stays still. Isaac Newton noticed this about objects and called it *inertia*. An object at rest, like a ball, stays at rest or not moving, until something gets it going.

We also noticed that a light object is easier to get into motion than a heavy object. It is easier for an adult to push a kid on a swing. The bigger an object the more push or force that is needed to get it moving. We also discovered that a small push or kick created a small reaction from an object.

"You need some energy to go!"

Experimenting with motion on the playground gives a teacher and students some common experiences and language for connecting to the concepts of Newton's laws. Students could then be asked to draw an example of what they discussed about motion or keep a list of some kind or record in the classroom when they notice something that they think fits with their discoveries of things in motion.

These are just two of many opportunities for students to get moving and feel the effects of forces in our world. Another idea is to explore the difference between potential and kinetic energy at the top of a slide and sliding down it. What else can you and your students discover in everyday playground experiences? ✎

Playgrounds offer many opportunities to experience full-body lessons in the laws of motion.

Tips for Teachers

FORCE AND MOTION

By Dr. Cody Sandifer

In the Fall of 2008, Dr. Cody Sandifer supervised a class of pre-service elementary science interns as they taught a ten-lesson force and motion unit. He noticed that after each lesson, he tended to give very similar feedback to all of the interns—and it was this repetition of advice that led him to believe that a short list of force- and motion-related teaching tips might be useful to others. —EDITOR

The exact words that a teacher uses to frame a science lesson can be extremely important.

Force and motion is a kid-friendly topic that provides students with a wonderful context for scientific inquiry. Classroom explorations of pushes, pulls, speeds, and accelerations naturally lend themselves to meaningful hands-on experiments, deep discussions of common experiences, and the types of behaviors that are the hallmarks of truly effective instruction: excited chatter and ear-to-ear grins.

That being said, force and motion also happens to be a topic that can be conceptually tricky and instructionally challenging—and with this challenge comes the possibility that a teacher new to the subtleties of force and motion might benefit from outside advice. In this article, I therefore attempt to generate a list of brief, easy-to-read teaching tips relevant to inquiry-based force and motion lessons, the purpose of which is to help upper elementary and middle school teachers avoid some obstacles specifically associated with these lessons.

Tip #1: Choose your words carefully

As picky as it may sound, the exact words that a teacher uses to frame a science lesson can be extremely important. In the case of force and motion, I've discovered, for example, that teachers and students tend to use the generic word "motion" without variation, which, depending on the specific instructional context, can lead to conceptual confusion.

The primary issue is that, rather than using the word "motion," it is often more accurate to use "speed." For example, asking a student whether a quick push on a book causes "increased motion" can be confusing. Does that mean that the book started moving right away? That it ended up at a different (larger) constant speed? That it sped up (accelerated) quickly? None of the above? In contrast, asking the students to consider whether a book experienced "an increase in speed" is much more conceptually to the point.[1]

A related issue is the need to differentiate between *average* speed (e.g., the "overall" speed of a sliding book during its motion) and *instantaneous* speed (e.g., the sliding book's exact speed half a second after it leaves the person's hand). Such a distinction is important because using the word "speed" without a clarifying adjective can lead students to believe that a sliding book possesses a single constant speed—when, in fact, the pushed book's speed continuously decreases once it leaves the person's hand.

Tip #2: Stay connected to students' physical intuitions

By the time students encounter formal science lessons in upper elementary and middle school, they have developed a fairly extensive repertoire of intuitions about the physical world around them. They know how objects typically look and feel, for instance, and whether specific phenomena are commonplace or surprising.

As a teacher, one of the nicer aspects of teaching physics is that students have already developed intuitive notions of distance, speed, time, and weight—all

1. I have intentionally avoided using the term "velocity" here, due to the fact that velocity and speed are two separate concepts in physics.

of which are key concepts in force and motion. This means that when the teacher or a fellow student brings up real-life events involving a car's speed, a bathroom scale, or a kitchen timer, most students are able to nod their heads and agree that these shared experiences (a) are relevant to science and (b) make intuitive sense.

One issue in teaching force and motion is that teachers can inadvertently bypass students' physical intuitions—especially when it comes to ideas of measurement. My experience has shown that students' intuitions about distance, speed, time, and weight are deeply tied to specific measurement units. Students know their weight in pounds, their height in feet and inches, and the speed at which their family car travels in miles per hour. This implies, in terms of meaningful instruction, that it can be beneficial during classroom discussions and scientific investigations for the teacher to strike a reasonable balance between pounds, inches, and miles per hour (customary units) and newtons, centimeters, and meters per second (metric units), respectively.

Helping students understand metric "SI" units (*Système Internationale* or the International System of Units) is a major goal of instruction. Teachers need to make a sustained effort across the curriculum to help students develop intuitions about these measurement units. On the other hand, it can be confusing for students when teachers exclude non-SI units from force and motion lessons. Consequently, I have observed that successful force/motion lessons (especially introductory lessons) include, to some degree, the customary units of measurement with which students are most familiar—primarily so as not to circumvent students' already strongly-developed intuitions that are based on these units.

Tip #3: Use carefully-defined time periods in your analyses

While teaching force and motion lessons, as you have students engage in different hands-on activities (often involving hair dryers, tennis balls, ramps, various types of frictional surfaces, etc.), it is important for follow-up analyses of these activities to be centered on carefully-defined periods of time that are tied to the existence or absence of particular forces. This is especially critical in cases where the forces acting on an object over time are mixtures of continuous and briefly acting forces.

To make the need for well-defined time periods a bit more concrete, let us continue with the example of the pushed book, and imagine a portion of a lesson where students are asked to analyze the forces acting on the book. To spice things up a bit, and to make things more realistic, let's consider the extended case where the pushed book leaves a student's hand, coasts across a table, and then crashes to a stop against a wall.

The relevant time periods for the pushed book, along with the appropriate force/motion analyses, are shown in Table 1.[2]

TABLE 1. ANALYSIS FOR THE PUSHED BOOK, BY TIME PERIOD

Period of Time	Forces	Net Effect on Speed
the book is in contact with the hand	the applied force of the hand; friction	the book's speed increases quickly
the book slides across the table after leaving contact with the hand	friction only	the book's speed decreases slowly
the book crashes into the wall and comes to a stop	the opposing force of the wall	the book's speed decreases quickly

Now compare the detailed step-by-step analysis in Table 1 with a more general approach in which the situation is mistakenly treated (either by students or teachers) as a single entity. The result of this type of "everything-at-once" analysis typically leads to force/motion descriptions similar to the following: The force of the hand and the force of friction are definitely present, although it isn't clear exactly when those forces pick up and leave off, and there are likely alternating periods of constant and changing speeds, with the specific details being a bit fuzzy. As you can see, the

2. Note that, in this seemingly innocent example, we implicitly assume four things: the applied force of the hand is much larger than the force of friction; negligible forces such as air drag can be ignored; the book does not bounce off the wall; and we are not interested in vertical forces such as gravity.

results of the step-by-step and everything-at-once analyses are very different from one another.

The root of the problem is that people frequently do not realize that even "simple" situations cannot often be described holistically with a single continuous set of forces. Instead, the appropriate procedure is to break down the process into individual time steps, each of which must be analyzed separately in terms of forces and changes in speed.

Tip #4: Become informed about students' pre-developed ideas

Inquiry lessons contain multiple opportunities for students to share and discuss each other's ideas. In science, these episodes of idea sharing arise spontaneously during small-group and whole-class discussions of evidence, experimental procedures, and students' predictions, hypotheses, and scientific questions.

An interesting paradox is that, as important as it is for teachers to help students share their ideas and connect these ideas to physical reality, force and motion is a content area in which students' pre-developed ideas often contradict scientifically accepted theories. Therefore, an important part of instructional preparation is to become aware of students' not-quite-accurate ideas about force and motion, so that, when confronted with these ideas during a discussion, the teacher isn't blindsided and left wondering how to react.

It is important to become aware of students' not-quite-accurate ideas about force and motion.

Many students' alternative conceptions about force and motion (which are scientifically inaccurate, yet grounded in everyday experience) include the following:

- Motion requires the presence of a force;
- Inanimate objects cannot exert forces;
- A force is something that can be transferred;
- Moving objects naturally slow down on their own;
- The words *force*, *momentum*, and *energy* can be used interchangeably.

The reason for being aware of these common ideas is not to warn students in advance that these ideas aren't true; that would be an instructional response not necessarily in alignment with inquiry-based science instruction.

Instead, being aware of these alternative concepts is vital to ensure that (1) the words spoken by the students are literally comprehensible to the teacher, since teachers often find it difficult to process students' ideas when they are very different from their own; and (2) the teacher has responses prepared so that discussions can be moved forward in an inquiry-appropriate manner when these ideas invariably arise. Such strategies are beyond the scope of this article, but they often involve the non-judgmental elicitation of other students' ideas and further discussion of scientific evidence and definitions.

Getting to the "Big Ideas"

Teaching force and motion is always interesting, often fun, and absolutely extraordinary in the ways that force/motion ideas provide students with very specific, very real access points to the laws that underlie our physical universe.

Given this last fact, it is important to recognize that teaching force and motion doesn't have to be frustrating, confusing, or intimidating. With instructional support, whether in the form of tips, hints, or friendly advice, it is possible for the teaching of these topics to result in both the students and the teacher gaining an increased understanding and enjoyment of the Big Ideas of physics.

Dr. Cody Sandifer is an Associate Professor of Science Education in the Department of Physics, Astronomy and Geosciences at Towson University in Maryland. For the past six years, he has been an instructor for a science internship course in which elementary education majors teach inquiry-based science lessons once a week in upper elementary classrooms. He welcomes your comments at csandife@towson.edu.

I'm Not Going to Tell

by Heather Taylor

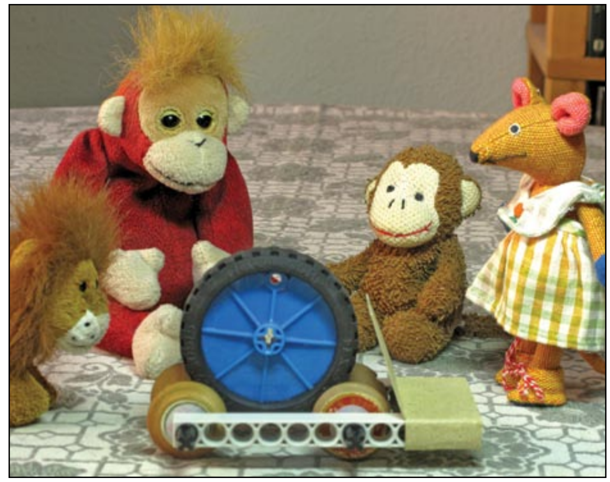
"Here, you should see this," my husband John said, pushing the laptop toward me. It was a podcast of "The Best of YouTube" for the week. It was called "Under the Ruler, Faster than the Ruler," (http://www.youtube.com/watch?v=k-trDF8Yldc). A man in Germany, Michael Cook, had posted a very sweet video. Four tiny stuffed animals sit in a semicircle and watch as the narrator poses the situation: A cart with spools for wheels has a larger wheel nestled on top of the smaller wheels. If the top wheel is pushed clockwise, the smaller wheels go counterclockwise. So which direction will the cart travel in if he puts a ruler on top of the large wheel, and pulls the ruler to the right?

The narrator names the stuffed animals one by one and states what they think. George has rationale for it moving to the left, Coco reasons it won't move at all, Louise says it will move to the right but she isn't sure why. My very favorite one is Terry, the orangutan, who knows exactly what's going to happen, but "he's not going to tell."

At this point John stopped the video and said, "So what do you think will happen?" *Piece of cake*. I thought, *I edit a science magazine, after all*. "If he pulls the ruler to the right, the top wheel will turn to the right (clockwise) too. That will cause the small wheels to turn to the left, and the cart will go the same way, to the left" (Just what George the Lion thought).

Then I watched the rest of the video. Of course, I now know exactly what happens, but I'm not going to tell. And of course, what I originally perceived as a sweet little video was causing great churning in my brain, in a way it hasn't churned in a while.

I so enjoyed the clip and the degree to which I felt perplexed by what I saw, that I posted the link to the video on a Facebook page. Several people commented. One said she was going to check it out using a site for "debunking frauds." She wondered if the videographer had it rigged somehow to be a kind of optical illusion, if he slid his hands along the ruler to make it appear as if it were moving, or maybe he tilted the ruler, and that affected the direction of the cart. These comments and questions mirrored the comments on the YouTube page. Accusations of fraud, outrage at someone proposing this can work, etc. were about a quarter of the comments recorded.



In response to my post, another person posted a link to what he called, "the old spool trick," which asks which way will a large spool of wire move, away from, or toward the direction in which it's being pulled (http://www.youtube.com/watch?v=dCBpTv0DsPI)? I tried this with a spool of thread (which was not a great model for the force at work), and learned some interesting things, which, of course, I'm not going to tell.

These kinds of links can be used successfully with your classes. It is almost impossible to see these clips and not ask questions. They are marvelous invitations to your students to get out spools and dowels and gears and such to try out the challenge for themselves.

Asking questions and testing out our ideas are major components of what it means to think scientifically, to do what scientists do. The more we can remind ourselves of the exhilaration of not knowing, the better for our teaching. In these moments of not knowing, we are closest to the wonder of learning, and that wonder is transparent to our students. Try looking for things that make you scratch your head, that have you reaching for a few odds and ends to test out something for yourself. Your students will be energized by watching you model what it is to learn through inquiry. And when you create the space, time, and offer materials for them to explore, you will not be able to stop them from learning about things in motion.

What I originally perceived as a sweet little video was causing great churning in my brain.

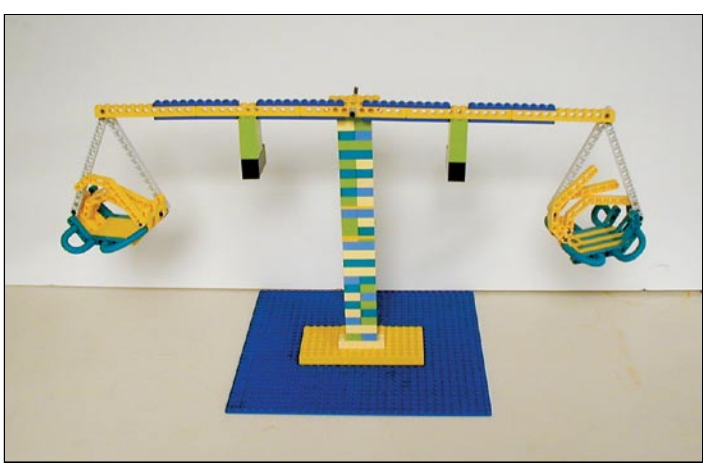
Using New Technology to Explore Historic Ideas

by Barbara Bratzel

Learning about Newtonian mechanics is a common experience in middle-school science. The students bring a wealth of intuition to this study—they have been experimenting with the motion of physical objects in an informal way since infancy. Knowledge that is grounded in experience is compelling! It is accepted by students at a gut level in a way that knowledge born of problem sets, though useful, is not. However, this gut knowledge tends to be qualitative, not quantitative. How do we give students quantitative experiences with these concepts that make this knowledge real to them? Combining a study of Newtonian mechanics with engineering design and robotics provides a powerful way to do so.

All in the balance

Every year, the eighth graders in my Physics by Design classes at the Shady Hill School in Cambridge, Massachusetts, design their own balances using prescribed materials: LEGOs, string, and a set of metric masses. But the design is left to them. The only requirement is that the finished balance must be accurate to within 0.5 grams. The students design and build, test and modify, until they are satisfied with their balances. When they decide they are ready, they put their balances to the final test: determining the mass of four unknown objects.



These students are thinking like engineers while at the same time applying what they have learned about balanced forces, center of gravity, and torque. Using the concepts in an actual design project reinforces them more effectively than completing any number of problem sets. In addition, the students have fun building their balances and feel a considerable sense of accomplishment when they successfully complete the challenge.

NXTs and ROBOLAB

Physics by Design is a project-based course that teaches classical mechanics through engineering. It covers motion, forces, fluids, stability, work, and energy. The topics are approached from an engineering perspective, with designing and building reinforcing the conceptual physics material and vice versa. Most of the lab work is done using LEGO bricks, including LEGO NXTs, programmable bricks that contain microcontrollers. The NXTs are programmed using ROBOLAB, an icon-based programming language. All of the students in the course learn ROBOLAB. By the middle of the year, they are adept at programming.

I started the physics course eleven years ago as a way to teach students engineering as well as science. It was inspired by my work with the Center for Engineering Educational Outreach at Tufts. The CEEO is dedicated to bringing engineering into the K–12 classroom. Traditionally, engineering is rarely taught below the college level. However, it has much to offer younger students. First of all, it is engaging. The students have a chance to design and construct their own projects and have the satisfaction of actually making something work. Second, engineering projects are a powerful way to teach and reinforce science and math concepts. Third, introducing engineering at a younger age encourages students who might otherwise never do so to consider it as a career.

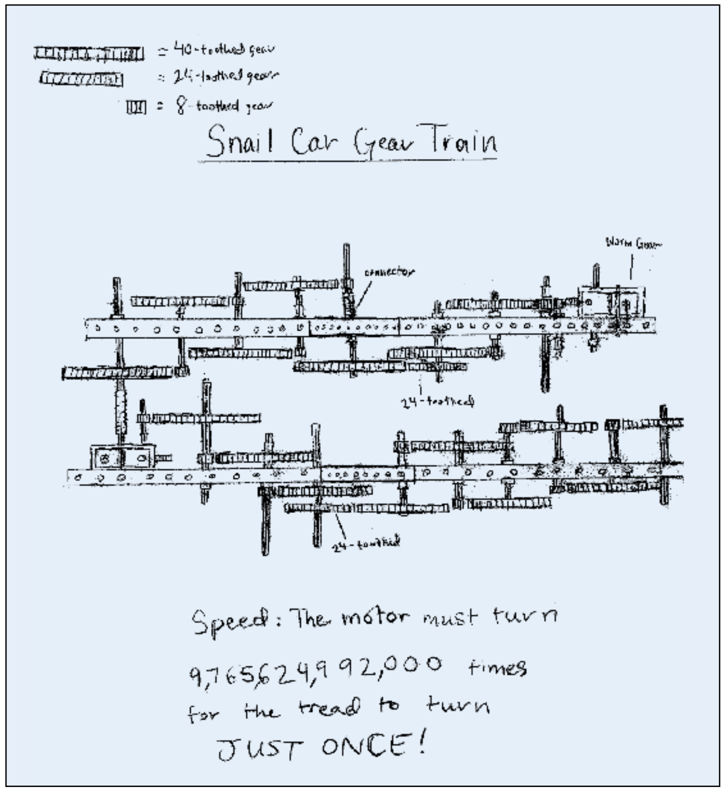
The students begin the year in Physics by Design by building simple, sturdy NXT cars and programming them to drive in a straight line. Using stopwatches, they see how much time their cars take to travel one meter, then use that information to estimate how long the cars will take to travel one-half meter, two meters, and other distances. After collecting the data, the students use them to graph distance vs. time for their cars.

An extra challenge

Once the students understand and can read and create their own graphs, they are given a challenge: use their data to estimate how much time their car will take to drive a specified distance. To raise the stakes, the specified distance is the location of a new pedestrian crosswalk. The students need to use the data they have collected to program their cars to drive up to the crosswalk and stop before they knock over the LEGO mini-figure pedestrians in the crosswalk.

The crosswalk test is the source of much excitement for the students. We run the cars one at a time. A small prize is awarded for each car that stops within 10 cm of the crosswalk, with a grand prize for the car that comes the closest to the crosswalk without entering it. I enforce a strict code of behavior for the test: cheers and compliments are encouraged for successful cars, but the only allowable response for a car that stops short or knocks over a pedestrian is a sympathetic “Ahhh.”

Programming the NXT with ROBOLAB allows us to datalog a number of different sensors. For example, during our study of motion, the students attach downward-facing light sensors to the fronts of their cars and drive them over a series of dark lines spaced 10 cm apart on a light background. They use the resulting pattern of dips (or valleys or local minima) in the graph to find the average velocity of their car and to see whether it is accelerating.

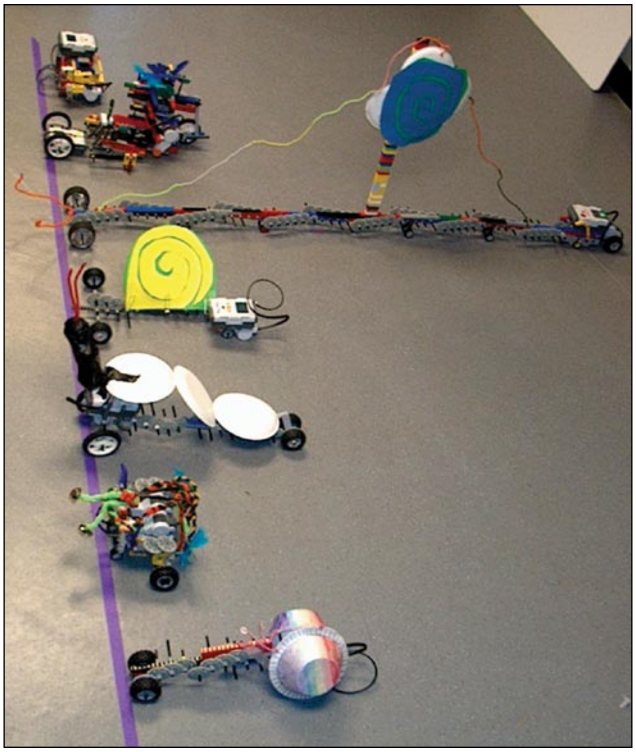


We then move on to using the built-in rotation sensors to analyze the cars’ motion in a more sophisticated way.

The students log the rotation sensor to measure the rotation of the wheels in degrees over time and display their data as a graph. They use the ROBOLAB software to analyze their results. Dividing the data by 360 gives them complete rotations over time rather than degrees. They then take the derivative of the data (which I explain to them as taking the slope of the line) to get a graph of velocity vs. time. To convert the velocity to meters/second, the students measure the circumference of the car’s tire and multiply the velocity data by that number.

These data manipulations are beyond what I would normally ask of eighth graders. However, because they can do them easily using the software and can display the resulting graphs immediately, these different ways of looking at the results make sense to my students. The distance vs. time and velocity vs. time graphs that they have generated for themselves look like the ones in physics books—but they are more understandable to the students, since the students can relate the graphs they see on the computer to the cars they see driving across the floor.

We then move on to using the built-in rotation sensors to analyze the cars’ motion in a more sophisticated way.



When last place is first

Another challenge that the students tackle is building geared-down NXT snails that move as slowly as possible. The students construct elaborate gear trains in order to slow down the motors. At the end of the project, we stage a snail race, where all of the snails are placed at the starting line and started at the same time. Because they are so geared down, none of the snails actually move, though their motors spin. To document the snail, each student must make a schematic of the gear train and calculate the number of times the motor must turn in order for the wheels to turn once. In the slowest snail yet created, the motor had to turn 5.3×10^{44} times for the wheels to turn once.

The NXTs can be used for much more than cars. We attach strings to them and swing them for pendulum experiments. To study heat transfer, we construct cocoa-cooling machines and use datalogging technology to find which are most effective. We also do larger design projects that integrate many of the concepts the students have learned. Past projects have included music boxes, gumball machines, and robotic animals.

At the end of last year, I gave my students a survey about the various aspects of the course—the discussions, problem sets, projects, and so on. Which piece did they find most fun? Predictably, they all said the projects. Which component of the course was most valuable in helping them to learn the concepts? Rather to my surprise, they overwhelmingly answered that the projects had taught them the most. I had always thought of the projects as a means of engaging the interest of the students, but the students found them the most useful way of learning the material as well. I feel that the projects we do in Physics by Design give my students a real-world grounding in formal, quantitative Newtonian mechanics—and I hope, a love for the subject.

I hear repeatedly from parents that Physics by Design is the course that their children talk about at the dinner table more than any other. For some of the students, this enthusiasm seems to last beyond the year. Two of my former students have returned to Shady Hill to volunteer as assistants in my class. Another girl went on to start a robotics club in her high school; she, and a number of other former students, have participated in the FIRST robotics competitions.

Throughout the year, the students often bring their parents, siblings, and classmates by the classroom in order to show their creations to them. The pride and confidence I see on the students' faces as they demonstrate their projects warms my heart—and convinces me that they are gaining something valuable from the experience besides a knowledge of physics.

Barbara Bratzel is a science teacher at the Shady Hill School, a preK–8 independent school in Cambridge, Massachusetts. In addition, she is a consulting teacher at the Center for Engineering Educational Outreach at Tufts University. The second edition of her book, Physics by Design*, was published in 2007. A new version, using the NXT Mindstorms software, will be published in Spring, 2009.*

Resources

Center for Engineering Educational Outreach. http://www.ceeo.tufts.edu.

Erikson, Sheldon, Tom Seymour, and Martin Suey. *Brick Layers II: Creative Engineering with LEGO Constructions*. Aims Education Foundation, 2009.

LEGO Engineering. http://www.legoengineering.com.

Spool Tractors

Here is a great activity that is full of potential. It's also great for exploring potential energy.

You'll need to gather these materials for each group of students:

- A thread spool, ideally one whose center is quite a bit smaller than the edges;
- A variety of rubber bands, especially one that is slightly larger than the length of the spool;
- A small disk of bar soap with a hole in the middle, or a slice off the end of a wax candle;
- A wooden skewer or thin dowel;
- A paper clip or a crochet hook.

To make a spool tractor that works well, you'll need to experiment with each piece to learn what works best. Varying the length, width, shape, or amount of an element will make a difference. Make sure to try your own tractor first so you are better equipped to support your students as they experiment with variables.

Testing it out

Wind the longer rod five to ten times and then set the spool on the ground or a tabletop. Does it move? If not, try turning the long rod twice as many times.

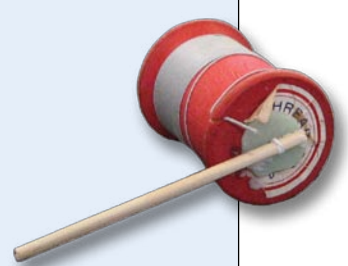
How can you make it go faster? Slower? Is there a way to change the edges of the spool to create more or less friction? Is there a way to weight the spool, and does that change how it works? What if you use a rod that is 20 cm long? 4 cm long? Try varying the length and width of the rubber band. Try using paper washers instead of wax or soap.

Putting it to work

As your students recognize the characteristics that make for the best working tractor, make a class list. The list can be modified to act as a guide for building the best tractor possible, using all of your class's accumulated knowledge. ✎

BUILDING THE TRACTOR

1. Bend the paper clip into a hook that will fit through the spool end (or use a crochet hook).
2. Use the hook to start threading the rubber band through the center of the spool—but don't pull it all the way through.
3. Insert a short length of dowel (less than the diameter of the spool) through the bottom rubber band end and hold it in place.
4. Pull the other end of the rubber band through the other end of the spool.
5. Stretch it out sufficiently to hold in your fingers. Remove hook.
6. Thread the end of the rubber band through the disk of soap or wax, then insert a longer piece of dowel through the rubber band loop (from 5 cm to 15 cm in length).



Technology for Learning

Making Sense of Motion

by

BOB COULTER

As our students grow up in an increasingly digital age, keeping them grounded in the fundamentals of physics can be quite a challenge. With real experience being replaced by electronic representations, kids' intuitive sense of how things work can be altered in ways that may not be productive. Examples of this abound in video games as the laws of physics are suspended to make a good game. Players leap from place to place toward a goal, or water droplets change phase from solid to liquid to gas as needed to solve a puzzle. Even if the physics within the game are realistic, there is a world of difference for young learners between seeing a screen representation of a ball being hit and having the experience of hitting one.

One tool to consider in bridging this gap between experience and representation is an electronic motion sensor. With the use of a sensor, students' motion shows up on the computer screen, allowing them to link their bodily-kinesthetic experience with a graphic representation. Probes like this have been used for more than a decade in schools, but they have often required expensive and somewhat cumbersome sets of equipment. Newer models provide a relatively inexpensive alternative with easy setup and a kid-friendly interface.

Data collection on the *Go!*

For these examples, I'll be using Vernier's *Go! Motion* probe, part of their *Go!* series of probes. In addition to the motion probe, others in the series include a temperature probe, magnetic field sensor, and a force plate. (Other probes can be added with an adapter.) Each of these *Go!* probes comes with basic data collection software and a probe that automatically links to the software. All you need to do is plug the probe into a USB port and start the included Logger Lite software. You're literally ready to start collecting data in seconds—no elaborate setup or calibration is required.

The probe collects data by sending out sound waves and "catching" their return when they bounce off an object. A simple introductory activity might involve having a student walk back and forth in front of the probe, noting how their motion is displayed on the screen. As they move away from the probe, their position is recorded higher on the graph; as they move closer, the line on the graph decreases. Once they "get" how the probe records motion, students can use the Predict tool to draw a line on the screen and then try to walk the line. It's not as easy as it sounds! With

Bob Coulter is the director of Mapping the Environment, a program at the Missouri Botanical Garden's Litzsinger Road Ecology Center that supports teachers' efforts to enhance their science curriculum through use of the Internet and Geographic Information Systems (GIS) software. Previously, Bob taught elementary grades for twelve years.
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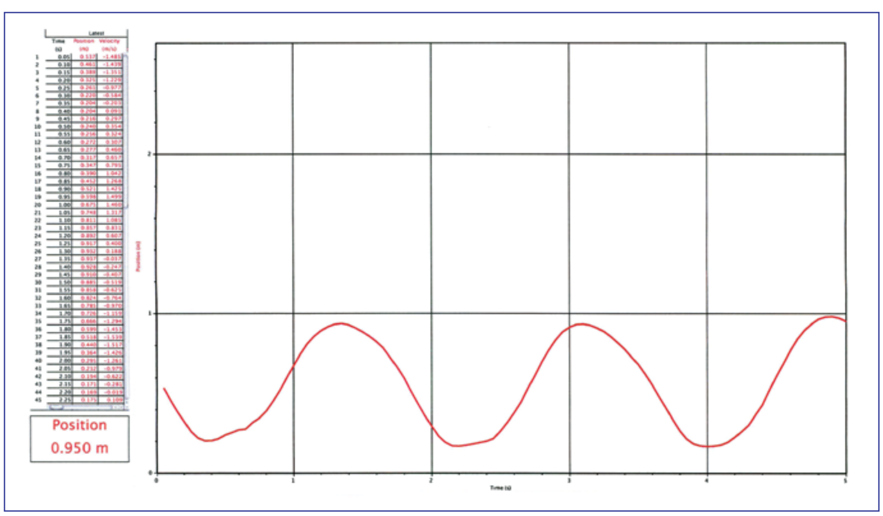


a couple of tries, they can forge a link between their actions and how they are recorded. As an added bonus, students are also building critically important graph-reading skills as they interpret their data and adjust their motion to match the target line they drew.

Extending the experience

One extension of this activity can be found in the optional *Elementary Science With Vernier* curriculum guide. Once students have a good understanding of how the probe works, they can write directions to replicate certain patterns in the graph. For example, the directions could tell someone to start 2 meters from the probe, wait 3 seconds, and then move slowly back for 2 seconds, reverse course, and move quickly back to the starting point, and so on. Activities such as this deepen understanding of the tool and build language and math skills in the creation and refinement of the directions.

From here, you and your students can explore more advanced concepts such as periodic motion. If you rig a simple pendulum so that it moves back and forth in front of the probe, students can track the motion of the pendulum back and forth. The trick in doing an investigation like this is to have a large enough target for the sound waves to hit. A balloon-sized target will give you better results than a smaller one, but in either case you will likely get some "noise" in the data. These odd spikes in the graph present a good opportunity to discuss what has happened and why the distance seems to have suddenly jumped. For example, one possibility for a suddenly higher reading might be that the probe missed the target and hit the wall further away from the pendulum.

Adding math to the study

To build a more mathematical dimension to your study, students can measure how many seconds pass between each swing. That data can be collected directly from the table (at the left of the Logger Lite screen), or from the graph itself. By clicking the "Examine" button, students can get the reading at any point in the graph. By gathering the time data for successive high or low points, the period of the pendulum can be calculated. Additional math angles that come from this investigation include looking at the data table to determine how you know the pendulum has shifted direction, and interpreting the velocity readings that are negative numbers. Over time, your students will become increasingly comfortable linking movement they observe with the associated graphic and numeric representations.

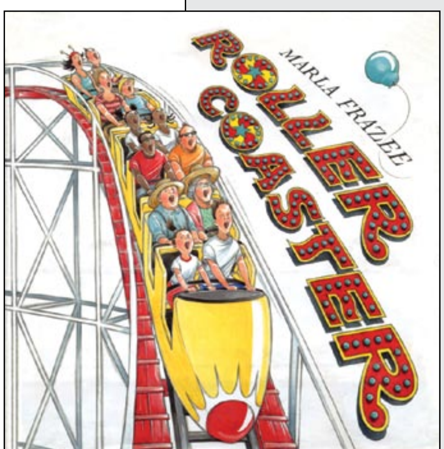
Moving forward, a number of additional studies become possible. Your students will have many ideas, but if you're looking for more, the *Elementary Science With Vernier* book suggests other periodic motion activities, such as having a Slinky bob up and down over a probe pointed upward, and using the probe to mimic bat sonar. In that project, students can act out the role of different insects trying to avoid capture. If you work with older students, you might find activities in the *Middle School Science With Vernier* book helpful. These include investigations of velocity based on measuring cars on a ramp, studies of falling objects, and measurements of classmates sliding down a playground slide. All of these projects help your students to develop a strong basis for understanding formal physics later in their school careers.

Resources

Vernier Data-Collection Technology for computers and handhelds: Find the easy-start package for *GO!* probes as well as over forty other probes that can connect to your computer. *Go!* products are Windows and Mac compatible. 888-837-6437. http://www.vernier.com/go.

Literature Links

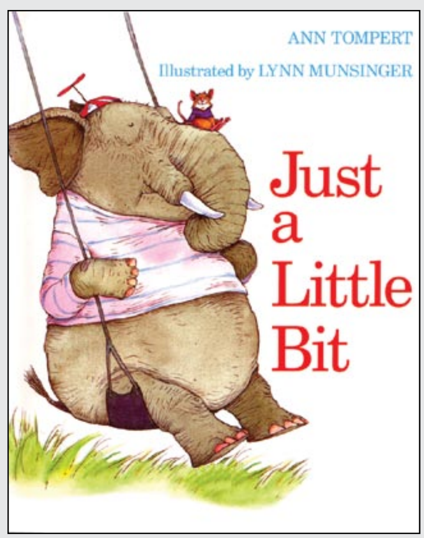
Eyewitness Science: Force & Motion, by Peter Lafferty (Dorling Kindersley, Inc., 1992), is filled with great photographs and paintings of gadgets, gizmos, inventors, and scientists who have furthered our understandings and applications of physics. Gears, levers, pulleys, and other simple machines are also examined. Examples are shown from diverse cultures and historical periods. Brief paragraphs give basic explanations that can pique the interest of readers to learn more from other resources. The large and interesting format lends itself well to independent reading and exploration for students six to twelve years old.



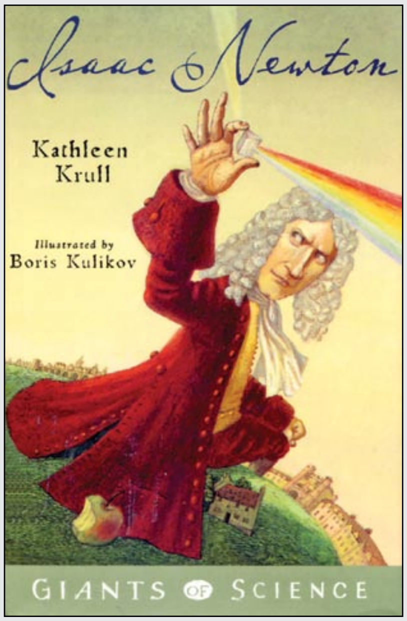
Roller Coaster, by Marla Frazee (Harcourt, Inc., 2003), is a picture book that portrays different people riding a roller coaster at an amusement park. The marvelous illustrations show a variety of ages, races, and styles, and peoples' expressions are great. The text repeats a pattern and in some places appears alongside the track of the roller coaster rather than in a usual block of text. Although there are no specific references to Newton's laws or physics concepts, this is a good book to augment a study of roller coasters, motion, or even simple concepts like up and down or slow and fast. Children six through ten will enjoy looking carefully at the pictures.

Forces Make Things Move, by Kimberley Brubaker Bradley (Harper Collins Publishers, 2005), is a non-fiction picture book that points out everyday experiences and how they relate to the laws of physics. "If you push a car along a shiny wooden hallway, it rolls much farther than if you push it along a thick bedroom rug." Illustrations by Paul Meisel are charming and show children in a variety of everyday activities. Forces, in particular, friction and gravity, are explained in simple language for five- to nine-year-olds in this "Let's-Read-and-Find-Out" series book. There are suggestions of things for the reader to try, using toys and household objects.

Sports Science Projects: The Physics of Balls in Motion, by Madeline Goodstein (Enslow Publishers, Inc., 1999), is an informative, nonfiction early chapter book with fascinating facts and challenges about different kinds of balls used in sports. Why do tennis balls have fuzz? Why are golf balls dimpled? Do the stitches on a baseball make a difference? Many experiments are included within the context of simple questions. One activity instructs dissecting a baseball and then asks lots of questions, some investigatable and some not, about materials and how they are used. This book for eight- through fourteen-year-olds is perfect for reluctant readers who have a strong interest in active play and sports. It is a good resource for teachers as well.

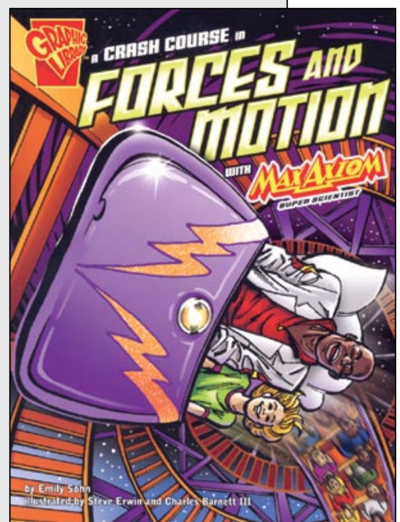


Just a Little Bit, by Ann Tompert (Houghton Mifflin, 1993), is a picture book that tells what happened when Mouse and Elephant tried to ride the seesaw together. Elephant has a hard time getting off the ground. Mouse gets help from lots of other animals, and ultimately it is the last critter, a small brown beetle, who gives enough weight to Mouse's side to tip the seesaw. This story for kindergarten through third graders is in the same vein as *Who Sank the Boat?* by Pamela Allen, and *Equal Shmequal* by Virginia Kroll. Acting out the story or creating a similar one using the predictable patterns of the story could work well to integrate science, math, and language.



Isaac Newton, by Kathleen Krull (Viking, 2006), is part of the "Giants of Science" series. This unique biography of Sir Isaac Newton examines his genius but also his curmudgeonly and petty ways that characterized him as "perhaps in need of therapy." This book follows his life within the greater context of significant findings elsewhere in the world of science. It relates his interactions, both friendships and rivalries, with other contemporaries. This is a fascinating read for adults and children down to age twelve. Learn about his somewhat silent stint in Parliament, his avarice for studying the Bible, and his devotion to pursuing alchemy. The author successfully includes both simple explanations of scientific phenomena and "juicy" stories of Newton's life that hedge toward a tabloid.

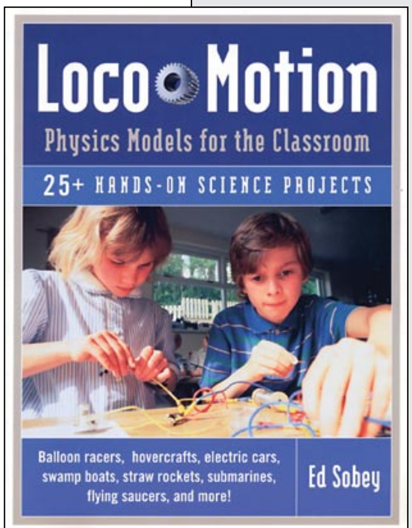
Isaac Newton for Kids, by Kerrie Logan Hollihan (Chicago Review Press, due out in July 2009), is another in the long-standing series of activity books from Independent Publishers group. Over twenty activities are included. Written for children, this book is also a great resource for teachers and parents. Clear and detailed illustrations show how to build a sextant, conducting a series of tests with a pendulum, and making homemade ink. There are background information and suggestions for extensions with each activity. These can be stand-alone projects, or integrated into a much larger study for children in grades two through six.



A Crash Course in Forces and Motion, by Emily Sohn (Capstone Press 2007), is a graphic novel for eight- to fourteen-year-olds. The character Max Axiom, Super-Scientist, is at an amusement park. There he defines Newton's three laws of motion using roller coasters, skating, and bungie-jumping, among other activities to demonstrate his ideas. Everyday examples of things in motion are also described. Concepts are explicitly defined using clear and developmentally appropriate language. This book includes a glossary, Web sites, and suggestions for further reading. The graphic novel format may entice reluctant readers to engage in nonfiction text.

Marveltown, by Bruce McCall (Farrar, Straus and Giroux, 2008), is an unusual picture book relating the events in Marveltown, a human-made city of inventions. Every Saturday, the grown-ups open the doors of the Invent-o-Drome and let children pick through the shelves in the Storage Center to create items like the rocket chair, to jettison you off to school and save walking time. A fluke produces a short-circuit that activates an army of robots to crush the town. Will Marveltown survive? What inventions might save them? This surreal tale can inspire a second- to sixth grade open-ended workshop for inventions and looking at the process of designing, building, and assessing one's own work.

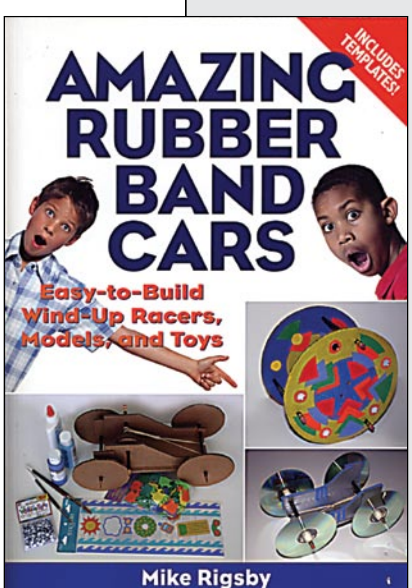
Resource Reviews



Loco-Motion, by Ed Sobey, is a great resource for hands-on projects that meld technology and inquiry. Science concepts such as gravity, air pressure, kinetic energy, Newton's laws, electrical circuitry, buoyancy, and inertia are explored. Among the models discussed in the book are gravity-powered cars, balloon racers, hovercrafts, gravity ball launchers, flying saucers, catapults, chemical mini-rockets, swamp boats, and submarines. The lessons are structured in such a way that students are supported and encouraged to test, modify, and redesign based on their observations of their models. Cooperative learning is also emphasized.

Loco-Motion. Chicago Review Press, 2005. 208 pages. $24.95. 800-888-4741. http://www.ipgbook.com.

Amazing Rubber Band Cars, by Mike Rigsby, features many activities for building wind-up racers, models, and toys. It is intended to be used by children with adults in after-school or out-of-school settings, but there are many applications in the classroom as well. There are explicit instructions and patterns for each project. All projects use simple materials like corrugated cardboard, white glue, pencils (as axles), pushpins, and rubber bands. Because all the design decisions have already been made, there will be a high degree of success with the projects. But it is important to encourage inquiry learning while working with the designs. The last project is perhaps the most spectacular: a cardboard car large enough to transport a human, powered by rubber bands.



Amazing Rubber Band Cars. Chicago Review Press, 2008. 121 pages. $12.95. 800-888-4741. http://www.ipgbook.com.

Awesome Experiments in Forces and Motion, by Michael DiSpezio, is a collection of over 70 easy experiments using everyday materials to show basic concepts. The investigations progress from very simple, such as observing inertia in liquids by spinning a cup of water with drops of oil on the surface, to more complex, such as a potato launcher. The activities are presented in five sections, each relating to a concept like, "Staying Put," or, "What's the Attraction?" Some of the directions are less than clear, and a certain amount of experimentation and fussing might be necessary to get the activities to work. But each one is directly related to science concepts and Newton's Laws are specifically referenced throughout. The book includes a good variety of tests that will fuel lots of discussion for students in second grade and up.

Awesome Experiments in Forces and Motion. Sterling Publishing Co., Inc., 2006. 160 pages. $6.95. Available through your library or local bookstore.

Physics by Design: Robolab Activities for NXTs and RCX, by Barbara Bratzel, is a complete guide that offers helpful advice for managing materials, groups, and sequencing lessons. Both tutorials and whole group instruction are included. The author has taught using these materials for many years and the experience and expertise she offers in the book are invaluable. Tips for discussions, reproducible masters, and helpful diagrams are a part of each lesson. Examples of children's work are provided throughout the guide. Appendices include alignment with National Standards and equipment needed for each activity. The text proceeds in a logical format that is easy to understand. For more about Barbara Bratzel's teaching, see her article on page 12 of this issue.

Physics by Design: Robolab Activities for NXTs and RCX. College House Enterprises, LLC, 2007. 360 pages $36.00. 865-558-6111. http://www.collegehousebooks.com.

Stomp Rockets, Catapults, and Kaleidoscopes: 30+ Amazing Science Projects You Can Build for Less Than $1, by Curt Gabrielson, is an entertaining collection of projects for ages nine and up. The activities include great questions to further understanding and to extend inquiry. Each activity is based on a real-life example, such as how our eyes see, how to make an electric car, and how a toilet flushes. Build a working model of the human hand's muscles, bones, and tendons using drinking straws, tape, and string. All projects are field tested. This is a great resource for inspiring interest in engineering and mechanics.

Stomp Rockets, Catapults, and Kaleidoscopes: 30+ Amazing Science Projects You Can Build for Less Than $1. Chicago Review Press, 2008. $16.95. 195 pages. 800-888-4741. http://www.ipg.book.com.

Experimenting with Model Rockets, by Cary I. Sneider, is another great resource for Lawrence Hall of Science in Berkeley, California. It builds on the guide *Height-O-Meters* (a pre-requisite for this unit). This guide will help you lead students through the analysis, modification, and record-keeping necessary in assessing the variables that affect rocket flight. Students plan and conduct controlled experiments, measure degrees and meters, and graph and interpret data. The guide includes safety precautions, materials management, and logistics of using a launch space. Although the photos are dated, the text is still helpful and applies to great learning in your classroom.

Experimenting with Model Rockets. Great Explorations in Math and Science, 1989. 30 pages. $18.00. 510-642-7771. http://www.lawrencehallofscience.org.

The Spinning Blackboard is one in a series of books based on "Science Snacks," developed by the Exploratorium in San Francisco (http://www.exploratorium.edu). It includes twenty-three Exploratorium experiments on force and motion. Each experiment uses simple materials and is easy to do, fully illustrated, and loaded with advice, ideas, and helpful hints to aid your students in making exciting discoveries. Projects include how to build a pendulum that swings in intriguing patterns and how to create a swirling, spiraling "tornado" of water. The Exploratorium specializes in engaging, hands-on activities that promote critical thinking.

The Spinning Blackboard. Wiley & Sons, 1996. 128 pages. $13.95. 877-762-2974. http://www.wiley.com.

WEB SITES

Estes Rockets For over thirty years Estes has been the source for model rocket sets, curriculum, safety codes and laws, and accessories needed for building model rockets with your class. You will need to go to a different source to purchase products, but this site has all the information. http://www.estesrockets.com.

The Science Source is a supplier of materials for kindergarten through university level physics classes. All products help to integrate science and technology. The Linx system is a brilliantly designed set of materials (wood, paper, glue) developed to facilitate successful structures using real hand tools and wood. http://www.thesciencesource.com.

Springs

Potential and Kinetic Energy/Force

by Richard Crawford, Marilyn Fowler, Jerold Jones, and Kristin Wood

Springs were invented to solve problems of energy storage. A spring allows you to use a component of a device for some purpose and returns it to its original position. When you operate the spring, you either create or release stored energy. We call this stored energy "potential energy." There are many examples of things that are elastic—that is, that stretch and return to their original dimensions—that also store energy. Springs made of metal are more predictable and durable for everyday use. When a spring releases its stored energy, it is converted into "kinetic energy," the energy of motion. Sound energy may also be produced by a spring. Equilibrium is reached in a spring when the potential energy and the kinetic energy are zero—when it is neither extended nor compressed.

Everyday spring things

In this initial activity you and your students explore everyday objects containing springs.

Materials: Devices and objects containing springs, one for every two students.

Use open-ended questions to guide the exploration:

- What is the device you have?
- How does it move?

Procedure: Give each pair of students one device and have them analyze it for about five or ten minutes, guided by the questions you displayed.

Discussion: Ask several students to report on their object and the ways it works and moves. Can the students determine what all of the objects have in common?

Each of the objects has a feature that allows it to return to an original position. The stapler, for example, may have a refill tray that slides out and then can be compressed to go back into place. In some staplers, a compressed spring pops the tray out, and can be compressed again when you snap the tray back. The stapler also may have a metal strip that bounces the stapler back up after stapling.

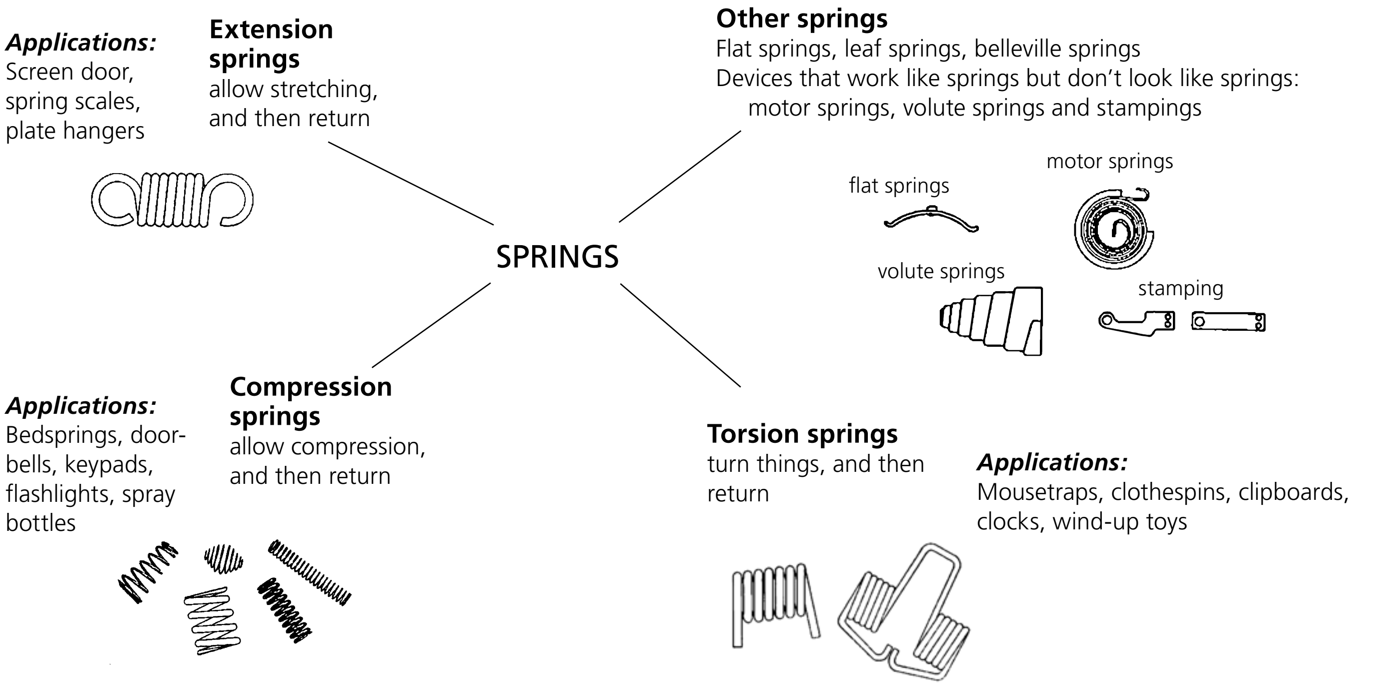
Ask the children to look again at their object and locate the mechanism that enables the device to return to an original position. In some cases, the mechanism may be hidden: decide beforehand if you want your samples taken apart! Guide their search with these questions:

- What mechanism allows the action of the object?
- What need does the mechanism serve?
- What decisions were made in using that mechanism?
- How would the object move if the mechanism were removed, or broken?

The mechanisms that you and the children located are probably types of springs. Springs perform many functions and come in many shapes and sizes, see Figure 1. Walk around the classroom and find other examples of "spring things." Ask the students to look for and bring in examples from home, and start a bulletin board or display table of the objects they bring.

Design and solve problems with springs

Materials: Springs of various types; cereal boxes, tagboard or other stiff paper; parts of disassembled toys, mechanisms, wheels; craft sticks, and other miscellaneous materials like colored paper, sewing scraps,



You may wish to make a bulletin board of this and write in additional examples as you discover them with your class. The pictures of the major spring types might be added to your bulletin board or made into take-home cards for spring searches.

Figure 1. Types of springs and their common applications

margarine tubs; connectors including craft glue, brads, tape, staples; tools like scissors and rulers.

Procedure: Ask the students to help think of some problems that springs could be used to solve or inventions that could use springs. Inventors sometimes target problems of safety, entertainment, convenience, and storage.

Here are some starters:

- Make a harmless trap for an escaped hamster.
- Make a toy that has buttons to push or knobs to turn.
- Make a child's book in which entertaining objects move with different kinds of springs. (Examples: pages that re-close after you open them; push-buttons that pop back up after being depressed; pull switches; bouncing characters, etc.)

Quantify the elasticity of your springs

Though they are very common, springs are precise mechanisms. In this activity, the children explore the effect of increasing force on springs and its mathematical relationship to the amount of stretch or compression, or elasticity.

Materials: A chart rack, support stand, playground apparatus, or some way to hang a spring; two S-shaped hooks; gram masses, or other known masses, to 1 kg; goggles; rulers; several springs: wire springs, rubberbands, and springs from retractable pens, flashlights, or new springs of the extension type (see Figure 1). Also provide graph paper.

Procedure: Create a set of weights from containers of sand or pebbles that you have weighed on a metric scale.

Set up the support for the first test. Hook the first spring at one end onto the support stand. Place an S-hook in the other end of the spring. Label or name the spring to be tested and measure its length in millimeters. Write the information on a data chart you develop with the students. The information you will need for each spring includes:

Spring number or label:

Length before loading:

The following readings (suggested pattern):

Length when loaded with 1 gram* of mass
Length with 10 grams of mass
Length with 50 grams of mass
Length with 100 grams of mass
Length with 500 grams of mass
Length with one kilogram of mass

** or whatever measure of mass you happen to be using. You do need a standard. Remember: To find out how much a spring stretches, you need to subtract the original length from each stretched length. Have the students who are doing the measurements wear goggles in case a hook comes loose or a spring breaks.*

Load the first weight on the first spring and measure and record the length. Load the next weight, measure and remove. Continue until you have recorded spring lengths resulting from each weight for each spring.

If the spring does not return to its original length after a weight is removed it has deformed: It is no longer elastic. That information should be recorded on the data chart and the spring "retired" from the test.

Spring constant (k)

Once the data chart is completed, convert the information to a graph. Whether you use a bar graph or a line graph, you should see a proportional relationship of weight to distance for each spring *until the point of deformation*. That is, you should see a fairly straight line. (Figure 2)

Write this relationship with the children in words and in mathematical notation:

The distance (d) a spring stretches is proportional to the force (F) applied to it. For example, if a spring stretches 1 cm with a 10 g weight, then it will stretch to 2 cm with a 20 g weight. (It is important to express these measurements in metrics cm/g.) If you double the force on a spring, the spring will stretch twice as far. (Please see footnote 1. You are not using force in this experiment, but mass.)

Mathematics: d~F, or d1/Fl=d2/F2. The slope of that curve, expressed as d1/Fl, gives a numeric value for each spring known as the spring constant (k).

When engineers want to select a spring for a particular application, they use a table such as that shown in Figure 3, and find the k value and dimensions they require. You can look in the table and see how k varies with changes in the coil diameter, length of spring, wire diameter and material. For instance, k goes down as the coil diameter increases.

Application Apply this information to predict the mass of unknown objects using a spring for a scale! Give the students an object whose mass is not known and ask them to use the graph to estimate its mass based on the amount it stretches a known spring. Then weigh the object on a metric scale and compare the results.

Integrate disciplines by using springs as a theme

Poetry, language and greeting cards: The language of springs is interesting, for words like "bounce" and "sprung" illustrate onomatopoeia, language that sounds like what the words mean. There are many meanings for "spring": how are they alike?

1. Force is measured in newtons, and to convert mass to the force it exerts requires multiplication of mass (kilograms) times the acceleration of gravity, which is 9.81 meters per second squared. This is Newton's second law of motion (F = ma, where F = force, m = mass, and a = acceleration of gravity). If you have spring scales calibrated in newtons, you can be more accurate.

If students created new springs, how would they advertise and market them?

The children can design interesting pop-up books and greeting cards as invitations to visit your classroom.

Analogs in living systems: What parts of bodies operate like springs? When you think about the function of returning a moved object to its original state, then tendons, muscles, and ligaments seem most like springs. Plant structures like stems and trunks are somewhat elastic, and some wildflowers (storksbill, e.g.) form a coil in their stems as seed pods form, then uncoil them under humid conditions while they poke the pod into the soil, literally screwing the seed pod into the ground!

Community ties: Walk with your students to find springs in the neighborhood, to visit your car and look underneath it, to talk with the custodian, and to receive a guided tour of the springs in the school kitchen. Walk to a garage and talk to auto mechanics about how springs are used in a car, from the seat cushions, door handles, and cigarette lighters, to the chassis.

Literature: Children's literature almost always pits the character(s) against some kind of problem. Can springs be used to solve the problem?

Geometry/Art: Predict and find out: what shape print would a spring make in clay? How would the print look if you rolled the spring across the clay? What if you dipped the spring in soapy paint (so the paint will stick) and rolled it across paper—what would the print look like?

Where teachers can get springs

The following everyday objects usually contain springs: stapler, staple-puller, retractable pen, toys, pump spray bottle, squeeze-handle spray bottle, lawn clipper, doorknob, clipboard, keyboard or keypad, hook switch on telephone, mousetrap, clock, ice cream scoop, car door handles, clothespin, vice grip, bulldog clip, spring scale.

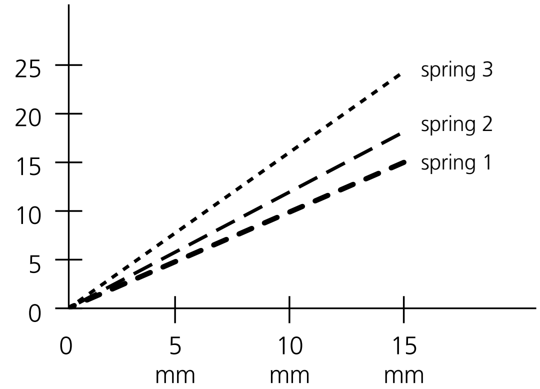


Figure 2. Possible line graph for weights and distances

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COIL DIAMETER (IN.)	LENGTH (IN.)	WIRE DIAMETER (IN.)	SPRING CONSTANT (LBS./IN.)	MATERIAL
3/16	0.023	1 1/4	2.40	zinc plated carbon steel
3/16	0.023	1 3/4	1.5	zinc plated carbon steel
1/4	0.015	1 1/2	0.14	music wire
1/4	0.020	1 1/2	0.35	music wire
1/4	0.023	1 1/2	0.87	music wire
5/16	0.035	1 1/2	4.50	zinc plated carbon steel
3/8	0.035	1 1/2	2.50	zinc plated carbon steel

Note: These spring dimensions (and therefore k) are in English units. You will need to convert them in order to compare them to metric dimensions.

Figure 3. Table of Spring Constants (k)

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It's Been Around a Long, Long Time

The wheel has been around a long, long time. The technology of rolling, winding, and catching the energy of moving wind or water has been in use for thousands of years, originating perhaps in what is now known as Syria. A brief look around will yield many real-life examples of wheels in our world.

Begin a study with the wheel itself: Is round the best shape for a wheel? Can a polygon work just as well? Younger students will enjoy testing this out by cutting pairs of shapes out of paper plates and inserting a pencil for an axles. Which shape rolls best?

The wheel is just the beginning, of course. When you put it to work, or use it to make working easier, whole worlds of ideas open up. The wheel makes a pulley possible, as well as gears, windlasses, pinwheels, and turbines.

Two examples of basic wheels at work: a pair of wheels on a pencil axle and a waterwheel.

Simple models of the machines can be built and experimented with in the classroom, either before or after field trips to see real wheels in action. Going to a nearby hydroelectric plant or wind farm can inspire students to create their own inventions. As well, a trip to the neighborhood hardware store will give students an opportunity to see wheels employed in objects of all different sizes and applications.

A great resource for studying wheels for students ages six and up is unfortunately out-of-print, but still on used book lists and in libraries. It is Bernie Zubrowski's *Wheels at Work*, published in 1986 by Beech Tree Press for the Boston Children's Museum, and it is well worth searching for. He is a master of starting simply and working toward progressively complex ideas, with instructions for making real machines with everyday materials. Your classroom can be an exciting laboratory of engineers engaged in pursuit of serious questions!