Toys That Teach Technology

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Robert W. Lally photographed in December, 1944 in Masstrict, Holland.

Except for a lengthy mission destroying things as an infantry squad leader and a scout during World War II, building structures has been the story of Bob Lally's life. He was first employed as a structural ironworker at age sixteen. Following the war, and earning B.S. and M.S. degrees in mechanical engineering at the University of Illinois, he helped guide and control missile structures as a servo engineer. Later, as an adjunct Associate Professor advocating a structural approach to sensing and communicating, he created modally-tuned test hammers, pendulum hammer calibrators, and the gravimetric calibrator. He also conceived the two-wire ICP® sensor idea, coined the term ICP®, helped start and build the original Kistler Instrument Corporation, and started PCB Piezotronics. Twenty years after leaving PCB®, he has entered a new field – educational toys. He was recently granted two patents on structural model creation and sensible 'eneracting' toys. (Information on *Technology Explorers* and other products mentioned in this article can be obtained from the author: lally@peopling.net.)

For many years, *Sound and Vibration* has presented an ongoing dialog between educators and consultants that seems to conclude that technical education ought to include both analytical and experimental learning tasks. Moreover, feature articles in S&V devoted to testing the behavior and monitoring the health of machinery and structures often include elaborate models of physical, graphical, mathematical and verbal forms. Inevitably, some of the dramatic events and puzzling oddities encountered in testing the behavior and monitoring the health of things have found their way into valuable educational structural models, called *Technology Explorers*, and into an executive toy version, appropriately called the *Enigma*™.

What are Technology Explorers? *Technology Explorers* (US Patents #6,962,260, #6,443,735 and pending) are desktop structural models instrumented with visual sensors resembling flexible lollipops.

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Figure 1. The Enigma™ executive toy. Sensors resembling lollipops both structurally sense and suppress motion.

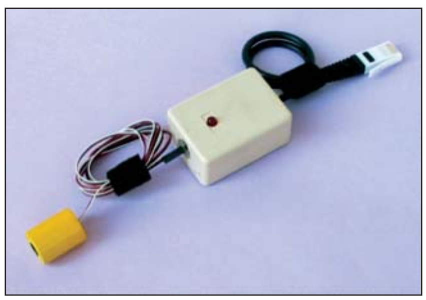


Figure 2. ICPIM acceleration sensor.

Structured mainly from sports items, such as hockey pucks and fishing line, they function to transfer forces of nature and man into motion and changes in motion into flexing of the sensors. Puzzling antics of the structures and sensors entertain, enlighten and educate. A new word 'eneract' was coined to contract the formidable term, energetic interaction, which is how things naturally interact through transfer of energy. The *Enigma*, an executive toy, contains all of the *Technology Explorer* ideas integrated into a simple, elegant, unified design; it is pictured in Figure 1.

Behavior testing involves disturbing a structure and observing (or sensing) the motion, similar to the way a doctor tests your reflexes. Afterwards, the doctor might tell you that when forced or pressured to do something, you feel the stress and the strain shows. The same thing can be said about a test object. Like humans, inertial motion sensors employed in *Technology Explorers* flex to structurally sense changes in motion caused by interacting objects transferring energy by pushing and pulling on one another, on the earth and on the sensors.

Dynamically flexing 'lollipops' are easy to see when the structure is perturbed.

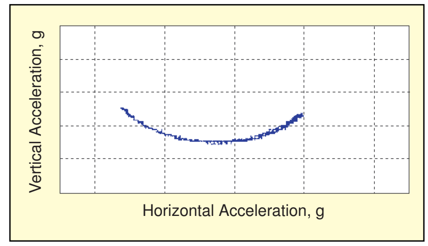


Figure 3. Swinging.

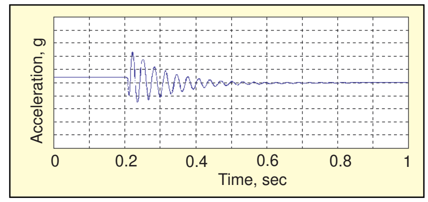


Figure 4. Bouncing.

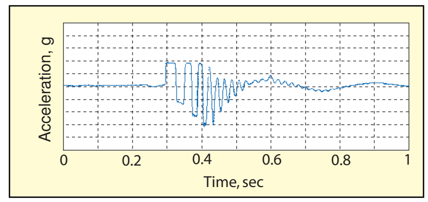


Figure 5. Bungee Jumping.

Since you do not have the *Enigma* sitting in front of you, I will utilize a different type of sensor to record graphic images for your consideration. Figure 2 illustrates an Integrated Circuit Piezoelectric Inertial Motion (ICPIM) sensor available as an adjunct to the *Enigma*. This two-wire accelerometer provides an analog voltage proportional to acceleration. An inexpensive DAQ card fitted to a laptop computer permits recording and viewing dynamic signals from *Enigma* experiments. Typical results are shown in Figures 3-5.

Baffling Behavior. Testing the behavior of the *Enigma*, experimenters encounter puzzling mysteries. Remembering the soothing, relaxed feeling you enjoyed when coasting on a simple childhood swing may help you to resolve some of the mysteries.

When coasting sideways as a glider-type swing, the lollipop sensors normally flex to sense motion, as expected. Surprisingly though, when coasting fore-and-aft as a simple swing, tangential motion sensors do *not* flex or sense the swinging motion, but the radial motion sensors flex to indicate motion when there is none (see sidebar).

When side weights are centrally added, the swing continues to coast and accelerate the same as before the change. The coasting motion does not change, in spite of the increased force and inertia. When elastically suspended with bungee-cord, the swing bounces while coasting. When lifted and dropped under certain conditions, the elastically suspended disk apparently does not bounce, but the side sensors fluctuate wildly. Solving these baffling behavior mysteries helps develop deeper insight into the dynamic nature and behavior of things, especially sensors.

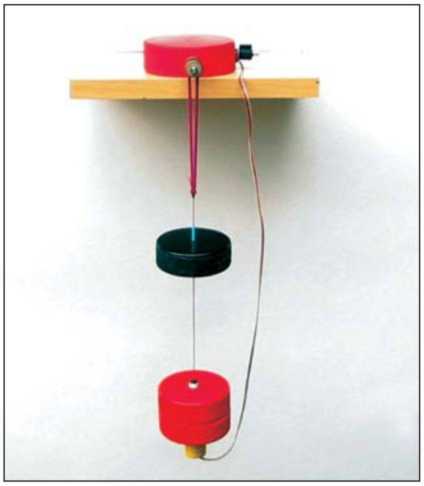


Figure 6. Drop Tester calibrating ICPIM sensor using Earth's gravitational field.

Applying Technology. The structure of the *Enigma* embodies, demonstrates and helps teach the technology needed to solve the mysteries encountered, as well as many other of life's perplexing puzzles. In the *Enigma*, interacting mechanical objects transfer energy by pushing and pulling on one another. They move, flex and animate things, trigger and power events and communicate information. They behave in accordance with laws of nature, such as Newton's and Hooke's. Moving is opposed by inertia, stiffness, friction and gravity, which store or dissipate energy in different ways.

Connected inertial and elastic objects form systems that oscillate at natural rates in various patterns, as the direction of the force and energy transfer automatically reverse. Structures typically contain many such resonances, which can create beautiful music or noise pollution; they can please, annoy or destroy.

Electrical objects transfer energy by potentially pushing and pulling on one another to move electrons as electrical current, creating magnetic and electric force fields. Movement of electrons is opposed by resistance, capacitance and inductance. Electrical energy is stored in different ways, in accordance with the laws of nature such as Ohm's law and the law of electrostatics.

Sensor systems conveniently employ either the voltage or current involved in the transfer of electrical energy to communicate information. ICPIM sensor systems conduct both signal and power over the same two wires to a fault-indicating light emitting diode.

Sensors employ structures that eneract to sense and communicate information. Too little energy transfer obscures the signal to be measured with noise. Too much energy transfer distorts the quantity being sensed. The *Enigma* dramatically shows what happens with none, little, some or too much eneraction.

Inertial motion sensors, like humans, flex to sense changes in motion caused by objects, including the earth, pushing and pulling on one another. They cannot tell the

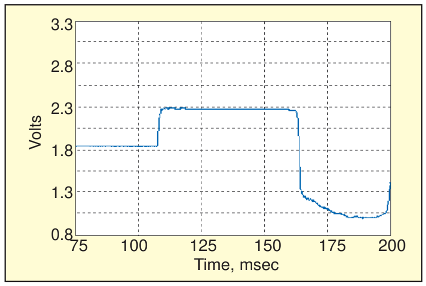


Figure 7. Output of ICPIM sensor during drop test.

difference between gravity and changes in motion. Commonly called accelerometers, the simple spring-mass structures of ICPIM sensors flex to structurally sense the acceleration aspect of motion.

Careful Calibration. Ancient wisdom encourages us to test all things and retain what is good. Testing the behavior of *Technology Explorers* instrumented with optional ICPIR electronic sensors requires an oscilloscope to display the sensor signals or a computer programmed to act like one. Commercial, low-cost data acquisition modules are now readily available to adapt analog sensor signals for computer display.

While the *Enigma* can do slow drop testing, the fast bungee-jumping and freely falling test results were taken from another educational structural model, called the *Drop Tester*, pictured in Figure 6.

The *Drop Tester* is designed to subject an acceleration sensor to a square-topped pulse with 1 g amplitude, about 50 msec in duration and of less than 1 msec rise-time. The sensor to be calibrated is mounted to the lower (red) mass as shown in Figure 6. This mass is suspended by monofilament fish line attached to an elastic bungee. A soft target piece sits on a knot in the fish line. A (black) mass is allowed to fall along the monofilament line. When it strikes the target, the bungee stretches, the monofilament slacks and the sensor and lower mass experience free-fall at 1 g. A typical drop test response is shown in Figure 7. In addition to sensitivity, the drop test reveals rise time, decay time, resonant frequency and damping, as well as any faults. This model was used almost exclusively to develop the ICPIR sensors.

Over the years, the same technology involved in the *Enigma* and *Drop Tester* also led to the development of modally tuned test hammers, pendulum hammer calibrators, gravimetric accelerometer calibrators and ICP® sensors. The concepts embodied in *Enigma* helped conceive these products.

Extending Knowledge. Eneract energy concepts apply to other energy realms as well, including both mental and spiritual. For example, energy transfer physically moves objects, mental feeling stimulates thought and spiritually inspires action. Eneraction always involves interaction between two variables as summarized in Figure 8.

Mindfully Concluding. Answering questions, solving mysteries and testing to explain puzzling behavior involves hands-on, minds-on, and inquiry-based learning

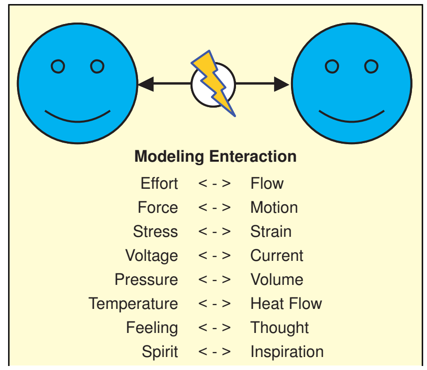
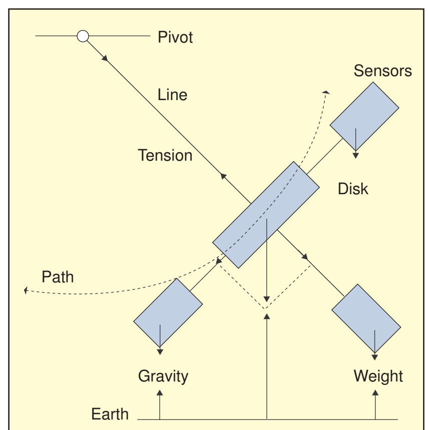


Figure 8. Eneraction variable pairs.

recommended by national educational standards:

- *Technology Explorers* and *Lollipop* visual motion sensors reflect the radiant, vibrant, communicant, interactive, automatic nature and behavior of people and things.
- Amazingly, the same *Enigma* structural model serves equally well as a children's plaything, student science kit, teacher technology trainer and puzzling executive toy.
- Like human senses, sensors are structures, not mystical devices. They structurally sense and communicate.
- Toying with the *Enigma* exercises technical skills and helps a person develop dexterity, deductive talents and practical technical knowledge. It can benefit people of almost all ages and persuasions. This can help make America more competitive.



Sensing Enigma. Coasting fore-and-aft as a simple swing, sensors do not flex to sense the swinging motion, but the side sensors flex to indicate changes in radial motion when there are none. When coasting sideways as a glider-type swing, inertial motion sensors (accelerometers) flex normally to indicate changes in motion caused by objects, including the earth, structurally pushing and pulling on one another. Some energy transfer is needed to sense motion. But too little obscures the signal and too much changes the motion unduly.