Simple and Beautiful Experiments XII by LADYCATS and the Science Teachers Group: In memory of Hiroshi Kawakatsu

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Abstract. The LADYCATS (LADY Creators of Activities for Teaching Science) were founded in 2005 in cooperation with Professor Hiroshi Kawakatsu (1945–2018) to encourage both female physics teachers and students who want to study physics more, and primary school teachers who feel unprepared to teach physics-based lessons. We have demonstrated ‘simple and beautiful experiments’ together for the past 14 years. Our concepts are as follows: the ‘simple’ experiments are easy to complete, while the ‘beautiful’ ones are interesting, and the ‘essential’ experiments demonstrate the principles of physics. We lost our leader, Professor Hiroshi Kawakatsu, in 2018. He always said, ‘Everyone has a right to learn’.
2. The spirit of Professor Kawakatsu and LADYCATS

LADYCATS includes many female teachers, which is rather unusual in the field of physics. Usually, female students in Japan are less interested in physics than their male counterparts are and do not typically take physics classes at the high school or university levels. Therefore, the ratio of female science teachers, and especially physics teachers, at the secondary school level is around 20% [3]. By contrast, there are many female teachers in primary schools who have little experience of enjoying science. To remedy this situation, we formed the LADYCATS to encourage such students and teachers and to show how women enjoy physics.

![Figure 1. Professor Kawakatsu (third from left) and LADYCATS at ICPE 2006, Tokyo](image)

We have presented the workshop ‘Simple and Beautiful Experiments’ at several conferences since 2005. In these workshops, we demonstrate and explain our experiments, and the participants make experimental tools from materials we have prepared in advance. Our policy is, following Professor Kawakatsu’s philosophy, is ‘Everyone has the right to learn. Let’s learn together’. He paved the way for everyone to learn. He did not mind whether we were excellent or not in physics and science (Figure 1).

Since 2006, 13 female teachers, 14 male teachers, 8 female students, and 21 male students have joined LADYCATS and presented these experiments. The themes have varied, but followed our concept: the ‘simple’ experiments are ones that teachers can use easily in their classes, ‘beautiful’ experiments spark children’s interest in the topic and ‘essential’ experiments demonstrate the principles of physics (Table 1).

### Table 1. The Experiments Featured in LADYCATS Workshops

| Electro-Magnetic | Mechanics, Gravity | Sound | Light | Atom |
|------------------|--------------------|-------|-------|------|
| Arago’s Disk     | Double Cone        | Paper Whistle | Colored Shadows | Voice of Atom |
| Faraday’s Motor  | Soap Film          | Voice-copter | Reflection Cup | Geiger-Muller |
| Magnetic Chasing | Running Cat        | String Telephone | Benham’s Top | Counter Made of a |
| Roget Jumping Spiral | Dragonfly | Loudspeaker | Small Box Camera | Film Case |
| Simple Motor     | TokoToko Horse     |       |       |      |
| Simple Transistor Circuit | Rolling Paper Roll | Popup Card |       |      |
| Paper Doll sit on Air Chair | Cartesian Divers | Plastic Bottle |       |      |
| Petbottle Water Rocket | Paper Doll | Microscope |       |      |

3. Workshop at GIREP 2019

The LADYCATS presented their 13th workshop as usual at the GIREP-ICPE-EPEC-MPTL Conference in 2019. Though it was the first workshop following Professor Kawakatsu’s death, many colleagues attended and encouraged us. A list of our experiments is below.
3.1. The Moon Model with Horizon (Kyoko Ishii)

Understanding the phases of the Moon is difficult for students of all ages. In Japan, students learn to observe the Moon in Grade 4 and examine the positional relationship between the Moon and the Sun in Grade 6\(^6\). However, many university students say they do not understand these concepts. One way to examine them is with an experiment using a Styrofoam ball, though it is hard to relate Moon phase models to real observations\(^5\). This hands-on modelling activity with cardboard aims to teach students and about the Moon’s phases and to serve as a bridge between direct observations and modelling. Before developing the model, students must observe the Moon for two or three months.

Materials: One 4- or 5-cm diameter Styrofoam ball (Moon model), one 15-cm skewer.

Experiment 1: Make a Moon model by inserting skewers into a Styrofoam ball. Go outside with a Moon model on a sunny day. Hold the Moon model with your left hand and point the Sun with your right hand. Imagine that your head is the Earth. Investigate the angle of Sun, Earth (your head) and Moon (Styrofoam ball) when there is a full moon (180°), halfmoon (90°), new moon (0°), etc. (Figure 2).

| shape       | Sun-Earth(your head)-Moon(Styrofoam ball) angle(°) |
|-------------|---------------------------------------------------|
| full moon   | 180                                               |
| half moon   | 90                                                |
| new moon    | 0                                                 |

Figure 2. Investigation of the angle outside. Full Moon (left):180°; Half Moon (center): 90°; New Moon (right): 0°.

Materials: One 4 or 5-cm diameter Styrofoam ball (Moon model), one 15-cm skewer, 1m square cardboard (to serve as the horizon), and LED flashlight (the Sun).

Experiment 2: This indoor group activity requires three students. One person (Student A) should be designated as “the Earth” and hold the cardboard to serve as the horizon. The second student (Student B) holds the Styrofoam ball, which is designated as the Moon, and then moves with it around Student A. The LED flashlight is designated as the Sun. The last student (Student C) observes the entire experiment and learns about the moon’s phases. Using the cardboard, they can easily imagine the Styrofoam ball as the Moon above the horizon.

As shown in Figure 3, Student A (on the left) represents the Earth and puts the cardboard on his shoulder. Student B (on the right) holds the Moon and moves, rotating slowly around Student A. At designated points, such as when there is a view like a half moon or full moon, Student A should ask Student B to stop and observe the Moon (the Styrofoam ball) above the horizon. Student C imagines and confirms which shape Student A is observing at each point. After they have changed roles to experience each of them, they discuss the relationship between the shape of the Moon and the angle of the Sun (LED light), the Earth (Student A), and the Moon (Styrofoam ball).
Figure 3. Indoor experiment with LED light and an Earth model with horizon (cardboard)

![Figure 3](Image)

Figure 4. Perspective view is from the Earth, while the top view is from the zenith

![Figure 4](Image)

This shows that it is possible to observe the Moon from two different views: one is the perspective from the Earth, the other is a top view, from the zenith. The experiment with a Styrofoam ball is effective for connecting the two views.

### 3.2. The Roget’s Spiral (Masako Tanemura)

Ampère discovered that parallel wires carrying currents attract or repel each other, depending on whether the currents are flowing in the same or opposite direction. Roget’s Spiral (Figure 5) [6] is a device that demonstrates that the electric currents running in the same direction attract it with parallelism each other by each magnetic field. The helix of elastic wire that contracts in length when an electric current passes through it easily demonstrates the attraction of parallel currents.

This apparatus was devised by Peter Mark Roget (1789–1868). The spiral expands under its own weight, so that the lower end drops back into the mercury (Figure 5). An electric current passing through the wire produces an attraction between the coils, causing the wire to lift out of the mercury and breaking the current. When the spiral is restored, the electric current flows again, because the tip is once more touching the mercury. By repeating this process, the spiral vibrates up and down.

You can easily make a toy like Roget’s Spiral without mercury (Figure 6). It can be used as a teaching aid to demonstrate the force between parallel currents.

1. Wrap the ferrite magnet with aluminium foil (STEP 1). (Neodymium magnets are very strong, so it would be dangerous for students to do this.)
2. Put the battery on it (STEP 2).
3. Place one end of the spiral on the battery pole and the other ending touch the aluminium foil (STEP 3). Use sandpaper to remove the coating on the wire that touches the battery and the magnet.
4. The electric current passing through the wire produces an attraction between the coils, and the spiral vibrates up and down.
3.3. The Faraday motor (Masako Tanemura)
The paper clip motor is an ideal teaching aide for elementary and junior high schools in Japan. It is not easy to make them; however, even elementary school students can make ‘Faraday motors’ easily. Students use soft and colourful aluminium wires instead of copper wires. These motors are simple and beautiful teaching tools to attract students’ interest.

A magnetic needle moves near the lead which current is flowing. Faraday studied how to make a magnet rotate. Then, he invented two devices, which he called ‘electromagnetic rotation’ (Figure 7). A wire extending into a pool of mercury with a magnet placed inside it will rotate around the magnet. The latter device is known as a unipolar motor.

You can make easily a unipolar motor without using mercury (Figure 8).
1. Shape an aluminium wire, as shown in Figure 8.
2. Use sandpaper to remove the coating on the wire that touches the battery and the magnet.
3. Put a battery on ferrite magnets covered with aluminium foil. (Neodymium magnets are very strong, so it would be dangerous for students to do this.)
4. The wire rotates when it is positioned as shown in Figure 8.
5. Let’s make motors in various forms and shapes.

3.4. Resonant Pendulum (Fumiko Okiharu)
Although there are many oscillation phenomena around us, it is not easy to understand the oscillation phenomena handled in physics by linking them to everyday phenomena. For beginners, the resonance
phenomena are the easiest to understand. The collapse of the Tacoma Bridge in the United States in 1940 is popular, but other examples include swings, micro ovens, radio, and so on. In Japan, where there are many earthquakes, we are familiar with the resonance phenomenon by explaining it using the specific example of the 2011 Great East Japan Earthquake, which was a magnitude 9.0 earthquake that caused substantial harm to people living on the land around the epicentre. On the other hand, a building that was 700 km away from the epicentre and located in Osaka where the seismic intensity was 3 (which is not so large in scale) shook by 2.7m on the top floor due to the resonance of the building and the ground: this became a big topic.

When dealing with resonance in introductory university physics, explaining everyday phenomena is useful, but trying to teach it using mathematics can be quite difficult. There is an object of mass $m$ that oscillates in a simple harmonic motion by receiving restoring force $-kx = -m\omega^2 x$. The motion of this object when it receives a resistance force $-2m\gamma v$ proportional to this velocity, and a periodically changing force $mf_0 \cos \omega_f t$ from outside, is represented by

$$\frac{d^2 x}{dt^2} + 2\gamma \frac{dx}{dt} + \omega^2 x = f_0 \cos \omega_f t$$

When this is solved, the amplitude due to the forced oscillation from the outside will be

$$x_0 = \frac{f_0}{\sqrt{\left(\omega_f^2 - \omega^2\right)^2 - 4\gamma^2 \omega^2}}$$

That is, it is a phenomenon in which the amplitude of the forced oscillation becomes extremely strong when the frequency $\omega_f$ of the external force is near $\omega_R = \sqrt{\omega^2 - 2\gamma^2}$. Therefore, in order to deepen the understanding of the phenomenon of resonance, and to connect it with an explanation of daily phenomena and mathematical understanding, the following experiment was introduced. By performing this experiment, students discover by themselves what the frequency $\omega_f$ of external force around $\omega_R$ means.

In the introductory physics course, the number of students per class is quite large, more than one hundred, so it is important to have access to easy-to-create experimental teaching materials at low cost, in order that students can get a qualitative understanding of resonance phenomena from short experiments.

The device shown in Figure 9 is an experimental material for students to help them understand resonance. The nut used as a weight is tied to a thread, and both ends of the thread are tied to a rod. In the figure, three threads of different lengths are hung on a stick. The stick is a long chopstick used for cooking. These are very popular in Japan. The student holds both ends of the stick in each hand and rocks the stick back and forth. Then the weights hung on the stick oscillate respectively. The point is that only one weight oscillates violently at a specific frequency. It is possible to observe resonance occurring when the frequency of the stick and the specific frequency of the weight are close.

In the class, we also show a video of the collapse of the Tacoma Bridge, but we hope that students learn the resonance phenomenon by experience rather than memorising it by watching the video. By using experiential learning, we would like to deepen the students’ interest in mathematically difficult phenomena and bridge the gap from qualitative understanding to quantitative understanding. Of course, we think this teaching material is also an effective way to deepen the qualitative understanding of resonance for primary, junior high, and high school students who do not deal with mathematical expressions. In the case of junior high school students, some students struggled to shake only one weight violently, but students understood that it sways violently only when the frequency of the stick and a specific weight become close, in this way exemplifying the resonance.
3.5. Magnetic Chasing (Haruka Onishi)

Traditional weighted toys were used by children around the world. This experiment includes a scientific component, magnetic characteristics and the moment (Figure 10). From this experiment students can learn about the magnetic poles (attract and repel) when in elementary school and the moment in high school in Japan.

If the Magnetic force is the same, poles repel, different poles attract. As shown in Figure 11, the Daruma doll reacts to the Magnetic force from Mt. Fuji. Then the Daruma doll spins because its bottom is round as shown in the Figure 11. The doll continues to spin because of the moment.

You can make one as follows:
1. Tape a magnet to a button cover.
2. Fold a piece of paper into the figure of a Daruma doll. Tape the doll to the magnet in the button cover.
3. Make a cone shaped mountain from heavy craft paper.
4. Tape a magnet on the slanting side of Mt. Fuji about 8 mm from the bottom. Make sure that the direction of the magnetic poles are as pictured in Figure 13.
5. Bring Mt. Fuji close to the Daruma doll, following the arrow as shown in Figure 10. The Dharma doll will begin to spin.

3.6. Paper Benham’s Disk (Naoshi Takahashi)
A toymaker Charles Benham sold a spinning top with the circle pattern of black and white in the end of 19th century. The top, called Benham’s Disk, made people to see various color during its spinning. It is an example of Fechner colors, however the phenomenon itself has not been well understood for 100 years. On the other hand, the disk is easy to make and easy to enjoy for every one because of the colorful illusion. Despite the unexplained details, this is a good introductory material when explaining colors. It is also used to explain the function of the optic nerve at such as medical schools.
Here is how to make it:
1. Prepare a sheet of thick paper.
2. Draw a circle with a diameter of about 10 cm like examples shown in Figure 14.
3. Cut out a disk, then make a pin hole on the center of the disk.
4. Insert a toothpick into the hole and fix it by glue if necessary.
5. Then turn the disk. That’s all!

![Figure 14. Examples of Benham’s Disk. The diameter of the disk should be roughly 10cm](image)

3.7. Paper Dragonfly (Naoshi Takahashi)
The bamboo dragonfly (bamboo copter) is a toy helicopter which first played in China more than 2000 years ago and carried to Japan later (around A.D.700). It used to be made of wood or bamboo, and plastic later on. And now, especially in high school, it is a good teaching material to teach the vertical vector, relationship between rotational motion and the vector. However, it is not so easy to purchase anywhere. So now our suggestion is to make it by using a straw and thick paper.

1. Prepare a sheet of thick paper and a straw.
2. Draw a wing of the dragonfly as shown in figure 15. And cut out the wing from above.
3. Prepare the shaft body using a straw like the middle part of the figure.
4. After fixing with staple, you can play with “bamboo dragonfly” made of paper and straw.
3.8. Paper Doll Sit on AIR CHAIR III - Annular Seat Method by Paper Craft 2019 - (Naoshi Takahashi)

How many people can sit on a chair? More than one thousand is the answer! (http://www.asahi.com/articles/ASH3Q5TBPH3QOHGB009.html). It is surprising not only the huge number of the people, but also just one chair. If the people sit annularly, they do not need any chair already. If there are many active students in the classroom, it is a good demonstration as an introduction to consider the forces applied to objects. It is also can be done with paper doll in your class room. You can try the annular seat method without chair by paper doll. How to make it is as follows:

1. At first, prepare a sheet of thicker craft paper (about 20 micro meters thick or more) for your paper dolls. Draw you some dolls (see left of figure15) and cut them out from the paper.
2. Make your dolls to sitting style by bending hip and knee along the dashed lines.
3. Fold around the head of a doll by your fingers, then sit another doll on top of the knee of the previous doll, and then, make other doll the same way.
4. Finally, you can make the circle as shown in figure16.

Figure 15. Parts of dragonfly

Figure 16. An example of paper craft doll (left), and a photograph of annular seat method by using ten paper craft dolls
4. Summary
LADYCATS is a professional learning community guided by the ideal that ‘Everyone has a right to learn’. We have developed and shared many ‘simple and beautiful experiments’ at many international conferences to show that ‘learning physics is fun’. As life-long learners, we collaborate together and pursue new activities. In every workshop, our colleagues encourage us to continue our work together.

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