Exploratorium Teacher Institute
Exhibit-Based Energy Teaching at the Exploratorium
Final Report: September 1, 1991–August 31, 1992

The *Exhibit-Based Energy Teaching at the Exploratorium* project was a twelve-month project in which the Teacher Institute developed publications and exhibits which explored the transfer of energy in its different forms. Our work on this project has had two particular points of focus: (1) developing interactive exhibits which demonstrate different aspects of energy; and (2) developing, writing, and disseminating a package of hands-on energy activities for use in the 6–12 grade classroom.

Energy Exhibits

USDOE funds were used to develop two exhibits which helped to elucidate the nature of energy. The exhibits were developed in-house through the collaboration of the Exploratorium's exhibit development staff, our teaching faculty, and our associate teachers from middle and high schools around the San Francisco Bay Area.

Tower of Energy

The first exhibit, the *Tower of Energy*, invites visitors to play with pumped water storage of energy, this allows the visitors to get a feel for one concrete realization of the abstract concept of energy. At the center of the exhibit is a transparent tower 5 m high and 25 cm in diameter. There are two ways to pump water into the tower and two ways to use the stored energy.

To fill the tower, visitors may use a lever action hand pump to pump water from a reservoir in the base of the exhibit, in this way visitors can feel the power (energy per time) which they must use. Visitors may generate as much as 75 Watts of power using the hand pump. Visitors may also fill the tower using a 750 Watt electric pump. Once the water has been stored in the tower, visitors can use the stored energy in two ways: They can empty the water into a fountain, which shoots a column of water into the air; or they can empty the tower into a transparent-turbine-generator—the power generated in this way is used to light several lamps.

For the use of teachers and their students, the exhibit includes power meters to measure the power used by the electric pump and to measure the power delivered by the turbine. When the tower is filled with water it has a high pressure head and delivers its maximum power lighting three lamps or sending the fountain to its highest point. As the tower empties the number of glowing lamps decreases, as does the fountain height.

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The favorite part of this exhibit is the fountain. Visitors quickly discovered that they could pump water by hand into the fountain at the same time that they were emptying the tower into the fountain. The added energy pulsed the water high into the air. Visitors enjoyed making the water dance in the air.

Photosynthesis Exhibit

The second exhibit, *Photosynthesis*, shows how plants use and release carbon dioxide, an important greenhouse gas. In this exhibit, a living leaf of an elephant ear plant is enclosed in a transparent plastic chamber. A carbon dioxide gas analyzer probe measures the level of carbon dioxide in the chamber. A floodlight illuminates the leaf. Visitors can use their hands to shade the leaf.

When the leaf is in full light the carbon dioxide level in the chamber decreases—the plant is using the carbon dioxide in photosynthesis. When the plant is shaded the carbon dioxide in the chamber increases as the plant expels carbon dioxide during respiration. The graphics that accompany the exhibit discuss the role of plants in regulating the carbon dioxide level in the atmosphere and also the role of carbon dioxide as a greenhouse gas.

The visitor's favorite part of this exhibit is the creation of hand shadows on the leaf. The needles on the carbon dioxide gas analyzer follow the size of the shadow on the leaf with a few second delay.

Energy Publications

We developed and published a collection of hands-on energy activities for use in classrooms. These activities focussed on three areas: what is energy, the role of energy efficiency, and side effects of energy use. We can describe these three areas as: the first law of thermodynamics, the second law, and pollution. We selected these areas in a conference with Philip Morrison of the Massachusetts Institute of Technology.

The activities were first developed in several workshops with teachers of grades K-12. The activities were then written and illustrated by an Exploratorium team of scientists, teachers, editors, and illustrators. The activities were then tested in several teacher workshops.

What is Energy: The First Law of Thermodynamics

In the area of the nature of energy we developed an activity in which students generate 40 Watts of power. We have them lift two two-liter bottles of water through a meter of distance once each second. We then discuss methods of generating energy; tracing the history from human power, through animal power, to coal and then to nuclear sources. In the same area of energy, we also created a ratcheted

wheel which lifted a mass to measure energy. The ratcheted wheel was powered by a "dipping bird," a very simple heat engine. The dipping bird can operate in two modes: first, with room temperature as the hot source of energy and an evaporatively cooled end as the cold sink; and second, using room temperature as the cold sink and a sunlight heated end as the hot source. Measurements show that the bird produces a microwatt of power.

Energy Efficiency: The Second Law of Thermodynamics

In the area of energy efficiency we developed a technique to use a simple light intensity comparator, made from two slabs of canning wax (10 cm x 7.5 cm x 1 cm) separated by a sheet of aluminum foil, to compare the brightness of a 60 Watt incandescent and a fluorescent which claimed to be a replacement for the 60 Watt incandescent. The comparator was moved back and forth between the two lights until a point was found where the two lights delivered the same light intensity. If this point were midway between the two lamps then they would be emitting equal light intensity. If the comparator were in balance closer to one of the lamps then that lamp is the dimmer of the two. The inverse square law can then be used to calculate the ratio of the brightness of the lamps. The comparator showed that the fluorescent emitted slightly less light (about 10%) than the incandescent.

Measurement of the voltage and current used by the fluorescent lamp confirmed the claim made on its packaging that the lamp used only a quarter of the energy of the incandescent to deliver almost the same amount of light. The fluorescent was therefore more efficient at converting electrical energy into light.

Energy Side Effects: Pollution

In the area of side effects we created an activity to measure the carbon dioxide content of a gas sample. We shredded and boiled red cabbage to extract a safe pH indicator. In a neutral solution the indicator was blue. As carbon dioxide, from human exhalation for example, was bubbled through the indicator solution carbonic acid was formed which lowered the pH and turned the indicator pink. Eight-liter bags of automobile exhaust were gathered and bubbled through the indicator solution. Next, equal volume bags of human breath were gathered and compared to the auto exhaust. Bags of air were also bubbled through—they had no effect on the color of the indicator. This activity shows two of the origins of the greenhouse gas carbon dioxide, animal respiration and internal combustion engine exhaust. These activities will be incorporated into a future Exploratorium publication similar to our *Exploratorium Science Snackbook*.

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