

Supporting Information for:

Evaluating Large-Scale STEM Outreach Efficacy with a Consistent Theme: Thermodynamics for Elementary School Students

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1 Energy and U Show Details

The following section contains the slideshow presentation for the 2015 Energy and U Show and descriptions of the demonstrations performed for the student audience. Two University of Minnesota faculty members led each show.

1.1 Energy and U Presentation

Slides for the Energy and U Show were prepared using Keynote (Version 6.5.2) and are available upon request.

1.2 Demonstration Descriptions

All demonstrations were prepared and led by Department of Chemistry Lecture Demonstration Director Joe Franek. Personal protective equipment (closed safety goggles and laboratory coats) were worn by faculty performers and given to student participants during these events for precautionary safety purposes, as needed. The following summarizes the main demonstrations shown during the Energy and U show.

Working Water Wheel. A student volunteer was asked to pump colored water from the bottom storage tank to the upper chamber, as shown in Fig. S-1 below. Eventually, the fluid flowed down piping past a water wheel, which lit up a small light emitting diode. Faculty performers explained that one definition of energy is the ability to do work and subsequently asked the student audience to illustrate this by standing up to dance. Here, students were directly introduced to the concept of work as a form of energy and how we can convert kinetic energy into potential energy.



Figure S-1. Photograph of the Water Wheel demonstration. Prof. Frank Bates illustrates the concept transferring mechanical energy of pumping the lever to transfer the water to the upper chamber of the device. Photograph courtesy of Eileen Harvala. Copyright 2016.

The Screaming Gummy Bear. After asking how much energy students think they gained from eating breakfast in the morning, a faculty performer dropped a single gummy bear into a

glass flask containing molten potassium chlorate. In the presence of this oxidizing agent, sucrose violently reacts to release heat and form water, carbon dioxide, and potassium chloride (Fig. S-2). This demonstration represents a classic combustion experiment in chemistry, where sucrose undergoes an exothermic reaction. Students were taught that heat is another form of energy.



Figure S-2. Photograph of The Screaming Gummy Bear demonstration. Photograph courtesy of Eileen Harvala. Copyright 2016.

Mini Motorcycle. After learning that heat is a form of energy from the previous demonstration, the students are informed that heat can be converted into work via the use of engines, such as those in a car or even a motorcycle. At this point in time, a professor rides in on a mini motorcycle and circles the stage.

Methane Mamba. Methane was bubbled into a soapy water container to create a 4-5 ft tall column of methane. This lesson centers on combustion reactions using methane, the simplest hydrocarbon and the most abundant natural gas on the planet.

Hydrogen Ba-BOOM. Following the methane mamba, the audience is asked whether combustion can be performed without forming carbon dioxide, a greenhouse gas. A professor then informs the class that hydrogen gas can combust to create only water. This professor then asks the audience if this explanation is believable and if hydrogen can combust. The professor then states that in order to see if hydrogen can combust, then an experiment must be performed. This interaction with the audience is intended to stimulate experiment- and evidence-based thinking that is the foundation of the sciences. An audience member is then selected and is supplied with lab coats, safety goggles, and sound resistant headgear. A balloon containing only hydrogen gas is then brought onto the stage and, under careful supervision, the student ignites the balloon using a stick of length >1 m with a flame on the end.

One of the presenting professors then asks the audience where the oxygen came from that is necessary for combustion, expecting the audience to indicate that oxygen from the air reacted with the hydrogen in the balloon. The professor then suggests that if oxygen was in the balloon a louder explosion would result as the reaction would proceed without oxygen needing to diffuse (this word is not used in the show, travel is instead) to meeting the reacting hydrogen. Another balloon is brought out containing both hydrogen and oxygen and the same student volunteer then ignites the balloon, resulting in a louder detonation.

Student v. Professor Energy Competition. A student volunteer was chosen to compete with one of the performing professors in a direct contest to determine which person had more energy. Two concrete blocks were attached to a pulley system and were connected to what appears to be two cranks. An audience volunteer is then enrolled in a “competition” to race a professor by turning the crank quickly enough to raise the concrete block to the top of the pulley

system. Partway through the race, the professor used an electric drill to raise the concrete block up and win (often to the displeasure of the audience). The students are then asked how the professor won the race, responding that it was the electric drill. This prompts the professor leads to indicate that electricity is another form of energy, the intent of this demonstration.

Energy and U Fan Cam. After the indication that electricity is another form of energy, the professor not involved in the previous demonstration starts a remote-controlled drone equipped with a camera that produces a live video feed of the audience which is projected onto the stage. The drone is flown over the audience for approximately 3 min before it is caught by the professor not currently controlling the drone and the camera is pointed at an audience member. This student is asked to describe where the energy in the drone originates, eliciting the common response of the drone's batteries. The presenters then describe that batteries operate using stored chemical potential energy, which is yet another form of energy.

Bicycle Electrolysis. Moving forward with the concept presented in the previous demonstration, the professors pose a way to convert the stored chemical energy in one's body into another form of chemical energy. In this demonstration, an adult volunteer from the audience is encouraged to mount a stationary bicycle which is wired to an electric generator that is subsequently attached to two electrodes emerged in a solution of water with a small amount of sulfuric acid to promote electrolysis. The volunteer is then instructed to pedal the bike to induce electrolysis of the water to produce hydrogen and oxygen gas which is captured in a balloon. After the balloon is filled, the presenters ask the audience about what experiment would verify that hydrogen and oxygen gas were actually generated from the bicycle electrolysis system (once again, with the intent to encourage experiment-based scientific thinking). The response is to

ignite it, which is then enacted in a similar fashion as described in the *Hydrogen Ba-BOOM* section above.

Light Show and Glow Sticks. The ignited balloon from the previous demonstration leads the professors to revisit the topic of combustion, in particular to discuss the combustion of gasoline. The audience is asked to trace where the energy from gasoline originates step-by-step ultimately leading to the light emitted by the sun. This leads the presenters to identify the light is yet another (and the final form discussed in the show) form of energy, prompting in one of the professors to turn on a laser light setup in the classroom that encourages the audience to dance.

After introducing light as a form of energy, the presenters throw common glow sticks into the crowd while explaining that glowsticks convert chemical energy and emit it as light. They then introduce another reaction that will produce this conversion of energy by igniting a mixture of carbon disulfide and nitric oxide in a tall clear glass cylinder, resulting in an intense emission of blue light. The professor that initiated the reaction then touches the side of the cylinder to indicate that the cylinder is still cool and that most of the energy of the reaction was released as light instead of heat.

Laser Balloon Showdown. After demonstrating the conversion of chemical energy to light, the professors then introduce the concept of subsequent conversions of light to chemical energy to heat. They bring out a larger balloon filled with hydrogen and oxygen containing a smaller balloon filled with hydrogen and chlorine gas that will, upon exposure to light, react via an explosive free-radical chain reaction, initiating combustion in the larger balloon. Two such balloons were then placed on both sides of the stage while two volunteers were chosen from the audience. One of the volunteers is given a laser pointer that emits green light while the other was

provided one that emits blue light. The volunteers were then placed back-to-back and asked to race to ignite the balloon they were facing before the other volunteer. In all of the shows, the volunteer with the laser pointer that emits blue light will win the race as green light is not of sufficient energy (or frequency) to initiate the reaction. This point will then be used to explain that the more-blue light has higher energy than green and, therefore, more-red lights. In all cases, this demonstration is intended to reiterate the conservation of energy by showing energy convert among different forms.

Energy Transformation Rube Goldberg Machine. To follow the intent of the previous experiments, the final demonstration of the show incorporates most of the forms of energy discussed in the show and displays that energy only changes forms rather than being created or destroyed. In this demonstration, Joe Franek uses a laser pointer connected to a wall socket to ignite a small wad of gun cotton wrapped around the end of a black powder fuse to initiate a reaction of a very small amount of peroxyacetone, which is constrained to be only small quantities and is reacted from a safe distance because of its explosive nature. The reaction of the peroxyacetone closes a switch which allows electrical current from a battery to flow through a circuit containing a resistive heating coil. This heating coil ignites a common sparkler that acts as a fuse to initiate the extremely exothermic reaction of iron oxide and aluminum to produce aluminum oxide and metallic iron. Finally, the heat generated by this reaction ignites a balloon containing hydrogen and oxygen gas as well as produces molten iron which melts through the bottom of the flower pot in which the reactants were contained.

2 Likert-Type Scale Analysis

In addition to Percent Free and Reduced Lunch, the Likert-type question results were also analyzed in relation to the students having seen or not seen the show. To analyze this, we conducted t-tests of independent means. For the question regarding interest in college, neither the original Likert-type scale, nor the simplified one yielded any significant difference between students who had or had not previously seen the show.

When comparing students' interest in taking more science classes, the original Likert-type scale yielded a significantly higher interest (within 1 percent) in taking science classes for students who had seen the show. However, when the scale was simplified, the students who had not seen the show significantly favored taking more science classes. Because the results seemed to switch direction when the scale was simplified, one could propose that the wording of the Likert scale may have created a bias in student responses. However, while both of these differences were statistically significant, it would be presumptuous to call the $\leq 11\%$ difference (11% difference for the full Likert-type scale and 7% in the opposite direction for the simplified scale) in averaged Likert score as substantial enough to extrapolate trends in students' responses. This caution in the responses to the Likert-type analysis is additionally fortified by the fact that the students in a college science classroom while answering these questions, potentially biasing the results to favor "Very True" or "Yes" responses to both questions.