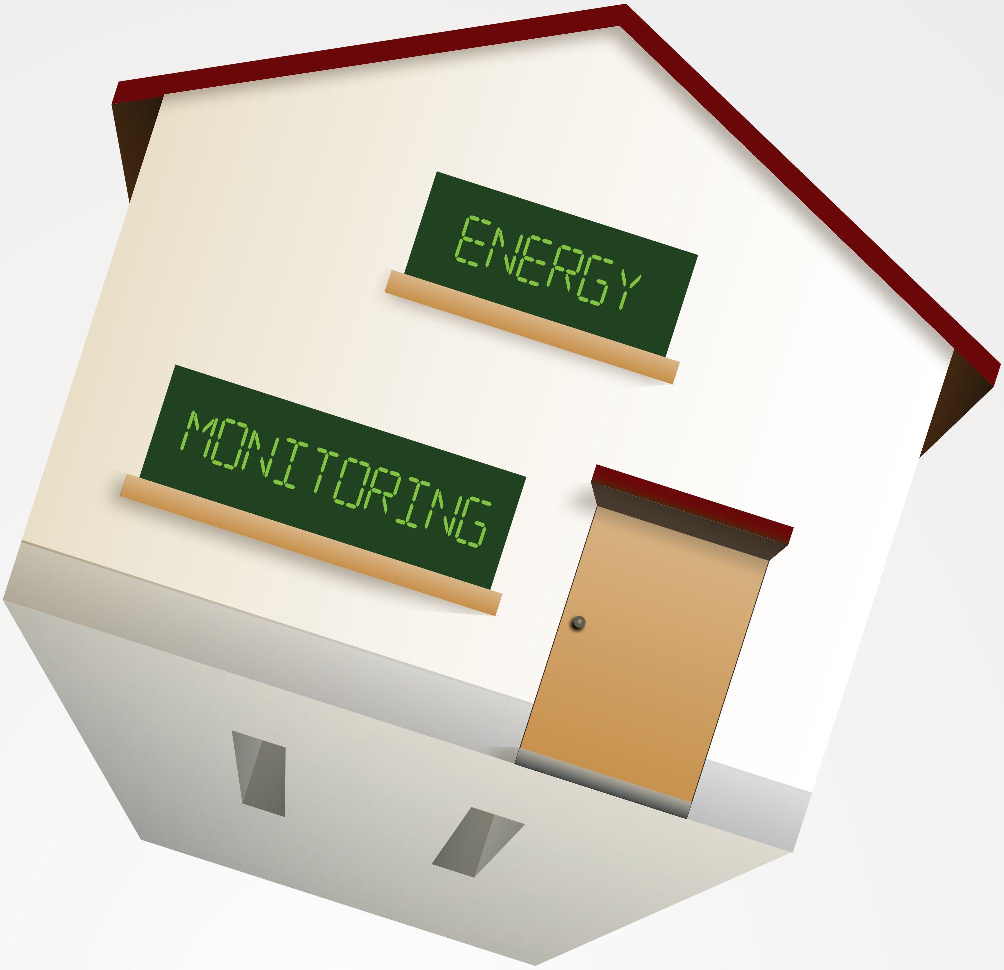


Energy Monitoring

Powerful Connections Between Math, Science, and Community

By Lynn Farrin and Jan Mokros

While it is likely that people have a good sense of how much gasoline their car uses or how much fuel they burn to heat their homes, comprehending how much electricity our homes use is more difficult, in part because electricity is not visible. Compounding the problem is the fact that electrical-energy use changes significantly over the course of an hour or day, depending on the mix of appliances and devices in use. Moreover, some small and innocent-looking appliances are energy hogs, while some larger devices use surprisingly little. Middle school students need to know about energy concepts and how they can reduce their energy use. How can we help students visualize patterns of consumption of electrical energy, understand what contributes to high levels of use, and determine how these patterns vary over time and type of use? See "Empowering Students to Investigate Their Energy Consumption With a Safe, Easy-to-Use, Low-Cost Electrical Energy Meter" in this issue for similar activities and connections to the *National Science Education Standards* (NRC 1996) and the new K–12 *Framework* (NRC 2012).

New energy-monitoring tools provide powerful opportunities for students to engage in authentic investigations rich in the science practices described in *A Framework for K–12 Science Education* (NRC 2012), while at the same time advancing their knowledge about energy and learning the mathematics of data that describe change over time. Analyzing, interpreting, and basing decisions on the wealth of energy data increasingly available to homeowners is rooted in mathematical, scientific, and communal questions. Herein lies the challenge—in terms of mathematics, middle school students often have difficulty with the related processes of measuring, visualizing, analyzing, and interpreting data. They may have learned units of measurement without understanding what they mean, and have typically learned to plot data points on a graph without understanding how a graph helps a person "tell the story of the data." Recent research has shown that middle school students need more experience thinking about how to represent a data set, especially one that involves their own measurements of data that change over time (Burrill 2006). On a qualitative level, they need to be able to explain how quickly or slowly change is taking place. The rate of change—such as sudden spikes in electrical use or more gradual changes in use—can be shown very clearly through slopes on line graphs. But students often pay little attention to what slopes on a graph reveal about a set of dynamically changing data. Given the research on students' understanding, it is no surprise that the middle school Common Core State Standards for Mathematical Practice emphasize understanding an entire set of data, rather than picking out individual points on a graph. For example, in sixth grade, the emphasis is on "understanding that a set of data collected to answer a statistical question has a distribution which can be described by its center, spread, and overall shape" (CCSSO and NGA 2010; 6.SP.2).

Energy-monitoring activities for middle school math and science

We developed a curriculum consisting of four modules on energy, PowerSleuth (*www.powersleuth.org*). One module, Maine Saves Energy (see Resources), focuses on monitoring and understanding household electrical use. This module is intended for use in conjunction with smart meters. Smart meters, which record consumption of electrical energy in intervals of an hour, are being installed in households throughout the nation and are on a fast track in Maine. This provided a timely opportunity to teach students how electricity is measured and how it might be conserved. Smart meters are one component of a nationwide effort to upgrade to a more modernized electrical system. Smart meters enable two-way communication between meters and centralized systems (utility companies), can gather data remotely, involve power-outage notification, and improve responsiveness in managing electrical loads.

Along with available data from smart meters, we worked with hardware and software tools that provide households with graphs displaying real-time electrical use in 10-minute increments. These supplementary devices were provided by the PowerSleuth Meets PowerMeter project, as not all areas of the state had equal access to smart-meter data. Since the time our initial project concluded, an increasing number of utility companies provide energy-monitoring tools, usually in the form of online portals, which allow smart-meter-data access.

While access to real-time electricity data may not be available to every homeowner at no cost, it is on the horizon and under development in many parts of the country (see the Utility Data Access Map and the Google Maps links in Resources). Until the time access to smart-meter data becomes commonplace, purchasing either hardware or software would be required to see one's real-time electricity use. A number of affordable commercial devices are increasingly available (prices range from $40 to over $600, depending on the type and amount of data desired).

Participating teachers were provided with a set of tools for their home, which included the Energy Detective (*www.theenergydetective.com*). This device measured the electricity use at home and exported data to a free online application, Google PowerMeter, which allowed teachers to share their data with students (in some cases, anonymously).

Working in teams, students developed questions that could be answered using data collected from the meters in their teachers' homes. (Contact the authors to access data sets or for more information.) Initially, students posed questions that allowed them to investigate patterns of use and how patterns changed over time, such as "How does electricity use in the morning (6–9 a.m.) compare to electricity use in the evening (6–9 p.m.)?" and "How does electricity use on the weekends compare to electricity use during the week?" The questions students investigated required collection of data over a period of time that ranged from one or two weeks to a month or more. Students recognized right away that the more refined their question, the more straightforward their data collection.

Naturally, students wanted to know what types of activities could be attributed to the patterns they were observing on the graphs. They wondered such things as "What types of household appliances would cause sharp spikes?," "What activities result in longer, more sustained spikes?," and "What can explain the relatively small, but regular blips of use throughout the day?" Because students could not witness first-hand which devices were in use and for how long, they had to ask their teacher or infer what was happening at specific time intervals. Their initial ideas about the kinds of activities that would result in the patterns they were observing were often incorrect. Large spikes in use were erroneously attributed to extended television watching, video-game playing, or computer use rather than to coffeemakers, driers, hot water heaters, or ovens.

Teachers strategically engaged students in activities that addressed specific aspects of electricity use and data interpretation to help them gain confidence and accuracy. For example, determining how much electricity a particular appliance uses was done by reading its electrical nameplate or using a watt meter (e.g., Kill A Watt meter). (See "Empowering Students to Investigate Their Energy Consumption With a Safe, Easy-to-Use, Low-Cost Electrical Energy Meter" in this issue.) Using the information gathered from these tools and some simple calculations, students developed a sense of whether the pattern they were seeing on the display could be attributed to using a 1500-watt hair dryer for 10 minutes or the continuous (24-hour) cycling of the home's refrigerator. By analyzing data and using the questioning strategies embedded in the module materials, students began to see that appliances involving heating and cooling are some of the larger users of electricity. In addition to using the Kill A Watt meter, this was accomplished by a number of activities and exercises outlined in the curriculum materials. For example, students were given narrative descriptions of a home's electrical-use activity and the electrical graph of that activity. Through analysis of these graphs, students learned to recognize graphical patterns typically made by particular appliances. A refrigerator's electrical pattern is readily identifiable, as they are always on but have a cooling cycle that draws higher amounts of electricity with periodic regularity. On a graph, this looks like a low, flat line interspersed with short, steady blips of higher use. (See module materials for specific activities; see Resources.) Students also were able to recognize appliances that likely contributed to the home's "always on" power load and were able to identify those with phantom loads (appliances that are seemingly off, but still draw electricity). To further develop their conception of a kilowatt-hour, students engaged in a scavenger hunt (see Resources), finding ways an appliance or combination of devices could be used to compose one kilowatt-hour (kWh). In this exercise, students could suggest using one 100-watt bulb for 10 hours is equivalent to using 10 100-watt bulbs for one hour; both result in using 1,000 watts/hour or 1 kWh. We paired this overarching student-led investigation with more discrete activities focusing on a particular concept/skill that helped students build a picture of electricity and how it is quantified.

Module activities also involved examining generic electricity bills and bills brought from home with parental permission. Students studied the monthly patterns of electricity use and investigated how the electricity costs were calculated. This was the first time the majority of students had seen an electricity bill or thought about how people are charged for their electricity. Through this activity, students recognized that their bill was one data tool that virtually all homeowners had access to and could use to begin making decisions about conservation.

What did students learn?

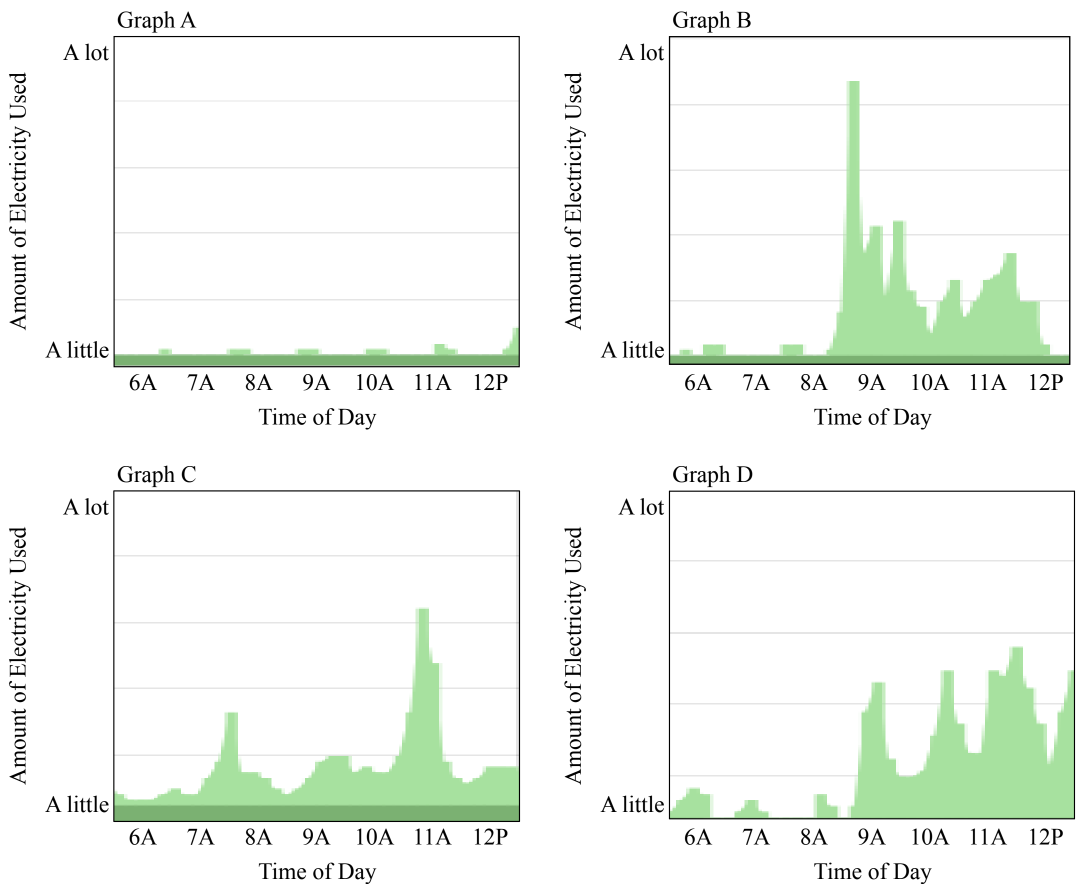
As we worked in classrooms, we studied the impact of the energy-monitoring curriculum on students' learning about household electrical data that change over time. We were especially interested in how students made sense of graphs like the ones they used in class. More generally, we wondered whether students learned to interpret the nuances of data that change over time. We asked two major questions: (1) What did students learn about electricity use, especially about the likely energy hogs in households? and (2) What did they learn about making and interpreting a graph of data that change over time? Assessment items included structured tasks that asked students to explain their reasoning.

FIGURE 1 **Telling the "story" of a family's electrical use assessment item**

Scenario 1

Today when Addison Fox and his family wake up, Addison starts the coffee maker while Mrs. Fox takes a quick shower and uses the hair dryer and curling iron. (They have an electric hot water heater.) Shortly after Mrs. Fox is out of the shower, the Fox twins each take their showers. After breakfast, the boys play with their computer games.

Please examine the graphs below and circle the one that is the *best match* for this scenario.



Circle the highest peak on the graph you selected. What is happening in the story at that time?

The first item involved determining which of four graphs most closely matched the "story" of a family's electrical use, then selecting the peak-use time and explaining what was happening at the time of peak use (see Figure 1). The best answer, graph b in Figure 1, shows a peak that corresponds to a high-level use of an appliance that generates heat.

Another item, designed to examine students' more generalized understanding of graphical representations of change, involved graphing the changes in population of a school over a six-hour period. This item, modified from an activity that was involved in an early version of the mathematics curriculum Investigations in Number, Data, and Space (Tierney, Nemirovsky, and Weinberg

1998), asked students to describe the nature of change over time and involved a qualitative description of high and low points, as well as changes in slope. This item, as completed by a student who showed a high level of understanding of change over time, is shown in Figure 2. Note that because we were examining how students construct the shape of a data distribution rather than whether they could "connect the dots" between numbers they have plotted, the y-axis ranges from "none" to "a lot."

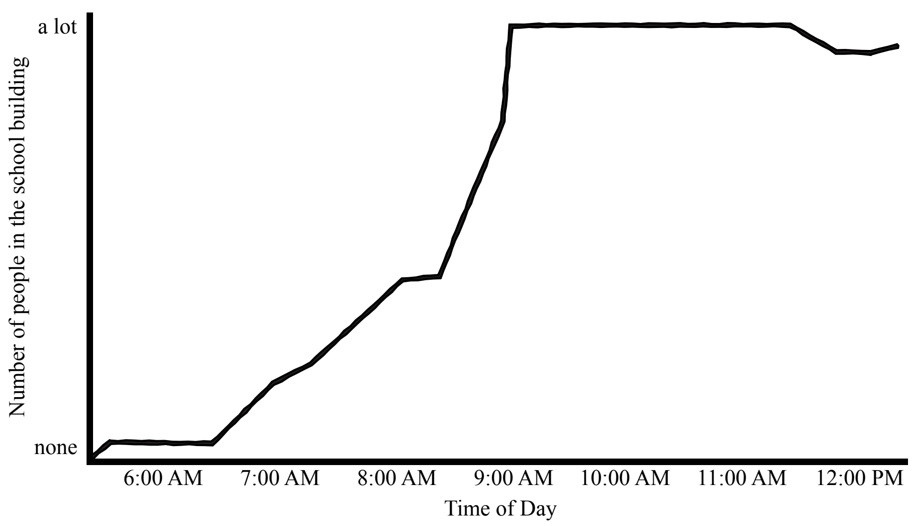
As part of a larger research study, 212 students in grades 7 and 8 completed the item about household electricity on both pre- and posttests, and 202 students completed the item on changes in the school's population on both pre- and posttests. The results showed that students made significant gains on both test items. On the first item, we scored both students' graph selection and how they explained their choice. On this item, we saw an average gain of about half a point (0.45) on a four-point scale ($t = 3.618$; $p < 0.01$, $N = 212$). The biggest change was that students at posttest better understood the fact that devices that create heat (hot-water heaters, curling irons) use more electricity than computers. That is, students were less likely to attribute peak demand on the graph to the family's use of computers.

On the test item involving graphing the number of people in a school over time, students again made significant gains from pre- to posttesting. On a six-point scale, students gained an average of 0.55 points from pre- to posttesting ($t = 5.503$, $p < 0.001$, $N = 202$). The

FIGURE 2 Describing change over time assessment item

Scenario 3

Make a line graph showing how the number of people in your school building changes during a regular school day from 6 AM to 12 noon.



Write two or three sentences that explain what your graph shows about how the number of people in your school building changes over time.

In the morning at 6:00 a.m. only, maybe, 2–5 people are at school, then at 7:00 a.m. it slowly increases until rapidly going upwards at 8:00 a.m. Until 12:00 p.m., lots of people are still in the school because school has not ended yet. The only reason the line graph decreases is because some kids might be dismissed early.

statistical tests tell only part of the story: We examined how students' responses had changed, particularly with respect to the general graphing item (school population). We found that the most typical change involved observing more detail about the graph and being able to describe what several points on the graph signified. However, most students did not learn to describe rates of change by using words such as "gradually," "suddenly," "stable," etc. The response from a student (shown in Figure 2) is something we had hoped to see more often, as it indicates an understanding of the meaning of slope.

Conclusion

Graphs of dynamic data, such as those becoming widely available through utility companies or those available commercially, have the potential to integrate science and mathematics learning. Not only did we find that students were fascinated by the "mystery" data, poring over the information to figure out what might be happening in the sample homes, they were also clearly engaged in collaborative research processes. Close examination of the graphs provided students with many opportunities to implement what they were learning about science to understand the mathematics of data and begin using their findings to make changes in the way they and their families personally consumed electricity.

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Resources

The Energy Detective—*www.theenergydetective.com*

Google Maps smart metering projects map—*https://maps.google.com/maps/ms?ie=UTF8&hl=en&msa=0&msid=115519311058367534348.0000011362ac6d7d21187&z=2*

Google PowerMeter—*www.google.com/powermeter* (retired September 16, 2011)

How many ways to a kilowatt-hour? Scavenger hunt (student handout)—*www.powersleuth.org/docs/MSE%20Electricity%20Monitoring%20files/16988_StdntHndout_How-Many-Ways-Kw-Hour.pdf*

Kill A Watt meter—*www.p3international.com/products/special/p4400/p4400-ce.html*

Maine saves energy—*www.powersleuth.org,*

Module materials—*www.powersleuth.org/save-energy/powersleuth_meets_powermeter/teacher-guide-resources*

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