Designing a Sustainable Neighborhood

An Interdisciplinary Project-Based Energy and Engineering Unit in the Seventh-Grade Classroom

BY MOLLY GOLDSTEIN, BOB LOY, AND ŞENAY PURZER

According to the United States Energy Information and Administration report, in 2015, approximately 40% of total energy consumed in the United States was used for heating, cooling, ventilation, and lighting of residential and commercial buildings (EIA 2016). To help lower the amount of energy consumed by these building, many construction companies now seek an energy certification called Leadership in Energy and Environmental Design (LEED), which verifies that the design, construction, operations, and maintenance of their buildings are energy conscious (USGBC 2016).

Studies show that children from a very early age think about energy consumption because their personal electronics require recharging, and parents are continually reminding them to turn off the lights (Fell and Chiu 2014). Research has also shown that children are motivated to save energy after learning about

total energy expenditure and ways that they can have a positive impact on the environment (Fell and Chiu 2014; Grønhøj and Thøgersen 2011). In addition to promoting environmental consciousness, energy-focused projects promote student learning. Prior studies have shown how activities that require students to design buildings reinforce science and engineering practices and the understanding of core science concepts (Purzer et al. 2015).

Bob Loy, instructional coach at Creekside Middle School in Carmel, Indiana, led the implementation of an interdisciplinary, project-based design curriculum named "Designing a Sustainable Neighborhood" with students working collaboratively to design energy-efficient homes. The project lasted a month. As junior engineers, 450 seventh-grade students explored the relationships between design criteria, such as energy efficiency and affordability. In designing their buildings, students also explored aspects, such as trade-offs, that became more concrete when students strived to balance the need to reduce cost while meeting energy requirements. Situating engineering design at the center of a middle school energy curriculum proved to be an engaging and effective way to encourage student learning of science and mathematics concepts. This article describes the implementation of this fully integrated engineering, science, and mathematics curriculum as part of an energy unit.

Getting ready

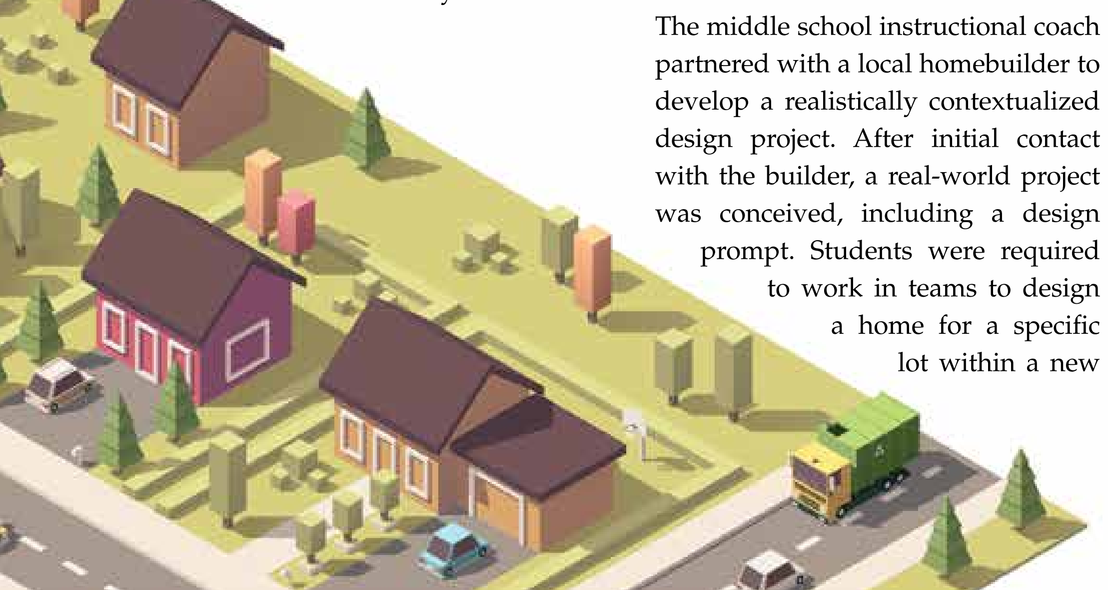
Organizing the collaboration between science and mathematics teachers

This energy curriculum, "Designing a Sustainable Neighborhood," was developed and implemented collaboratively by three science teachers, three mathematics teachers, one instructional coach, the owner of a residential community construction company, and two researchers at Purdue University.

The main role of the instructional coach was to work with six teachers to identify a common goal of facilitating the required teamwork and collaboration. The common goal of this interdisciplinary project was to work with external stakeholders to bring authentic experiences to seventh-grade students with an integrated, real-world project.

A real stakeholder: Homebuilder

The middle school instructional coach partnered with a local homebuilder to develop a realistically contextualized design project. After initial contact with the builder, a real-world project was conceived, including a design prompt. Students were required to work in teams to design a home for a specific lot within a new



CONTENT AREA

Science

Math (math 7, prealgebra, and algebra I)

GRADE LEVEL

7

BIG IDEA/UNIT

Energy

ESSENTIAL PRE-EXISTING KNOWLEDGE

Basic data analysis skills

Basic geometry (area and scale)

Basic understanding of slope

Basic energy transfer

TIME REQUIRED

35 hours

COST

None

FIGURE 1: Timeline of project planning, collaboration, and implementation

Month	Who	What	Planning and collaboration details
August	Coach, builder	Idea emerging	Contact and date planning with Old Town Design began
September	Coach, mathematics teachers	Planning	Discussed and finalized pre-algebra standards and milestones Discussed and finalized Math 7 standards and milestones
October	Coach, science and mathematics teachers	Planning	All science and math teacher planning and collaboration with focus on launch Can we do a site visit? How can we better communicate expectations between math and science teachers?
November	Coach, science and mathematics teachers, builder	Planning	Math/science teacher collaboration Continued contact and collaboration with Old Town Design to coordinate site visit
December	Coach, builder	Planning	Continued contact and collaboration with Old Town Design on site visit and how to better follow through with winners and plans
January	Coach, science and mathematics teachers, school administrators, Purdue University researchers	Planning and expanding	Teachers and administrators attend STEM conference at Purdue University and are shown the Energy3D software
February	Coach, science and mathematics teachers, builder, school administrators, Purdue University researchers	Planning and launch	Math/science teacher and Old Town Design collaborate on site visit details and use of new program Faculty from Purdue come to train students and staff on Energy3D Whole grade-level meeting with administration coordinating and explaining details of launch at site visit. Host administrators, teachers, and instructional coaches from around the district show what students will be doing and give overview of the process students will be going through Launch of project
March	Coach, science and mathematics teachers, school administrators, builder, Purdue University researchers	Implementation	Creekside Middle School hosts various guests, including Purdue University, district administrators and teachers and Old Town Design throughout the duration of the project Culminating event
April	Coach, science and mathematics teachers, builder, Purdue University researchers	Conclusion	Teachers and coach debrief each other about the project Final judging of lot winners by teachers, Old Town Design Group, and Purdue University researchers
May	Coach, science and mathematics teachers, Purdue University researchers	Debrief and future planning	Teachers and coach debrief with Purdue University researchers about student learning and use of Energy3D software

building community that was attractive, buildable, and energy-efficient. The builder played a key part during a kick-off meeting with students and participated in reviews of the final designs during student presentations at the conclusion of the project. Additionally, the builder met with the winning team to discuss possibilities for actually building their home design. Figure 1 shows a timeline of the planning and teaching process.

FIGURE 2: Lessons and labs

Science mini-lessons and labs	Math mini-lessons
Mini-lessons: • Renewable and nonrenewable resources • Fossil fuels versus alternative energy sources • Electricity generation for work and energy efficiency • Law of conservation of energy	Surface area • Calculate roof cost • Calculate siding cost Slope • Roof slope Data analysis • Data displays: Histograms, bar graphs, line graphs, circle graphs, box and whisker plots
Labs: • Testing roofing materials • Testing siding materials • Testing flooring materials	

Planning the assessment

Backward design is essential to developing ongoing, standards-based assessment in any curriculum. In this case, teachers started with the topics and standards to be assessed and came to a common understanding of an objective that would help meet those expectations. In science, this focus was around the topic of energy, including energy efficiency and heat transfer. A key concept in both science and math was design and application, thus creating a natural fit for homebuilder as a community stakeholder and partner.

When math and science teachers met during their common planning time, the instructional coach discussed the natural fit with math in the design project. Math teachers agreed that the essential skills and content standards encompassing geometry (area, surface area, slope, and measurement) and data analysis would be well-covered through this project.

Another factor in student learning and performance, in this case, was the software program being used in the design of their home. Teachers needed to consider and take into account that students were to be assessed and ultimately graded on their knowledge of the content and not their ability to navigate a software program. This was another point of collaboration for teachers as well as something to take into consideration when writing the rubric for both math and science classes.

Collaboratively, teachers designed milestones and preliminary mini-lessons on the necessary skills and content students must learn during the design challenge (see Figure 2).

Milestones addressed essential skills and content standards through worksheets (e.g., Milestone 2 required calculation of roof surface area), while mini-lessons helped scaffold these concepts. The adaptability of mini-lessons was important to ensure students continued to have a voice in their learning and that their needs were met. Student inquiry plays a large role in the development of a unit such as this, creating and sustaining motivation throughout the duration of the project.

Each milestone and mini-lesson enabled students to work toward their final product and meet the design criteria and constraints provided by the community partner. Cycles of student building and teacher feedback not only provided students the guidance and coaching they needed, but also gave teachers the continued feedback they needed to provide responsive instruction.

After each milestone, teachers conducted small formative assessments to continue to monitor student progress and help guide additional instruction.

These assessments also assured teachers that students were being assessed on the required content standards. Because teachers assessed students periodically along the way with formative, standards-based assessments and milestones in their home design, every student finished their design and showed proficiency in the understanding of the content. The final student presentations were a culminating event in which students were able to showcase their skills to community stakeholders in a unique way. While presentations did not impact overall grade, it provided an additional layer of authenticity and an opportunity to practice professional skills. In the future, science and math teachers hope to work more closely with the English language arts teachers to incorporate speaking and listening assessments within the context of this particular project.

FIGURE 3: A sample lot layout and its location in the neighborhood

Organizing student teams

Initially, all 450 students were assigned to three different academic teams—one academic team for each of the three science/math teacher duos. Within each science class, students were then divided into groups of four or five, for a total of six to seven teams per science class. Each group was assigned one of seven lots from the targeted neighborhood (see lot 74 in Figure 3). These lots differed in size and orientation, with the purpose of varying the energy needs and analysis, along with the size of the home being built.

Once students were in teams and their lot had been assigned, they then chose one of the following roles on which to focus:

1. Architect
2. Landscape architect/urban planner
3. Construction manager
4. Mechanical engineer

The majority of the team role work was completed in the science classroom, while work in the math classroom consisted of both data analysis and individual design work in Energy3D.

Project kickoff

The design challenge

Figure 4 shows an excerpt of the letter students were given from the local builder, Old Town Design Group, which served as the design challenge prompt. The design prompt was shared with students during an all-grade assembly. The local builder set the real-world context for the challenge with a brief history of the development and visuals of the development layout.

Scoping and understanding the design problem: Sources of information

Site visit

Immediately following the kick-off of the design challenge with the homebuilder, students and teach-

FIGURE 4: Design prompt

The city of Carmel, Indiana, wants your firm to help in the design of a new housing development. They are interested in talking with your team of experts on Sustainable Living. Your group has worked on projects like this one over the years and you have been selected as one of the teams that will be submitting ideas for the new development. Growing concerns over our "carbon footprint" are a major factor in how this new development is designed. Carmel, Indianapolis, is a city that is striving to build environmentally sensitive neighborhoods to benefit our current air quality, but also the global concerns as well. Your firm will have many choices to consider in the design of the homes and the entire development. Renewable and nonrenewable resources must be considered, with each option being compared to the others. The development will have many home varieties that you will use as an example of your new "Green Technology" ideas. The development will also provide your firm with the opportunity to explore alternative developmental ideas. Examples are pavement that reduces water runoff, irrigation sources, and incorporating renewable resources such as wind power, solar power, water power, and other low-carbon emission fuels. Your company will also explore options on how to reduce, reuse, and recycle within the development and the homes being built. Your group will finally develop key options to reduce the amount of fuel needed by making the homes as efficient as possible.

Your goal as the design firm is to provide a 10-minute presentation to a panel representing "Sunrise on the Monon." You will be addressing all of the new ideas that are 21st-century driven, making a home and development as environmentally sustainable as possible. Your team has the opportunity to present your project in many different ways.

ers (from one academic team) went to the construction site to see the lots for which they would be designing (see Figure 5). The other two academic teams followed throughout the day. While at the building site, students broke into smaller groups, by teacher direction, and went with a staff member to the lot for which they were designing a house. At that lot, students gathered data concerning the orientation of the of the house toward the Sun, size of lot, placement of house within lot, and likely buyer needs for the house. During this time, students could also ask the builder any of their questions prompted by physically being at the construction site.

Experiments in the science classroom

Throughout the next four to five weeks, members of teams worked together individually in their assigned roles. Students conducted research through several labs managed by the teachers, as well as targeted internet research (on subjects such as internal lighting options). Each team member developed suggestions and recommendations on how to make homes as ef-

FIGURE 5: Site visit

FIGURE 6: Student team role descriptions

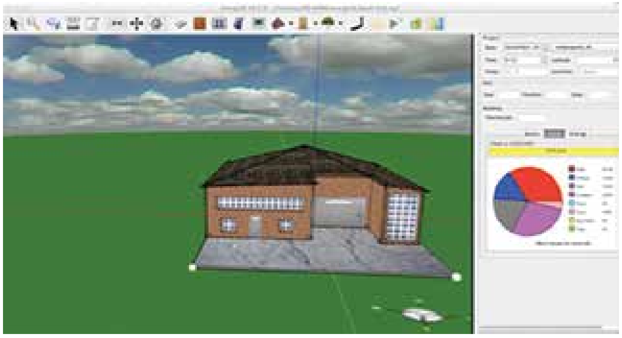
Team role	Lab/research area	State (IN) science standards (I will understand...)
Architect Plans, designs, and oversees construction of buildings. Concerned with the overall energy efficiency of the house design.	• Flooring materials • Lighting options (bulbs) • Room layout • Siding materials	• Housing energy and efficiency • Heat transfer, conduction, and radiation in the housing industry
Landscape architect/urban planner Planning and design of the physical arrangement of the development including landscaping for energy efficiency of homes and the neighborhood as a whole.	• Orientation of the home on the lot • Plants (trees, shrubs) and their locations • Wind mill lab (wind power for irrigation, water runoff, erosion, greenspace, etc.) • Solar panel lab	• Environmental impact of development • Renewable and nonrenewable identification/options
Construction manager Does the actual building of the architect's plan. Concerned with costs, materials, and equipment.	• Roofing • Lighting options (bulbs) • Room layout/orientation	• Carbon emissions from fossil fuels • Energy conservation
Mechanical engineer Performs installation of mechanical components of home. Concerned with the energy efficiency of the heating, cooling, and refrigeration units.	• Wall construction • Insulation • Windows • Appliances • Solar panels	• Where energy comes from and how we get it • Energy conservation

ficient as possible. Figure 6 describes the team roles with associated labs and state science standards addressed.

Designing in the mathematics classroom/simulated learning environment

During the same timeframe, students worked independently in math class designing their home with a computer-automated design software, Energy3D (Figure 7). Energy3D is an open-source tool for designing, analyzing, and constructing energy-efficient buildings that use renewable energy. Using Energy3D, students can quickly sketch up a realistic-looking building and then evaluate its energy performance for any given day and location. At the end of the design, Energy3D allows users to print out their design on regular paper or cardstock, cut out the pieces, and use them to assemble a physical scale model (see Resources). Students saved their computer design files to USBs or to Google Drive to access their files from school or home. While Energy3D runs on both PCs and Macs, it does not currently run on tablets. Students need access to a computer to be able to design in Energy3D either through individual laptops or through computer labs. No log-in or passwords are required. Groups of approximately 30 students came to the computer lab for a Purdue researcher to introduce the Energy3D software, and to scaffold designing in Energy3D, including how to incorporate design

FIGURE 7: Example of a student's final design in Energy3D



features, run analyses, and interpret graphs. In addition, the Energy3D website has instructional videos for students who were absent on the day of instruction. Because of the large number of students, three separate researchers came to run three separate labs over the course of one day.

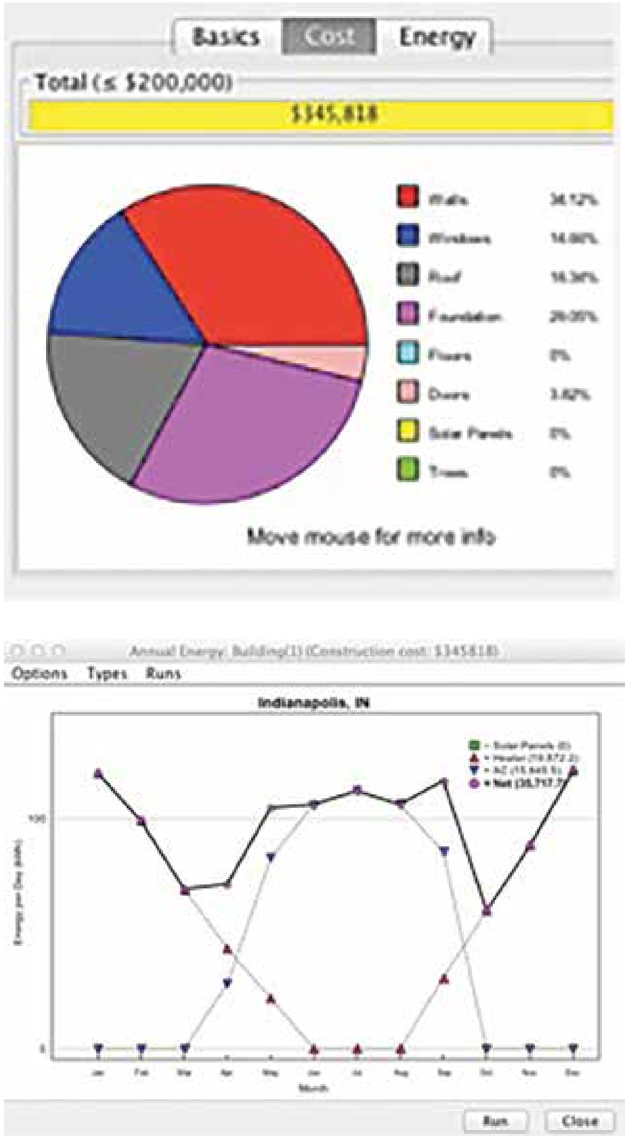
While in math class, students focused on the design features of the home and used Energy3D tools to analyze energy consumption (Figure 8a) and cost (Figure 8b). In addition, they worked with math-specific concepts including scale, size of the home, and slope of the roof. Students were given time in class, over the course of the five weeks of the project, to prepare their slides for their final presentation and to rehearse with their groups. Each class was approximately 90 minutes. This time was broken into several different components, including mini-lessons focused on the content and skills needed for students to complete the assigned task, work time for groups to collaborate on applying their knowledge to improve the design of their home, and time for group collaboration on how to best present their findings.

Closure and celebration

Formal presentations to experts and stakeholders

Student teams were given 10 minutes to present their final team design and findings to a panel composed of homebuilders, architects, realtors, city officials, and other community members. Six

FIGURE 8: Example of a student's graph of energy consumption and graph of construction costs



panel reviews (one panel for each land lot) ran simultaneously. Within each of the six panels, there were two judges. So, within the first hour, 36 of the approximately 173 teams were able to pitch their ideas. The presentation focused on the material choices teams made and the reasons for those choices (e.g., solar panels and their positioning, wall thickness, roofing and siding materials). An energy analysis was completed in Energy3D and shown to the panel along with the building design.

Stakeholders then decided on which group did the best overall job. A week after the panel judging, the winning group was then able to sit down with the homebuilder and architect to discuss the specifics of their design. After the design conversation, the architect worked to complete blueprints of the student design to include in the real house options in the neighborhood.

Assessment

A Purdue-developed instrument specific to the Energy3D learning environment and design challenge, "Green Design Science Applications Test," assessing student learning of integrated design-science was used as a pre- and post-test. The specific topics measured were:

- Sun path and *insolation*, exposure to the Sun's rays (i.e., Sun path, hours of Sun exposure, angle of incidence, seasonal variation, geographic variation, solar heat gain coefficient)
- Heat transfer (i.e., thermal radiation, flow from warm to cool [energy], surface area, temperature difference, thermal conductivity)
- Representations (i.e., solar heat map, graphs, interpretations)

Lessons learned

During the project, teachers and students developed a greater familiarity with Energy3D. While technology glitches appeared during the design portion of the project, the occasional issues around the software showed the consequences of not saving designs often and encouraged students to take notes regarding their design rationale.

Additionally, from initial planning through student team presentations, it was evident that teacher collaboration was critical to the overall success of the endeavor. The role of a lead teacher or instructional coach makes a project of this scale more feasible for one key point person to facilitate meetings with external stakeholders and organize events (such as the kickoff and panel presentation day).

Finally, we saw how important it was to provide students with an authentic activity. For similar projects involving the design of energy efficient buildings, we foresee partnering with local real estate agents to provide a written request to students to design a home for their clients. The essential component of making an activity authentic for the students is to establish a local partnership. Many local businesses are more than willing to help provide design scenario support if schools reach out to them. ●

ACKNOWLEDGMENTS

This work would not have been possible without the collaboration of the Creekside Middle School science and mathematics teachers (Chris Bartley, Jeff Kirch, Becky Cheetham, Katie Abel, Joel Haynie, and Madison Schaffer) and Justin Moffett and Mark Einselen of Old Town Design Group. We also would like to express our gratitude to Robin Adams for her collaboration in our work, and the Concord Consortium for their innovative software and support, especially Charles Xie, Jie Chao, and Saeid Nourian. The work presented in this manuscript is based upon work supported by the National Science Foundation (NSF) under Grant DUE #1348547 and DUE #1348530. Any opinions, findings, and conclusions or recommendations expressed in this paper, however, are those of the authors and do not necessarily reflect the views of the NSF.

REFERENCES

Fell, M.J., and L.F. Chiu. 2014. Children, parents and home energy use: Exploring motivations and limits to energy demand reduction. *Energy Policy* 65: 351–58.

Grønhøj, A., and J. Thøgersen. 2011. Feedback on household electricity consumption: learning and social influence processes. *International Journal of Consumer Studies* 35 (2): 138–45.

Purzer, Ş., M.H. Goldstein, R.S. Adams, C. Xie, and S. Nourian. 2015. An exploratory study of informed engineering design behaviors associated with scientific explanations. *International Journal of STEM Education* 2 (9): 1–12.

U.S. Energy Information Administration (EIA). 2016. How much energy is consumed in residential and commercial buildings in the United States? *www.eia.gov/tools/faqs/faq.cfm?id=86&t=1.*

U.S. Green Building Council (USGBC). 2016. Leadership in Energy and Environmental Design (LEED). *www.usgbc.org/leed.*

RESOURCES

Energy3D—*http://energy.concord.org/energy3d*

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

- The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectations listed below.

Standards

MS-PS3 Energy
www.nextgenscience.org/dci-arrangement/ms-ps3-energy

MS-ETS1 Engineering Design
www.nextgenscience.org/dci-arrangement/ms-ets1-engineering-design

Performance Expectations

MS-PS3-3. Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.
MS-ETS1-3. Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practices	
Developing and Using Models Analyzing and Interpreting Data	Students use Energy3D to create a model home. Students conduct an energy analysis of their model home to determine its energy efficiency.
Disciplinary Core Ideas	
PS3.B: Conservation of Energy and Energy Transfer • Energy is spontaneously transferred out of hotter regions or objects and into colder ones. ETS1.B: Developing Possible Solutions • There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem.	Students use Energy3D to sketch a realistic-looking building and then evaluate its energy performance for any given day and location, taking into account the impact that structures such as windows and solar panels have on energy loss/energy efficiency. Students research flooring materials and lighting options to determine their energy efficiency.
Crosscutting Concepts	
Energy and Matter Systems and System Models	Students research renewable and nonrenewable energy options for their home. Students use Energy3D to model and analyze energy consumption and cost.

Molly Goldstein (*goldstm@purdue.edu*) is a PhD candidate in the School of Engineering Education at Purdue University in West Lafayette, Indiana. **Bob Loy** is the instructional coach at Creekside Middle School in Carmel, Indiana. **Şenay Purzer** is an associate professor in the School of Engineering Education at Purdue University.