Solarize Your School

A solar energy system design challenge

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As solar energy becomes increasingly affordable, many schools are considering installing new solar power systems. Can students contribute to the design, evaluation, and decision-making process in any way? Many students are familiar with solar power and energy, having researched solar energy on the internet, built solar cookers, inspected mini solar cells, gone on field trips to local solar farms, and so on. Well-informed and motivated, they are just one step away from taking responsibility for their own schools.

In this article, we present Solarize Your School, an engineering project that gives students the opportunity to design and evaluate solar power solutions for their own schools. This STEM project requires students to learn and apply skills and practices related to solar energy and photovoltaic technology concepts, such as architectural measurement and modeling techniques, graphical interpretation and data analysis, budgeting and investing, scientific inquiry and engineering design, and collaboration and communication (see *Next Generation Science Standards* table, p. 47).

Solarize Your School can be incorporated into environmental science, physical science, and engineering courses, and can be adapted to fit any curriculum scope and time frame. We suggest a 10-day sequence of learning activities. All the technologies and materials mentioned are freely available (see "On the web").

Technologies

Energy3D is a computer-aided design (CAD) tool for designing buildings and power stations that harness solar energy. In addition to common CAD features, Energy3D integrates the design, modeling, analysis, testing, and evaluation processes to accelerate iterative improvement and enhance design performance (Xie et al. 2018). Students can quickly sketch realistic models of their schools (Figure 1), design solar power systems (Figure 2), analyze the energy generation of their designs (Figure 3, p. 42), and estimate the costs and return on investment (Figure 4, p. 42).

Powered by computational physics and weather data, Energy3D allows students to explore the Sun's path for any given time and location (Figure 5, p. 43), examine how solar energy is distributed on building surfaces (Figure 6, p. 44), and experiment with multiple designs. Energy3D has been tested by thousands of middle school, high school, and college students. The majority of students learn to create 3D structures and solar power systems within one or two class sessions (Chao et al. 2017; Goldstein, Loy, and Purzer 2017; Kite and Park 2018; Schimpf, Sleezer, and Xie 2018).

Virtual Solar Grid (VSG) is software that models interconnected, distributed solar energy systems and storage on a global scale (Figure 7, p. 44). The world map interface allows students to navigate to locations of interest, view existing solar power projects, and download Energy3D models of those projects. Students can learn from hundreds of existing real-world projects and can also submit their own. Once reviewed and accepted, students' projects can become valuable public assets for renewable energy researchers, educators, and advocates (Figure 8, p. 45). As students contribute data points representing the solar power potential of usable sites, they actually make it increasingly possible to answer big questions like how much of humanity's energy needs can be realistically met by solar power generation and power grid optimization.

Google Earth Pro shows high-resolution images of the Earth and provides a variety of tools to take measurements (Figure 9, p. 45). Students can use Google Earth Pro to conduct a virtual site survey of their campuses, noting design constraints such as building structures and rooftop fixtures. They will also use elevation data (if available) and the virtual ruler to measure the dimensions of school buildings and surrounding objects.

FIGURE 1

Realistic-looking model of a school building.

FIGURE 2

Design of a solar power system.

FIGURE 3

Energy output analysis of a solar power system.

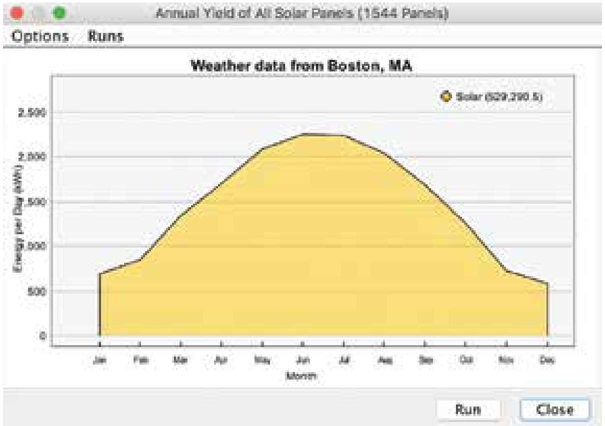
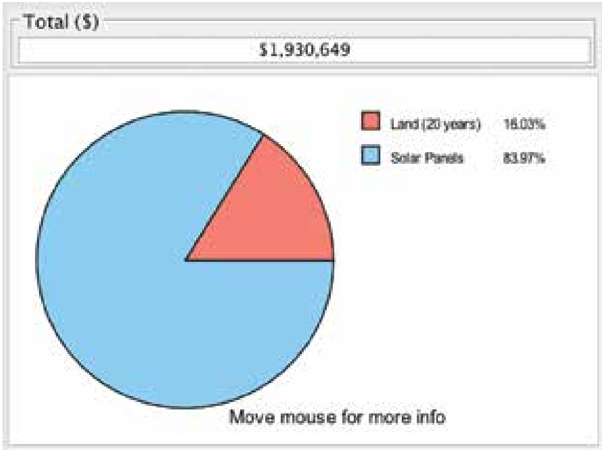


FIGURE 4

Cost analysis of a solar power system.



Project overview (day 1)

To set the stage, discuss the numerous ways solar energy can be harnessed and used, the molecular mechanism underlying photovoltaic (PV) technology, various types of PV projects, and how solar engineers design PV systems (see "On the web"). If possible, present the electricity usage at your school, as well as the cost and carbon footprint.

Modeling the campus (days 2–3)

Most students have never closely observed their school buildings and environment. As they inspect and measure using Google Earth Pro or photogrammetry techniques, they will discover the dimensions and orientations of all types of buildings, structures on the roof (skylights, vents, and chimneys), and the histories and future plans of school expansion.

When they begin to create models using Energy3D, many learning opportunities will emerge. For example, students may ask why the model needs to be so accurate or whether they should ignore objects such as trees and flagpoles. These are opportunities to discuss the nature of modeling—would the dimensions of the school building and the surrounding objects affect how the solar panels perform? A great way to assess student learning is to have them compare models and justify their modeling approaches.

Solar science concepts (days 4–5)

Students investigate solar science concepts including the horizontal coordinate system, seasons, day and night cycles, the path and angles of the Sun, and factors affecting solar energy potential and the energy output of solar panels. For example, in the tutorial model in Figure 10 (p. 46), students can investigate how tilt angles of solar panels affect energy output.

Ask students to explain the results using science concepts. For instance, they may explain different energy outputs by the varying intensity of sunlight striking the panels. Such investigation activities not only engage students in inquiry-based learning but also familiarize them with experimentation—a critical skill for both scientists and engineers (Chao et al. 2017). We have included several assessment tools (see "On the web") to make sure the students have an understanding of the underlying science.

Tackling the design challenge (days 6–9)

The design requirements typically include a target amount of energy generation, a reasonable payback period, and minimal negative impact on curb appeal. Constraints include budget, non-removable existing structures, and fire code compliance. Assisted by the modeling tools in Energy3D, students can quickly visualize their design ideas, analyze the energy outputs of their designs, and estimate the costs and return on investment of the proposed system.

We also provide a design guide to facilitate the initial design cycle, a design journal template to aid the design process, and a design report template to structure the presentation of design artifacts and rationales (see "On the web"). The design journal template requires students to record each design iteration, lessons learned, and plans going forward. Through these reflections, students gain a deeper understanding of the relationships among design variables and become more informed in making design choices.

A design performance scoring rubric is available (see "On the web") to assess students' levels of performance across multiple dimensions: the quality of students' designs, mastery of relevant concepts and skills, engineering principles, ability to reflect and

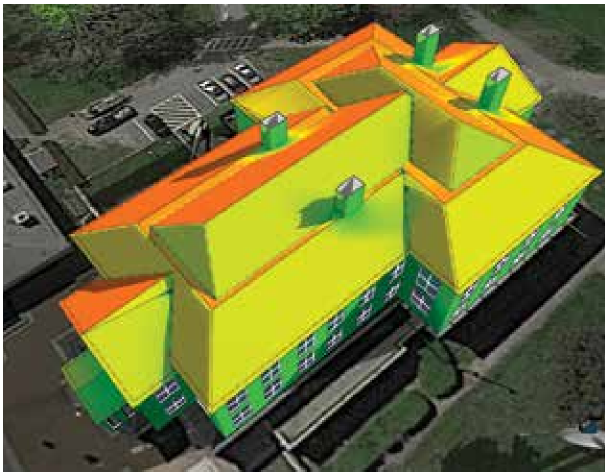
FIGURE 5

Sun path simulation.

make thoughtful decisions, modeling skills, sense of responsibility, and demonstrated effort. The rubric describes each level of performance on a particular dimension. For example, to be rated as accomplished along the engineering principles dimension, students must "explore multiple solutions. Their innovative thinking develops and expands during project" (see "On the web").

FIGURE 6

Solar irradiance heat map.



Presenting, publishing, and advocating (day 10 and beyond)

Finish the project by sharing it during an in-class presentation, a poster session in the cafeteria or shared space, a presentation to the school council, or a showcase in a science fair. Last but not least, encourage your students to submit their designs to the Virtual Solar Grid, where their contributions will be shared with the world.

Classroom implementation results

As of March 2018, 11 teachers from five high schools and three middle schools (a total of 464 students) have included Solarize Your School or adapted versions in their classes or afterschool programs. Our analysis of selected students' design reports showed that the majority of students understood the relevant science concepts (e.g., Sun path, insolation) and improved their designs accordingly. However, transferring that knowledge to other contexts was still difficult without explicit instruction and deliberate practice, as reflected in the pre- and post-knowledge assessments. We recommend supplementing the project with activities that promote knowledge transfer.

Of the 178 students who responded to our exit survey, 75% recommended the project to other students because they found the project enjoyable, informative, highly relevant, and stimulating. This recommendation rate was consistent across gender groups (75% for girls and 76% for boys). Some gaps ex-

FIGURE 7

Current world map view of solar energy projects posted in the Virtual Solar Grid and their aggregated outputs.

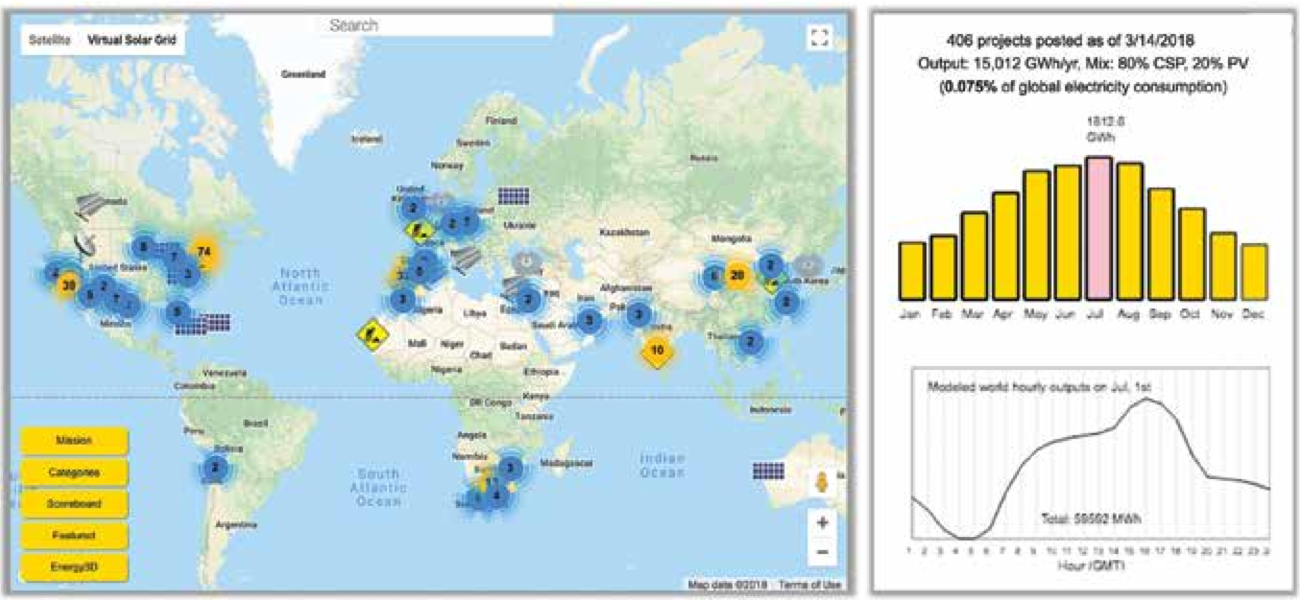
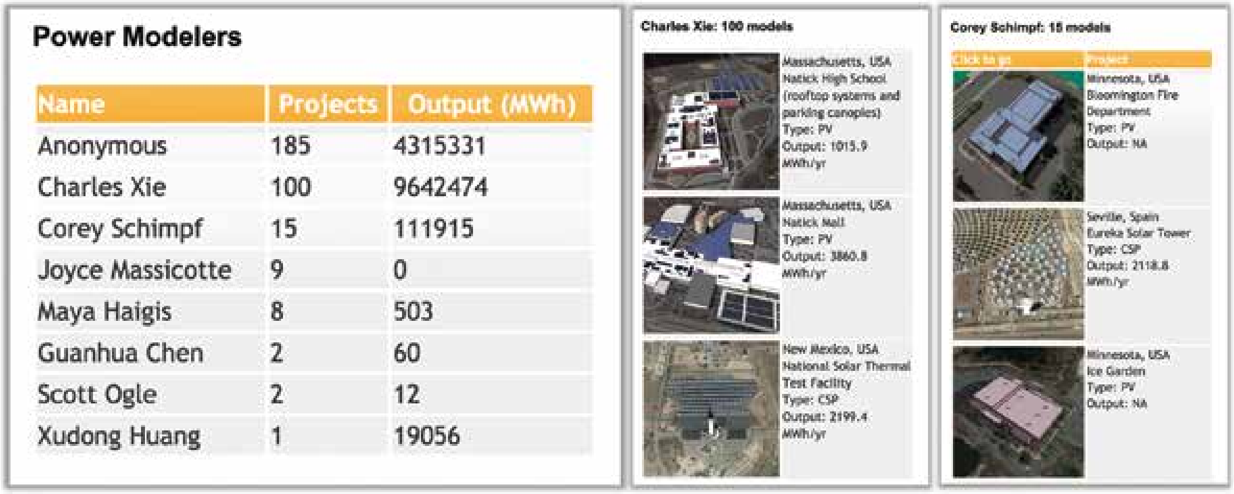


FIGURE 8

Solar power system designs submitted by modelers from all over the world.



Power Modelers

Name	Projects	Output (MWh)
Anonymous	185	4315331
Charles Xie	100	9642474
Corey Schimpf	15	111915
Joyce Massicotte	9	0
Maya Haigis	8	503
Guanhua Chen	2	60
Scott Ogle	2	12
Xudong Huang	1	19056

isted between ethnic majority (79%) and minorities (71%) and between 11th-grade engineering classes (82%) and 9th-grade science classes (74%), but these differences were not statistically significant.

However, in "inclusion" classes with many students on individualized educational plans, the recommendation rate (48%) was significantly lower than "college prep" classes that had a normal range of achievement levels (78%). Teachers who attempted this project in "inclusion" classes experienced many one-on-one tutoring demands. Many curriculum materials on the project website were developed to accommodate these high-need classrooms. For example, the lecture slides present step-by-step instructions with software screenshots and can be printed as handouts for students to follow on their own.

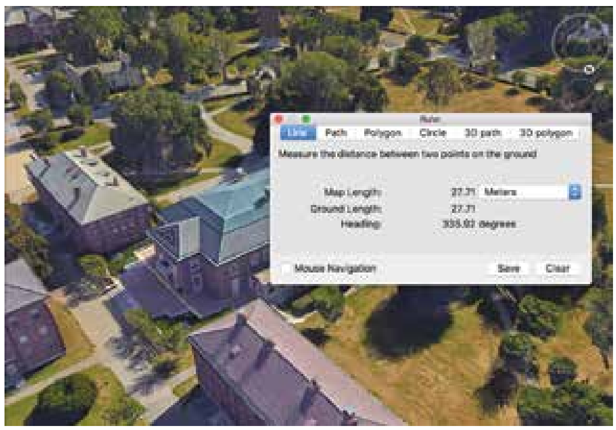
The teachers unanimously considered the project an exceptional approach to deepen student learning and expose them to authentic engineering challenges. As one teacher commented, "This curriculum gives the students a more accurate portrayal of their design, it is far more interactive, they learn a tremendous amount more about solar science in general (heat distribution on the roof, sun angles, panel angles, solar offset, etc.)."

Classroom implementation challenges and recommendations

Most of the implementation challenges stem from the novelty of the technologies and the complexity of the solar energy topic. Teachers may need to answer many conceptual and technical questions from students, especially those with special needs and English learners. To create an accessible learning environment, consider these strategies suggested by our participating teachers:

FIGURE 9

Measurement tools in Google Earth Pro.



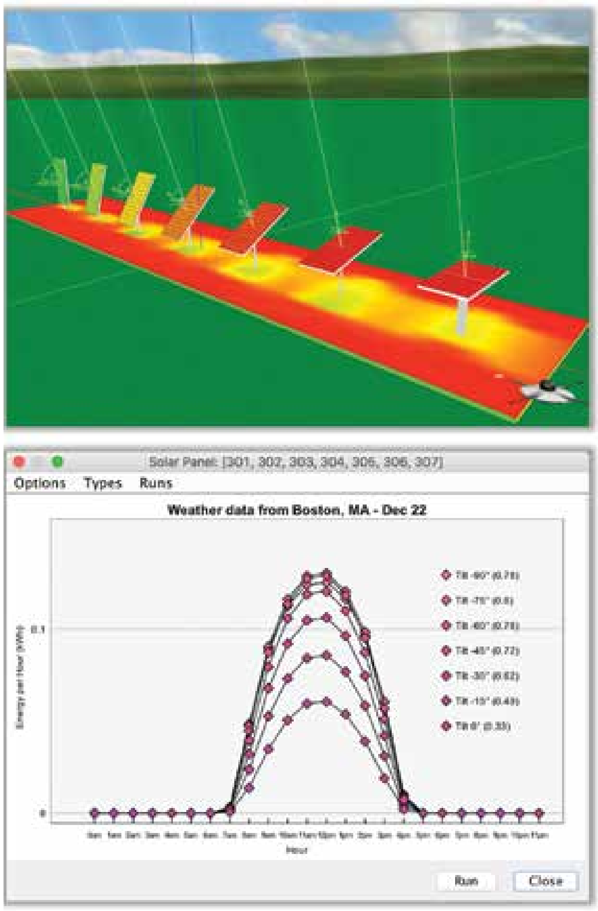
1. Implement frequent classroomwide sharing and discussions to address common issues and questions;
2. Frequently assess students' mastery of key concepts and skills using quizzes and prompts and address any gaps immediately;
3. Recruit highly capable students as your teaching assistants to help struggling students;
4. Assign short, step-by-step tutorials (available on the project website) to struggling students to help them master the basics before approaching the design challenge.

Another implementation challenge is less visible but may generate significant, long-lasting impacts on students. Research shows that in many engineering classrooms, underrepresented groups such as girls and racial minorities frequently take on the roles of note-takers and report-writers instead of designers, testers, and analysts (Tonso 2007). Such narrow experiences not only deny them the opportunities to develop a full range of design skills but also perpetuate the stereotypes of engineering careers among all students (Margolis and Fisher 2002). Consider several strategies to create an equitable learning environment:

1. Assign the entire design challenge or parts of it as individual work;
2. If students work in teams, implement a schedule for students to switch roles;
3. Explicitly encourage underrepresented groups to participate in classroomwide discussions.

FIGURE 10

Investigating the effect of tilt angle on the energy output of solar panels.



Adaptations

If your school already has a solar power system, students could model the existing system, analyze its performance, and then propose alternative designs or expansion plans. If time is limited, you could create the school model on your own or invite some tech-savvy students to create it in advance. If your school buildings are too complicated, you may contact the Energy3D team (*energy@concord.org*) to request a free modeling service. ■

ACKNOWLEDGMENTS

This material is based upon work supported by the National Science Foundation under Grant No. 1512868 and General Motors under Grant No. 34871079. We also thank the teachers and students who participated in the pilot testing of this curriculum for their support and feedback.

ON THE WEB

Design guide, journal, report template, and performance rubric: *www.nsta.org/highschool/connections.aspx*

Solarize Your School project website: *https://concord.org/solarize-your-school*

Virtual Solar Grid: *http://energy.concord.org/energy3d/vsg/syw.html*

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

Standard

HS-PS3 Energy
HS-ETS1 Engineering Design

Performance Expectations

- 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.

HS-PS3-3. Design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

HS-ETS1-1. Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practices	
Asking Questions and Defining Problems Analyze complex real-world problems by specifying criteria and constraints for successful solutions.	Students interpret general design requirements for a solar power system and specify criteria and constraints specific to their own schools.
Constructing Explanations and Designing Solutions Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations.	Students design and evaluate solar power solutions for their own schools.
Using Mathematics and Computational Thinking Use mathematical models or computer simulations to predict the effects of a design solution on systems and/or the interactions between systems.	Students use computer-aided design (CAD) software to model their school buildings, and design, prototype, and analyze solar power systems.
Disciplinary Core Ideas	
PS3.A: Definitions of Energy At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.	Students use visual, scientific simulations to explore the apparent movement and angles of the Sun, the distribution of solar energy on building surfaces, and the conversion of solar energy to electric energy through photovoltaic cells.
ETS1.A: Defining and Delimiting Engineering Problems Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.	Students brainstorm and discuss what factors need to be considered for their own schools to install solar power systems as well as how to quantify these factors for the purpose of evaluating design solutions.
ETS1.B: Developing Possible Solutions Both physical models and computers can be used in various ways to aid in the engineering design process.	Students use computer-aided design software to design and prototype 3D models of solar power systems as well as test, analyze, and present their design solutions using the simulations embedded in the software.
ETS1.C: Optimizing the Design Solution Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.	Students are guided to decompose design requirements into actionable and testable pieces and use a variety of tools to make trade-off decisions and optimizations.
Crosscutting Concept	
Systems and System Models Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions within and between systems at different scales.	Students explore computational models of solar energy, buildings, and photovoltaic modules to understand natural systems, artificial systems, and interconnections between the two.