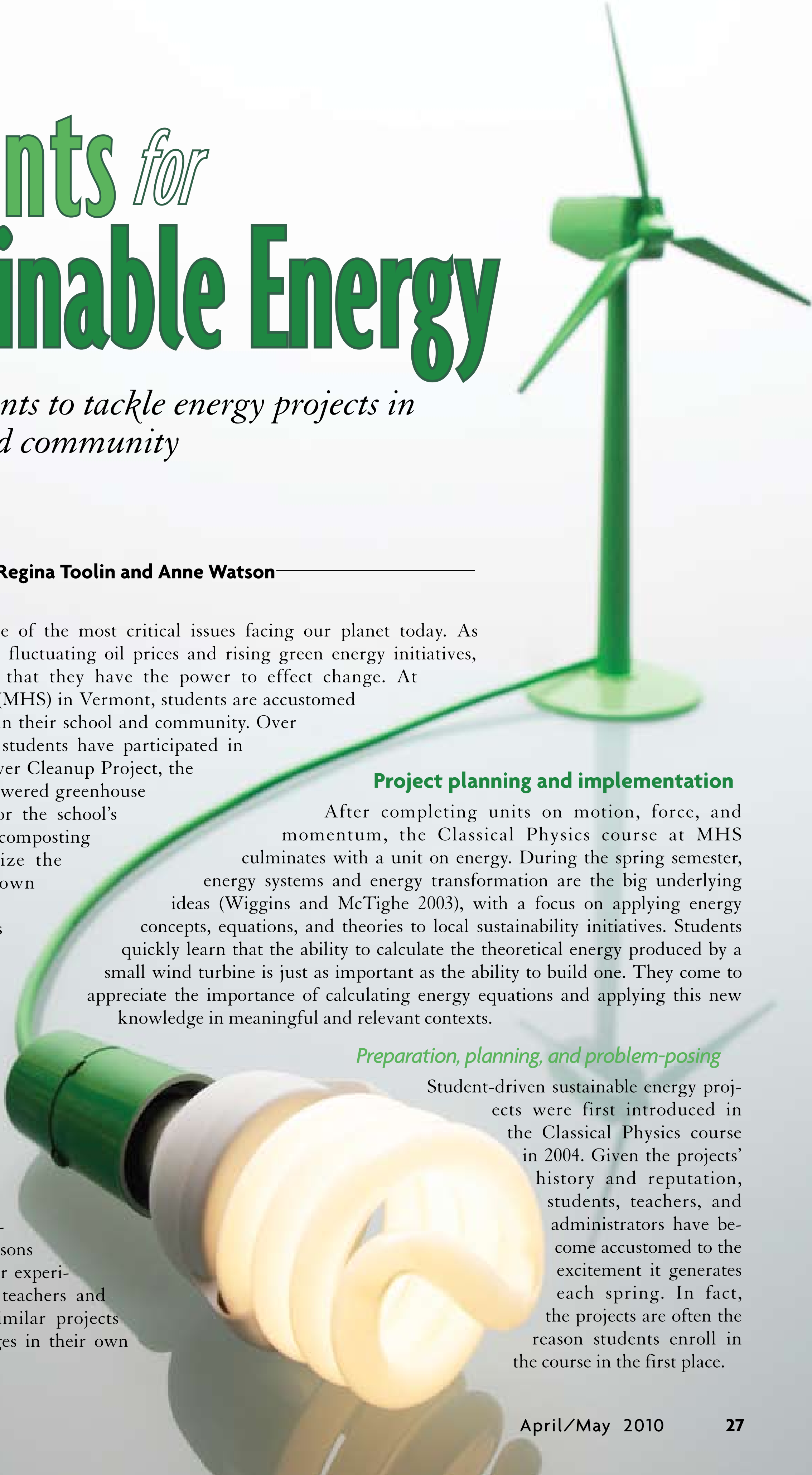
Students *for* Sustainable Energy

Inspiring students to tackle energy projects in their school and community



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Sustainable energy is one of the most critical issues facing our planet today. As the world struggles with fluctuating oil prices and rising green energy initiatives, students need to know that they have the power to effect change. At Montpelier High School (MHS) in Vermont, students are accustomed to making such changes in their school and community. Over the last six years, MHS students have participated in the Annual Winooski River Cleanup Project, the construction of a solar-powered greenhouse that provides produce for the school's cafeteria, and a thriving composting program used to fertilize the produce and plants grown inside the greenhouse.

This article describes the sustainable energy projects that MHS physics students designed during the spring semester of 2008. An overview of the project is followed by a description of the planning and implementation processes, examples of specific student energy projects, and a discussion of outcomes and lessons learned. We hope that our experiences will inspire other teachers and students to undertake similar projects and create positive changes in their own communities.

Project planning and implementation

After completing units on motion, force, and momentum, the Classical Physics course at MHS culminates with a unit on energy. During the spring semester, energy systems and energy transformation are the big underlying ideas (Wiggins and McTighe 2003), with a focus on applying energy concepts, equations, and theories to local sustainability initiatives. Students quickly learn that the ability to calculate the theoretical energy produced by a small wind turbine is just as important as the ability to build one. They come to appreciate the importance of calculating energy equations and applying this new knowledge in meaningful and relevant contexts.

Preparation, planning, and problem-posing

Student-driven sustainable energy projects were first introduced in the Classical Physics course in 2004. Given the projects' history and reputation, students, teachers, and administrators have become accustomed to the excitement it generates each spring. In fact, the projects are often the reason students enroll in the course in the first place.

Parents and community members are central to project development. Beyond being informed of project goals and objectives—through a letter and the school website—they are invited to participate in project development and to attend final presentations.

In 2008, there were 43 students—12 females and 31 males—enrolled in two sections of the Classical Physics course. Most were seniors, heterogeneously mixed in terms of their background and ability. Given the gender ratio in both sections of the course, we encouraged equitable participation in group discussions and project work. At the beginning of the energy unit, we built students' background knowledge and addressed their prior misconceptions. The first three weeks were dedicated to assessing and teaching the fundamental concepts of energy (i.e., kinetic and potential energy and conservation of energy) through inquiry, cooperative learning, and direct instruction.

Next, student projects were initiated through a brainstorming activity that examined the question "How can we reduce the need for energy or switch to alternative forms of energy consumption in the Northeast?" This activity served to spark student interest about the problems and limitations of energy resources, which led to questions about local efforts to reduce energy consumption. For example, after discussing hydropower as an alternative energy source, one student asked, "Don't we have a dam in Montpelier? Do you think it could be used to generate electricity? How much energy? Would the cost be worth it?" Similarly, after a discussion on the kilowatt usage of electric appliances, one student announced, "I bet the school's walk-in refrigerator uses a huge amount of energy. We could save a lot of energy and money by replacing it." From comments and questions such as these, the class developed a menu of possible projects to pursue (Figure 1).

FIGURE 1

Sustainable energy projects.

Project title	Goal	Artifact or product
Solar hot water	Construct and estimate payback period of a solar hot water system.	Prototype
Hybrid cars	Compare hybrid car energy use with conventional car energy use.	Efficiency and feasibility report
Photovoltaic systems	Educate public about photovoltaic systems.	Efficiency and feasibility report
Wind turbine	Construct power-producing wind turbine. Estimate the payback period.	Prototype
Undershot water wheel	Construct power-producing undershot water wheel. Estimate payback period in the Montpelier section of the Winooski River.	Prototype
Connecting two segments of Montpelier bike path	Estimate carbon and financial payback of bike path through Montpelier.	Efficiency and feasibility report
Pyromex waste gasification	Evaluate benefits and hazards of a proposed power generation system for Montpelier.	Presentation to city planner
Refurbishing a derelict electric car	Refurbish an electric car used by the school.	Restored electrical system
Montpelier's hydroelectric dam	Evaluate potential power-generating capacity and financial payback of a local dam.	Efficiency and feasibility report
Creating an additional bus route in Montpelier	Collect data on student interest in a new bus route in Montpelier.	Efficiency and feasibility report
Creating an additional bus route from Montpelier to Burlington	Collect data on student interest in and potential energy savings of a new weekend bus route from Montpelier to Burlington, Vermont.	Efficiency and feasibility report
Montpelier High School's walk-in refrigerator	Evaluate efficiency of the school's walk-in refrigerator.	Efficiency and feasibility report
Refurbishing a bicycle-powered lightbulb system	Refurbish a bicycle generator. Calculate the power-generating capacity and payback period.	Efficiency and feasibility report
Pellet heating systems	Compare and educate public about pellet heating systems.	Efficiency and feasibility report
Electric efficiency for homeowners	Educate public about appliance efficiency. Calculate energy savings.	Efficiency and feasibility report

Project teams were then formed according to common interests that emerged during the brainstorming activity. Driving questions (Weizman, Schwartz, and Fortus 2008) were generated by each team and served to focus each project. As students engaged in problem-posing (e.g., "How much energy does this lightbulb use?" and "How can I make this fan generate electricity?"), they realized that learning new science concepts would be necessary to move forward in their projects. Whenever more than one group had a question regarding the same concept, we introduced all students to the concept through a brief lesson. In this vein, project-based science not only provided motivation for learning new material but also for revisiting old material.

In preparing for these projects, standard safety practices were implemented. We "identif[ied] risks that [could] put students into harm's way" (Roy 2009, p. 12) and required that all students wear personal protective equipment (PPE) when working with tools and equipment. The safety precautions taken for each project were varied. For example, using power tools to construct wind turbines and solar panel boxes required the use of goggles or safety glasses and gloves (actual construction may also require hard hats), modeling of appropriate equipment use, and special instruction and supervision by the industrial arts teacher. Refurbishing the school's electric car also required supervision by a certified electrician and teacher to properly install potentially dangerous 12V batteries. For these and other projects, appropriate experts were consulted to ascertain and implement the proper safety precautions. However, because it is ultimately the classroom teacher's responsibility to ensure safe practices, all procedures—even those suggested by experts—were checked in accordance with board of education safety policies, legal safety standards, and best safety practices and approved by the teacher. (**Safety note:** If students are working with acid batteries, an eyewash station within 10-second access is required, along with appropriate PPE.)

Project implementation

Actual project work began in the fourth week of the unit and was defined by the following introduction:

> As American society approaches its limits involving natural resources, energy has become one of the most important topics of our time. If we are to achieve sustainability, we will need to re-vision the future and change our energy policies and practices. This project is an opportunity for you to be a part of that change. The goal is to research a question of interest regarding energy sustainability, draw some conclusions about your research—based at least in part on your knowledge of physics concepts and calculations—and present your findings to the class and community.

We provided students with a set of flexible project criteria that addressed essential science standards, concepts, and skills—this was key to the success of the student-initiated projects. During a class brainstorming session, students helped develop a project rubric. The rubric included a detailed description of the project, consultation with a community expert, and a discussion of the underlying physics concepts. (**Editor's note:** This rubric can be downloaded online [see "On the web"].) Students were also evaluated on the projects' professionalism and a discussion of its feasibility and potential obstacles.

Community experts from local businesses played a valuable role in contributing to the success of student projects. Over the last six years, we have developed an expanding list of contacts that includes parents, representatives from local businesses, and the city planning commission. Beyond the list of contacts we provide, students have found their own experts through car dealerships, out-of-state companies, additional parents, and school employees. Students also used the internet, when appropriate, to gather information.

Most experts interacted with students via e-mail or phone. Others, such as the certified electrician, actually came to the school to help with student projects. Prior to contacting any organization, students were instructed on proper etiquette and procedures for contacting and interacting with professionals. They were also directed to report any issues encountered to the classroom teacher; issues were few and were mostly limited to lack of phone call or e-mail response. Students did not give out personal information or meet anyone in person without teacher approval.

Project example

All of the student-designed projects were engaging and informative. However, one project deserves a closer look—it was conducted by a team of three students that studied the efficiency and feasibility of restoring the hydro-turbine at the Lane Shops Dam in Montpelier (see photos, p. 30). The team's goal was to research the dam's operation and calculate the energy efficiency, environmental impact, and payback period needed to restore the hydro-turbine; the "payback period" refers to the time necessary to recoup the initial investment. Consultation with the town planner revealed the hydro-turbine's basic components and operation as well as essential data to calculate energy efficiency, impact, and payback. The team obtained the yearly average flow rate and height of the dam to calculate the number of kilowatt hours (kWh) that would be generated by the dam per year (Figure 2, p. 30).

Through information obtained from the team's expert (i.e., the town planner), students found that Montpelier would require approximately 476 million kWh per year for its electricity needs. Students calculated that the restored dam could produce 893,000 kWh per year—

FIGURE 2

Energy calculations for the hydro-turbine at the Lane Shops Dam in Montpelier.

Yearly average flow rate	3.88 m^3/sec = 3,880 kg/s = mass
Gravity	9.80 m/s^2
Height	3.35 m
Efficiency coefficient (α)	0.800 (80%)
Formula	Power= $Mgh\alpha/t$ = J/s = watts
Calculation	102,000 W = 893,000 kWh per year

PHOTO COURTESY OF LUKE MARTIN

The Lane Shops Dam in Montpelier.

PHOTO COURTESY OF ANNE WATSON

A student measures the height of the Lane Shops Dam.

enough electricity for 218 working couple households, 290 single person households, or 165 households with two children. Finally, if the estimated cost to restore the dam was $500,000 with a kWh cost of $0.13, students determined that about $116,000 per year would be saved by the restored hydro-turbine with a payback period of 4.3 years.

Project assessments

Performance, self-, and peer-assessments are integral to evaluating student understanding and achievement in the project-based classroom. In the early phases of the project, students were engaged in a brainstorming session to determine the essential criteria for project performance. The following questions summarize the outcome of this session and became the rubric criteria (see "On the web") by which students were evaluated for the sustainable energy project:

- What are your driving questions and goals?
- What is your plan?
- What are your results?
- What are your recommendations?
- What is the science behind it all?
- Who are your references and consultants?
- How well do you convey your ideas?

There were varying degrees of frustration along the path to success for students involved in the energy projects. For those who built prototypes, for example, trial and error was often the best teacher. In analyzing class evaluation data for the project, 14 out of 16 project teams met or exceeded all standards for the project.

Another essential feature of project-based learning is the opportunity for students to participate in an open-ended survey to assess overall project goals and objectives. In our classes, this included the following questions:

- What did you find most valuable about your project work?
- What recommendations would you offer to improve the project?
- What makes this project different from others you have done in this or other classes?

In the survey, students reported being motivated by their ability to build a hands-on model and to discover the relevance of their projects to global and local energy issues. A student engaged in the walk-in refrigerator project (Figure 1, p. 28) wrote, "It was a real-world project. We had the ability to improve the efficiency of an aspect of our school." A student involved in the home electrical efficiency project (Figure 1) was excited by the fact that "little changes could really add up and save a lot of money." Still another student who took part in the pellet stove project (Figure 1) commented that her project would help to "make the world a better place on a small scale."

Students had various responses to the question "What makes this project different from others you have done in this or other classes?" Many appreciated that the projects had to do with the "real world" and that "it connected to a real-life situation." One student summed up her experience with the following quote: "It meant something to me. I was passionate about the outcomes. And, the outcome was not just a grade."

Elements of project-based learning.

Good project-based learning experiences include

- a rich, complex driving question that is relevant to students' lives,
- production of artifacts,
- student-centered learning,
- collaboration,
- accountability,
- use of technology,
- appropriate safety considerations,
- interdisciplinary and cross-disciplinary inquiry,
- extended time frame, and
- reliable performance-based assessment.

THIS LIST IS ADAPTED FROM COLLEY 2008

Outcomes and lessons learned

Engaging in student-initiated projects often requires teachers to relinquish the role of expert and let others step in. In the project-based classroom, the teacher becomes a manager or coach who learns alongside students and directs them toward worthy and credible resources. Often, the most successful projects involve a community expert who is as invested as students are in the project. Teachers should be prepared to help students generate a sizeable list of experts and resources. When new project topics emerge, students should be encouraged to find the appropriate source on the internet or in the local community. With guidance, students learn to critically evaluate sources of information.

To effectively manage the implementation of a vast number of student projects over time, teachers must be on board with every project and commit to guiding students through each phase. The establishment of milestones throughout a project is essential. Milestones help students readily complete project tasks and help teachers provide frequent formative assessment and feedback. Teachers considering such projects for the first time might have multiple student groups work on the same question. This allows groups to compare project plans and results and thus learn from one another.

Projects of this nature can be conducted on a limited budget. Our entire budget for 16 projects was approximately $150. Feasibility studies—such as those described in Figure 1—can be conducted with little to no expense. Materials needed to build prototypes can be donated or acquired at a local hardware store for a small cost.

Most of the projects undertaken in 2008 entailed residential-scale changes. By inviting parents and the community to listen to project presentations, students had the opportunity to speak directly to an audience for whom their work was most meaningful. Ultimately, it is the parents and adults who make decisions about whether to buy a pellet stove or solar hot water heater, or conduct a weatherization audit. Through these presentations, families in the Montpelier community became more educated about local issues and thus were more likely to make informed decisions about home-based energy consumption.

Students who addressed current civic concerns, such as restoring the local dam or the waste gasification project, were invited to share their results with related decision-making committees. This helped the community's decision makers to be more informed; it also communicated to students that their education is valuable and that adults do care about what they have to say. In addition to learning important physics concepts, students came to understand the applications of these ideas to important community, national, and global issues.

Conducting long-term, standards-based projects that are interesting and relevant is essential to science teaching and learning today (Krajcik, Czerniak, and Berger 2002). The projects described in this article are a means to engage students in true scientific inquiry. By posing and answering questions that are relevant to their own lives and communities, students ultimately produce tangible products that can have meaning far beyond the walls of the science classroom (Colley 2008). ■

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NSTA connections

For more information on energy, see the "Energy: Energy Transformations" NSTA Science Object. NSTA Science Objects are online, inquiry-based content modules for teachers that are free of charge. For more information, visit *http://learningcenter.nsta.org/products/science_objects.aspx*.

On the web

Sustainable energy project rubric: *www.nsta.org/highschool/connections.aspx*

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