NEXT STEP LEARNING: BRIDGING SCIENCE EDUCATION AND CLEANTECH CAREERS WITH INNOVATIVE TECHNOLOGIES

RATIONALE

The Next Generation Science Standards (NGSS Lead States, 2013) envisions "three-dimensional learning" in which the learning of disciplinary core ideas and crosscutting concepts is integrated with science and engineering practices. A goal of the NGSS is to make science education more closely resemble the way scientists and engineers actually think and work (National Research Council, 2012). To accomplish this goal, an abundance of opportunities for students to practice science and engineering through solving *authentic* real-world problems will need to be created and researched. If these learning opportunities are meaningfully connected to current industry practices, they can also increase students' awareness of cognate careers, help them construct professional identities, and prepare them with knowledge and skills needed by employers, attaining thereby the goals of both NGSS and ITEST simultaneously.

While there have been studies on connecting science to everyday life or situating learning in professional scenarios to increase the relevance or authenticity of learning (e.g., Bouillion & Gomez, 2001; Hofstein & Kesner, 2006; Hurd, 1998; Kwiek, Halpin, Reiter, Hoeffler, & Schwartz-Bloom, 2007; Rivet & Krajcik, 2008; Strobel, Wang, Weber, & Dyehouse, 2013; Wiser & Amin, 2001), the strategies of using industry-grade technologies to strengthen these connections have rarely been explored. In many cases, often due to the lack of experiences, resources, and curricular supports, industry technologies are simply used as showcases or demonstrations to give students a glimpse of how professionals use them to solve problems in the workplace. In this project, the Concord Consortium (CC), Next Step Living (NSL), and the Virtual High School (VHS) will join forces to put innovative technologies into the hands of thousands of secondary students and create a technology-enhanced learning pathway from school to home and then to cognate careers, establishing a data-rich testbed for developing and evaluating strategies for translating innovative technology experiences into consistent science learning and career awareness in different settings.

CC is **an innovator in educational technology** whose work has impacted millions of students. A unique feature of the CC technologies to be used in this project is that they are either based on industry technologies such as infrared (IR) thermography or similar to industry practices such as computer-aided engineering (CAE) using computational fluid dynamics (CFD). Unlike many industry technologies, however, these CC technologies were designed to support learning at precollege levels. Some of them have been successfully used by thousands of students and have created impacts in the education community. For example, the *Journal of Chemical Education* acclaimed our IR experiments as "captivating, intriguing, and thought-provoking" (Jacobsen & Slocum, 2011). Dr. Jonathan Nathan at Ben-Gurion University in Israel called our Energy2D CFD software "the best computer-based tool I have found so far [compared with MATLAB and Mathematica]" for helping high school students "quickly check out ideas and learn from intuition and not only from equations." Despite their simplicity of use, these CC technologies are sufficiently sophisticated for serious science and engineering applications (Heagney, 2013; Mallard, 2013; Xie, 2011, 2012c, 2014).[1] As a result, the technical competency that students acquire from using them will likely translate into skills on employers' wish lists. NSL is **an Inc. 500 company** (in both 2013 and 2014) that provides comprehensive home energy solutions in New England. NSL was named a 2014 Global Cleantech 100 company and received a Hire Power Award from the Inc. Magazine for "leading the way in creating American jobs."

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[1] For instance, many scientists and engineers have found Energy2D (Figure 2a/b) useful in their work. Among dozens of people who wrote appreciation emails to us, Dr. David Bobela, an engineer at Protoflex Corporation and a former postdoc researcher at the National Renewable Energy Laboratory, commented: "This software seems well suited and saves us the $$ of buying something like COMSOL." Arash Soleimani, a system engineer at Bombardier, also testified about its usefulness: "It is indeed [an] excellent tool for simplified 2D problem... Your tool (with some improvement) can find vast marketing opportunity in industrial applications very quickly." Today, Energy2D has become one of the most popular software for thermal analysis, currently listed as No. 1 in Google search for "heat transfer software."

NSL has launched the Sustainable Energy Education Drive (SEED) Program that aims to empower students to enact sustainable changes to their campuses and communities. VHS is **a collaborative of 735 member schools** that has provided high-quality online learning for over 15 years. VHS develops and delivers standards-based, student-centered online courses. Combining the unique strengths of these partners, this project will respond to an important ITEST objective emphasized in the **ITEST Solicitation**: "*Strongly encouraged are projects that actively engage business and industry to better ensure K-12 experiences are likely to foster the skill-sets of emerging STEM and cognate careers*."

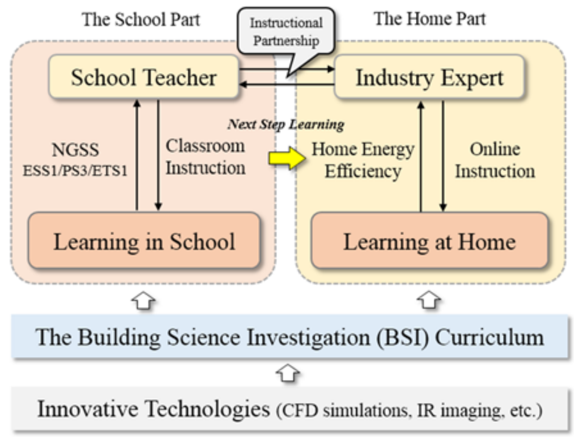


Figure 1. The blended learning model of this project will involve teachers and industry experts through classroom and online learning, respectively. This model will be supported by an integrated curriculum enhanced by innovative technologies that serve as the "connecting tissues."

GOAL AND OVERVIEW

The goal of this project is to develop and test an education model that fuses science learning in school and energy efficiency at home using CC's innovative technologies, NSL's industry expertise, and VHS's online capacity. Student learning in this project will consist of two parts, in school and at home, supported by the same set of technology as illustrated in Figure 1. More than 2,000 students from diverse socioeconomic backgrounds in over 10 middle and high schools across Massachusetts will participate in this research to take the *next step learning* beyond the classroom. They will learn and apply science and engineering concepts and skills required by NGSS ESS1 (Earth science related to seasons), PS3 (physical science related to energy and heat), and ETS1 (engineering, technology, and applications of science), using home energy efficiency as a driving force. A distinguishing feature of this project is that students will use infrared cameras, sensors, simulations, and mixed-reality technologies to visualize, investigate, and design invisible heat and mass flows in real and virtual worlds. These technologies enable students to not only learn science concepts through inquiry and design activities in classrooms, but also deepen their understanding through performing quantitative thermal analyses of their own homes. The latter practice will provide cleantech career education as students gain firsthand experiences through playing the role of an energy specialist *realistically*. For these technologies to effectively support and integrate classroom and home learning, a new curriculum *Building Science Investigation* (BSI) will be developed to align their applications with education and industry standards, classroom and online instruction, and educational assessments. The entire learning process from school to home will be scaffolded by the BSI Curriculum. The home part will be assigned and graded as homework. All student data will be collected through the Internet and sifted to measure the effectiveness of the technologies and the curriculum on improving outcomes of student learning and stimulating their interest in cleantech careers. Research on the effect of innovative technologies on career motivation will be guided by the Social Cognitive Career Theory (Lent, Brown, & Hackett, 1994). Research will also address how technologies can support teachers and involve industry more deeply.

STRATEGIES AND OBJECTIVES

This project will create a strong education-industry partnership using the following strategies:

1. **Collaborate with industry on curriculum development**. CC and NSL will jointly develop the BSI Curriculum to meet both NGSS and Building Performance Institute (BPI) standards. NSL's BPI-certified experts will ensure that the curriculum results in authentic experiences and skill development through conducting meaningful home energy experiments and assessments using the provided technologies. To maximize the compatibility with industry procedures and formats, the *Home Performance XML* (HPXML) schema defined in BPI-2100-S-2013 (Building Performance Institute, 2013) will be

used to standardize the data students collect, whenever applicable. The adoption of these industry standards in the BSI Curriculum will not only increase its integrity in building science, but also provide consistent technical data for assessing student performance more reliably.

2. **Build an instructional partnership with industry**. As most teachers will not have the expertise or time to guide student work after students move to the home part of the BSI Curriculum, NSL's experts will join the teachers to provide online mentoring to students through VHS's online learning services. This instructional model exploits the expertise and resources available at the three partners to create opportunities for students to interact with industry experts through the Internet so that their technical questions can be answered, their experimental results can be checked, and their project reports can be appraised. Based on the student data and outcomes in these online activities, the experts will provide inputs to the teachers for grading student work and making instructional decisions.

The objectives of this project are as follows:

1. **Develop the BSI Curriculum that scaffolds student activities**. The curriculum will be Web-based, free, and flexible for use in different grades. *The school part* will comprise four units in basic science: "**Thermal Energy**," "**Heat Transfer**," "**Solar Energy**," and "**Building as a System**." These four units will cover the NGSS standards ESS1, PS3, and ETS1 and prepare students for the next step learning in the home part. As most of the content in the four units is widely taught at the secondary level[2], these units can replace current classroom instruction on the related topics, which typically takes 2-4 weeks in many of the participating schools (Table 1). A teacher guide for implementing these units at different grade levels will be provided. *The home part* will comprise four units on building science: "**Home as a Lab**," "**Home Energy Inspection**," "**Insulation, Weatherization, and Renewable Energy**," and "**Green Building**." Students will start with discovering common thermal phenomena in a home, such as the vertical temperature gradient due to natural convection (which contributes to heat loss through the attic), and then connecting their findings back to what they have learned in school. These units will gradually engage students to apply their knowledge and skills learned in the classroom to investigate energy efficiency problems of their homes and find solutions. A guide will be provided to inform parents or guardians of the educational purposes, experimental procedures, and possible risks (minimal) of the home activities. The home part will take a minimum of eight hours to complete. The entire BSI Curriculum will require 2-3 students to collaborate throughout, as some of the experiments can only be conducted by multiple students (e.g., Figure 2c).
2. **Power the BSI Curriculum with innovative technologies**. The BSI Curriculum will extensively use a combination of technologies such as sensors, infrared

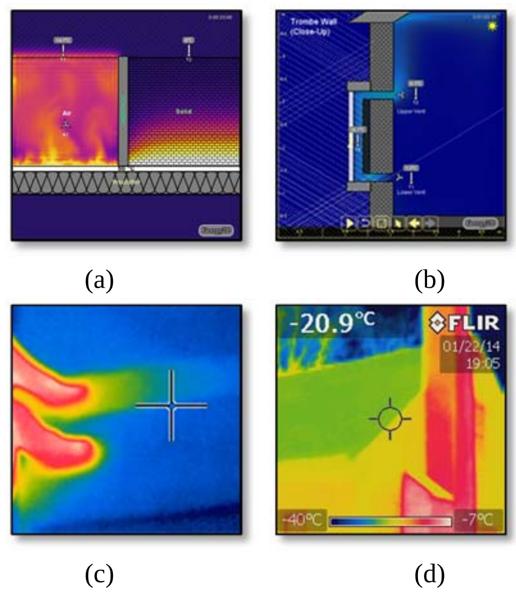


Figure 2. (a) Basic science with Energy2D: A CFD simulation that compares convection and conduction. (b) Home connection: A CFD simulation that shows how a Trombe wall circulates the heat converted from solar energy. (c) Basic science with an IR camera: A hands-on experiment that shows the difference of wood and metal in conducting thermal energy, using two fingers as identical heat sources. (d) Home connection: An IR image that shows the energy loss through a chimney on a cold evening (no fire was lit in the fireplace at the time this image was taken).

[2] For example, the concepts of thermal energy transfer are explicitly required by NGSS MS-PS3-3 and HS-PS3-4. They are covered in many textbooks such as Active Physics' *Designing the Universal Dwelling*, Prentice Hall's *Focus on Physical Science* (Chapters 5 and 6 in Unit 1), and CPO Science's *Foundation of Physics* (Chapters 25 and 26).

cameras,[3] science simulations, and computer-aided design (CAD) software to support both content learning and science and engineering practices. For example, our Energy2D simulation software (Xie, 2012b) can cover basic science concepts such as conduction, convection, and radiation (Figure 2a), but it can also be used to design solar architecture (Figure 2b). Similarly, IR cameras are used in home energy inspection (Collins, 2008; Snell, 2010), but they are also extraordinary tools for visualizing invisible science concepts (Figure 2c). These hardware and software will be packaged as a **BSI Kit** that can be configured to conduct real, virtual, and mixed-reality experiments (Xie, 2012a). These experiments will be the core parts of the BSI Curriculum. More than $80,000 has been budgeted to equip 160 BSI Kits to support the participating schools on a rotating basis.

3. **Collaborate with teachers to implement the school part**. Nearly $120,000 has been set aside in our budget to support the participation of teachers scheduled in the following timeline. In Year 1 (8/1/2015-7/31/2016), CC and NSL will work with 10 pilot teachers to develop, test, and improve the BSI Curriculum and the research instruments iteratively. To move the curriculum into classrooms at a larger scale, in the summer of Year 2 (8/1/2016-7/31/2017), we will provide a three-day professional development workshop for 20 teachers. This workshop will be repeated in the summer of Year 3 (8/1/2017-7/31/2018) for 40 teachers. Through these workshops, teachers will learn about the curriculum, the enabling technologies, the pedagogical strategies, and the industry connections. Business leaders in the cleantech industry will be invited to speak at these workshops to provide additional perspectives and inspirations. In collaboration with these teachers, the school part will be implemented in the following autumns in Years 2 and 3, setting the stage for the home part in the winters (when the indoor-outdoor temperature difference is significant enough for the thermal experiments to yield pronounced results).
4. **Implement the home part and provide equipment and online support**. Each team of students will take a BSI Kit home. For those without a computer at home for data collection and analyses, CC will loan computers from its 100-laptop pool with preloaded software and curriculum that can run offline. These students will log their home energy data, report their findings, and complete their work in their schools where there is an Internet connection. As described earlier, NSL experts will mentor students on the technical aspects whereas teachers will continue to oversee the overall student learning. We will set up a website to support these online activities. For students to receive timely feedback and instruction, this website will notify the mentors whenever students upload new reports or post new questions.
5. **Extend learning to industry practice**. NSL's outreach programs will provide culmination experiences for students. Motivated students will attend lessons on building and renewable energy technologies at NSL's facilities. A number of summer opportunities will be created for these students to participate in exciting, high-profile projects such as **Renew Boston**. By inspiring and preparing students in an industry environment, this project will cultivate the next-generation cleantech workforce and leaders.
6. **Engage diverse underrepresented populations**. The student population to be involved in this project is highly diverse (Table 1). For example, Lowell High School will be a major partner. Among the school's nearly 4,000 students, 63% are minorities and 70% receive free/reduced price lunches. In two other partner schools, Dorchester Academy and Josiah Quincy Upper School, 97% and 93% are minorities and 69% and 82% receive free/reduced price lunches, respectively. Our strategies to support the participation of *all* students are as follows: a) **Content accessibility**: Our technologies serve students with various mathematical abilities—compelling visualizations from either computer simulations or IR cameras will be the main instructional method for delivering obscure science concepts both qualitatively and quantitatively (Figure 2); no complex math will be required in order to succeed in this project.

[3] With the releases of two competitively priced IR cameras for smartphones, the year 2014 has become a disruptive year for thermal vision. Early in 2014, the global IR technology leader FLIR unveiled the $349 FLIR ONE, the first IR camera that can be attached to an iPhone. Months later, a startup company Seek Thermal released a $199 IR camera that has an even higher resolution and is attachable to most smartphones. These game changers can take impressive IR images just like taking conventional photos and record IR videos just like recording conventional videos, and then share them online through an app. Both companies provide a software developers kit (SDK) for a third party to create apps linked to their cameras, which this project will use to collect IR images or videos from students.

b) **Curriculum flexibility**: The home part of the BSI Curriculum will be applicable to a wide variety of homes such as apartments, single-family houses, multi-family units, town houses, and mobile homes—different versions of experiments will be devised for different types of home buildings with different configurations (e.g., if a home building lacks a feature needed in an experiment, an alternative version of the experiment will be suggested). c) **Logistic support**: As mentioned earlier, this project will lend a BSI Kit to each student group and a laptop to those who do not have a computer at home. These strategies will ensure all students, regardless of their academic and socioeconomic backgrounds, will have an equal opportunity to participate in this project.

7. **Conduct research and evaluation**. This project will measure student learning gains in two dimensions: **science learning** and **career awareness**. The research on science learning will be based on data generated by students in school and at home. These data include pre/post-test results about understanding of science and engineering concepts, constructed responses to embedded assessments, software logs, student self-reports, sensor data, and IR images. The research on career awareness will be based on student pre/post-questionnaires and interviews. Questionnaire items will draw from the *STEM Career Interest Survey* developed for middle school students (Kier, Blanchard, Osborne, & Albert, 2014) and the *Educational and Career Interest Scale* developed for high school students (Oh, Jia, Lorentson, & LaBanca, 2013). The collection of these data will strictly follow the regulations described in "Protection of Human Subjects." Sun Associates will conduct external project evaluation independently. Their project evaluation will focus on how the project partners collaborate to achieve the goal and objectives defined in this proposal and how students, parents, teachers, and industry respond to these project activities (see "Project Evaluation").
8. **Disseminate products and findings**. For the BSI Curriculum to reach more students, CC and VHS will expand it into an online short course as part of VHS's technical education program. VHS will deploy and administer it through its large collaborative network. NSL will also use a selected set of interactive visualizations from the BSI Curriculum on its website to educate the general public about home energy efficiency. For example, our software can provide interactive simulations for explaining some common energy efficiency issues that may be more interesting than text, images, or simple animations. We will also disseminate our curriculum materials and research findings through publications in peer-reviewed journals and presentations at conferences.
9. **Plan post-NSF-funding strategies**. We envision that the work of this project would lead to a cleantech education alliance sponsored by the industry. This is possible because students' investigation of potential energy savings of their own homes could convince their parents—with scientific evidence specific to their houses, *not* marketing hype—to consider retrofitting their houses or installing solar panels, indirectly creating business opportunities that benefit the entire industry, the environment, and our energy security. NSL, a cleantech leader, is already committed to sponsoring the BSI Curriculum and integrating it into its ongoing educational programs such as SEED. We will also reach out to other cleantech businesses such as SolarCity to explore incentives of collaboration in other states.

Research Questions and Hypotheses

This proposal represents a technology-based model of education-industry collaboration that aims to simultaneously achieve multiple goals in science education, workforce development, and energy efficiency. Based on data to be collected from more than 2,000 students and their teachers, this project will evaluate the effectiveness of this model, specifically around the following questions that ITEST seeks to answer (copied from the ITEST Program Solicitation with minor adjustments):

- **RQ1: What coherent sets of experiences support student competency and motivation for productive participation in STEM learning and workforce?** Our hypothesis is that student-friendly, industry-grade technologies will create coherent experiences across science learning and industry practices and, therefore, result in **strong connections and resonance between education and industry**. Guided by a carefully designed curricular and instructional model illustrated in Figure 1, this project will use a few such technologies developed by CC to test this hypothesis.

- **RQ2: What instructional and curricular models can effectively engage teachers to utilize and integrate technologies so as to enhance student understanding of STEM concepts and careers?** This project will involve at least 60 teachers from diverse schools, providing a sizable testbed for probing this question. Our hypothesis is that the experimental nature of the BSI Curriculum and its strong connections with science and engineering practices in industry situations will necessitate the use of technologies and create novel instructional possibilities for teachers.
- **RQ3: What roles can business and industry play in motivating students to become aware of, interested in, and prepared for STEM careers?** We think business and industry can and should play a greater role than occasionally showing up in outreach activities. The instructional partnership between teachers and experts illustrated in Figure 1 provides an example of how in-depth education-industry collaboration may be developed. The extensive participation of NSL throughout this project will provide an excellent opportunity to shed light on this research question. Our research will focus on finding and evaluating strategies for **integrating inherent logic and flows between education and industry practices**, permitted by the rules set in the "Protection of Human Subjects" section, to sustain and advance this education-industry partnership.

PROTECTION OF HUMAN SUBJECTS

Although NSF "strongly encourages" engaging business and industry in ITEST projects, CC's Human Subjects Institutional Review Board (IRB) was concerned about possible adverse effects of (unintentionally introduced) commercial operations on minors. After carefully reviewing our research plan, CC's IRB Committee approved our IRB protocol. Under the protection of this IRB protocol, all student participants will be given an informed consent form with which their parents or guardians will grant or deny researchers access to student data generated in school and at home. Data from the students whose parents or guardians have not consented will be eliminated from this research. All students will be assigned randomized online IDs by their own teachers with which they can log into pre-created Internet accounts to upload their experimental results, analyses, and reports (for more information, see our Data Management Plan). Students will be required *not* to disclose any personally identifiable information in their data and artifacts. Online mentoring will be provided to students strictly on an anonymous basis (i.e., only the randomized IDs are known to mentors for identifying and tracking students). The BSI Curriculum will not include any promotional materials from NSL and VHS or refer to their specific products and services. This IRB protocol, abided by NSL and VHS, will effectively **insulate all participating students and their families from any commercial operation**. For students under 18 who sign up for NSL's outreach programs, an additional consent form will be used to request the permission of their parents or guardians. Students without a signed consent form will not be included in these outreach programs.

THEORETICAL JUSTIFICATION

This project is grounded on the **Social Cognitive Career Theory** (Lent et al., 1994; Lent, Lopez, Lopez, & Sheu, 2008), which postulates that career development is influenced by self-efficacy, outcome expectations, and personal goals. The theory states that some students eliminate possible career prospects due to faulty self-efficacy beliefs or outcome expectations—the greater the perceived barriers to a career, the less likely students will pursue it. Hence, modifying faulty self-efficacy and outcome expectations can help students acquire successful experiences and open their eyes to STEM careers (Brown & Lent, 1996). The primary sources of self-efficacy include personal performance and accomplishments, vicarious learning, social persuasion, and physiological and affective states. To develop students' interest in STEM careers, learning experiences should be designed to promote their self-efficacy and outcome expectations in the related science and engineering practices. Because of the technical nature of cleantech careers, learning experiences should involve authentic applications of industry technologies, appropriately customized to entice students and help them accomplish learning goals from classroom to real-world scenarios.

The Next Step Learning model will exploit the affordances of innovative technologies to lower the barriers to science and engineering concepts and practices related to cleantech careers. For example, terminology such as thermal conductivity and infrared thermography often intimidates students and misleads them to believe they are necessarily difficult. But this intimidation will quickly dissipate after students gain hands-on experiences, skills, and confidence through carrying out simple IR imaging experiments designed to bring obscure science concepts to life. For example, by looking through the lens of an IR camera at the difference of heat transfer rates from two thumbs through a conductor and an insulator, respectively (Figure 2c), the idea of thermal conduction becomes self-explanatory. Through these experiments, students will also see how easy it is to use an IR camera to capture heat flow and apply it to detect heat losses in their homes. This outcome, in turn, can translate into self-efficacy needed to develop a long-term interest in careers related to energy auditing and building diagnostics. In addition, this project will provide opportunities for students to interact with NSL's energy experts. These authentic experiences will help students develop relatively accurate beliefs in their abilities to pursue cleantech careers. This kind of authenticity is particularly important to engage underrepresented populations in science learning as it allows them to see the true value and purpose of science in their everyday life (Basu & Barton, 2007).

Research Participants

We plan to work with at least 60 secondary teachers from more than 10 socioeconomically diverse Massachusetts schools over the three project years. Many schools have enthusiastically responded to the ideas of this project. The following public schools have expressed their interest in participating in this project (see the attached letters from teachers, schools, and districts):

School	Principal/Chair/Lead	# Teachers	Minority	Lunch Aid
Arlington Public Schools	Larry Weathers	10	17%	11%
Bird Middle School	David Kujawski	3-4	10%	9%
Dorchester Academy	Steve Nixon	2-3	97%	69%
Greenfield Public Schools	Susan Hollins	20	20%	4%
Josiah Quincy Upper School	Mark Knapp	2-3	93%	82%
Lowell High School	Roger Morneau	7	63%	70%
Mansfield High School	Kelly Melendez Loaiza	3-4	7%	7%
North Reading High School	Jess Weathers	2-3	4%	4%
Remington Middle School	June Thall	2-5	10%	9%

Table 1. Participating public schools in Massachusetts.

Two private schools, St John's Preparatory School (3-4 teachers) and Holyoke Catholic High School (1-2 teachers), are also interested. We expect more schools will join once the project starts. In total, we estimate that this project will engage at least 2,000 students.

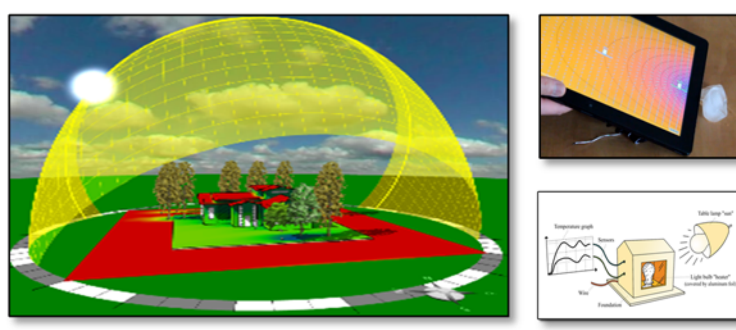


Figure 3. Left: An Energy3D simulation of the Sun path and solar radiation on buildings. Upper right: An app that uses the data acquired by a temperature sensor to drive a simulation to create a mixed-reality experience as if heat could flow into or out of the tablet screen. Lower right: An experiment to measure the energy usage of a scale model house using temperature sensors.

Prior Work

This proposal is based on the following prior work of the partners:

1) Enhancing Engineering Education with Computational Thinking (NSF 0918449, $2,191,552, 10/2009-9/2013, PI: Xie). **Summary of results**: This project has developed two computational tools, Energy2D (Figure 2a/b) and Energy3D (Figure 3a), and the *Engineering*

Energy Efficiency Curriculum (which guides students to learn science and engineering through designing, constructing, and testing a scale model house iteratively with maximizing its energy efficiency as the goal—see Figure 3c). The project has also demonstrated the concept of desktop remote sensing using IR technology. These technologies lay a solid technical foundation for this proposal. **Intellectual merit**: This project studied how computational tools can be used to infuse science into engineering activities and thus deepen learning. The interactive, visual simulations developed by this project remove the barriers to learning due to difficult math that often stymies conceptual understanding. **Broader impacts**: The work of this project has been featured on *NSTA Reports*, *Physics Teacher*, *Norrköpings Tidningar*, and *Journal of Chemical Education*. The project website currently attracts approximately 6,000 unique visitors each month (as of October 2014). **Publications**: Seven peer-reviewed journal papers (including a cover paper and a featured paper), one book chapter, and five conference presentations.

2) Next Step Living. Founded in 2008, NSL has grown into a workforce of more than 800 employees. NSL partners with over 400 municipalities, civic organizations, and leading corporations to deliver energy-efficient and environmentally friendly solutions to residents in Massachusetts and Connecticut. Currently, NSL is cooperating with Boston to "greenovate" the city (Boston Mayor's Office, n. d.). In collaboration with Lincoln-Sudbury Regional High School and Newburyport High School (which will also join this research), NSL's SEED Program has successfully engaged more than 2,000 students in energy education. According to Michael Parent, Principal of Newburyport High School, "SEED was the perfect vehicle for both civic engagement for our students and a green initiative for the city." Through SEED, Newburyport High School has turned students into energy educators and saved residents nearly $40,000 in energy spending.

3) Green Energy for Urban Students. Supported by the U.S. Department of Energy under grant DE-FOA-0000152 ($45,000), this project was implemented by VHS with 29 students at the Hartford Academy of Engineering and Green Technology in Connecticut in 2012. The project used a three-part approach: classroom learning in science, online courses in technology, and internships with businesses. Student and teacher feedback showed that the students were more engaged, and the online experiences and apprenticeships opened their minds to STEM careers. Two online courses were developed to connect formal learning and workforce development. The course entitled "Mathematics of Electricity," for example, helped students learn math by grounding it in real-world applications, with practical problems that helped them learn math and science from a career perspective.

THE SUPPORTING TECHNOLOGIES

This project will use the following technologies (some have never been used at such a large scale in education):

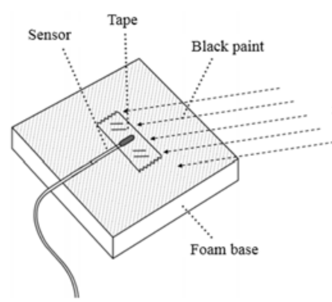


Figure 4. The temperature sensor in the BSI Kit can also be used to approximately measure the intensity of visible light or thermal radiation.

- **Sensors**. CC has over **30 years of research experiences with sensor technologies and applications** in schools (Tinker, 2000). The BSI Kit will include a surface temperature sensor connected to a computer for real-time data acquisition, display, and analysis (Vernier, n. d.). Located at the tip of a wire, this fast-response sensor is ideal for measuring the temperature distribution in a thermal system. Attached to a black surface, it can also be converted into a light or radiation sensor (Figure 4), making the kit more versatile without incurring any extra cost. In addition to this sensor, the kit will also include a HOBO data logger (Onset, n. d.) for recording temperature changes inside or outside a house over a long period of time.
- **Infrared cameras**. The **plummet of the price of professional IR cameras to below $200** in 2014—now much more affordable than portable sensor interfaces such as the $329 LabQuest 2 and $349 SPARK widely used in schools—has heralded the widespread applications of educational imaging in science education. We have been paving the road for educational imaging since 2010 (Xie, 2011, 2012c; Xie & Hazzard, 2011; Xie, Hazzard, & Nourian, 2010) and, in collaboration with Linköping University

and Uppsala University in Sweden, have conducted empirical research on cognitive processes stimulated by this "augmented sense" of thermal vision (Schönborn, Haglund, & Xie, 2014). **Our contributions to applied thermography have been recognized by the industry**: In 2012, FLIR, the global leader in IR technology, invited PI Xie to deliver a 45-minute keynote speech at the Opening Plenary of InfraMation (the world's largest conference on IR imaging). Based on this foundational work, together with NSL's tremendous field experiences in IR home inspection and FLIR's Infrared Training Center manager Orlove serving on the Advisory Board, this project is well prepared to realize the educational potential of IR imaging. It will be a true demonstration of how an innovative technology can enable education and industry to collaborate on promoting science education and career education.

- **Heat transfer simulation**. Our Energy2D software (Xie, 2012b) simulates complex heat transfer processes based on fast algorithms we invented to solve the Heat Equation and the Navier-Stokes Equation. Since its first release in 2011, Energy2D has been used by more than 60,000 people and written into a Springer book as a major tool for simulation-based learning (Landriscina, 2013). As it produces dynamic heat maps resembling IR images, Energy2D is often regarded as a simulation of IR thermography. **Capable of modeling a wide range of natural phenomena, engineered systems, and technical procedures**, it can supplement sensor or IR-based experiments with computational experiments (or mixed-reality experiments if connected to sensors). For example, experiments that are impractical to do on real buildings can be simulated. Phenomena that happen too slowly can be accelerated in simulations. Those that happen too fast can be slowed down. A unique feature of Energy2D is that it can simulate many solar applications such as solar ovens, Trombe walls, solar chimneys, and solar updraft towers, making it a powerful tool for students to learn conceptual design of sustainable technologies.
- **Computer-aided engineering**. Our Energy3D software is a unique computer-aided design (CAD) tool for students to rapidly **sketch up complex buildings with realistic appearances and renewable energy features**, **analyze their solar and energy performances**, and **print them out for assembling into paper scale models** (Xie et al., 2010; Xie, Zhang, Nourian, Pallant, & Bailey, 2014; Xie, Zhang, Nourian, Pallant, & Hazzard, 2014). Energy3D provides an embedded solar simulator for accurately calculating and visualizing insolation on a building at any location and time (Figure 3a). This simulator can also be used to calculate the energy outputs of solar panels.
- **Mixed reality**. Mixed reality (more commonly known as augmented reality) refers to the integration of real and virtual worlds to create new environments where physical and digital objects coexist and interact in real time to provide user experiences that are impossible in either the real or virtual world alone. Mixed-reality apps use computers to render science concepts as dynamic visualizations and sensors to link the simulations with physical changes in the real world (Xie, 2012a, 2013). In this way, **the simulations can respond to changes of sensor signals caused by the user's actions, creating powerful illustrations of science concepts at work in the real world** (Figure 3b). For example, students can walk around a building holding a tablet that is running a simulation of air molecules and experience how the air temperature they feel is related to the animated motion of molecules. This kind of mixed-reality activity represents a novel method of blending simulations into the real world.

CURRICULUM DEVELOPMENT

The BSI Curriculum will use the above technologies to support learning in school and at home. The curriculum will take advantage of their complementary nature to enrich learning experiences (e.g., sensors measure air temperature whereas IR cameras measure surface temperature; simulations can be used to find or design solutions before doing real experiments). To ensure that the curriculum will meet school needs, the curriculum development will be guided by the following NGSS standards:

NGSS	Concepts and Skills
MS-ESS1-1	The seasons are a result of that tilt [between Earth's spin axis and its orbital around the Sun] and are caused by the differential intensity of sunlight on different areas of Earth across the year.

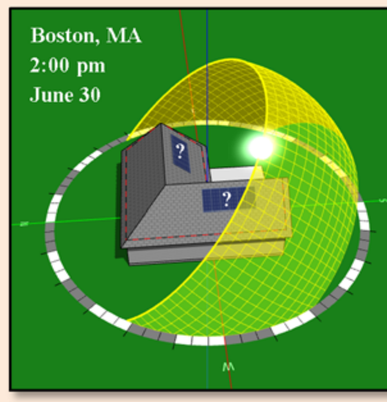
MS-PS3-3	Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.
MS-PS3-4	Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.
HS-PS3-1	Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.
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-PS3-4	Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).

Table 2: The NGSS standards that the BSI Curriculum will be aligned to.

NGSS standards with regard to science and engineering practices, such as "Analyzing and Interpreting Data" and "Constructing Explanations and Designing Solutions," or crosscutting concepts, such as "Systems and System Models" and "Structure and Function," will be integral parts of the BSI Curriculum and interwoven with inquiry and design activities throughout. The outlines of the four school units and four home units are described as follows (due to space limitations, the descriptions focus primarily on technology implementations of key ideas, concepts, and practices; the two text boxes provide concrete examples of building science investigation):

1. **Thermal Energy**. This unit will cover the basics, which include, but are not be limited to: a) **The nature of thermal energy** (NGSS MS-PS3-4): A mixed-reality app, linking the temperature data stream from a sensor to a molecular dynamics simulation (Xie et al., 2011), will be used to render the microscopic picture of heat and temperature and show how molecular motion changes with respect to temperature change and heat transfer in the real world, thus providing a vivid demonstration of micro-macro connection; b) **The Law of Conservation of Energy**: An Energy2D simulation will be used to verify this law—in conjunction with the concept of heat capacity—in exactly the way suggested by HS-PS3-1 (Xie, n. d.-a); c) **The Second Law of Thermodynamics**: An Energy2D simulation will be used to explore this law in exactly the way suggested by HS-PS3-4 (Xie, n. d.-b). Compared with real experiments whose results are inevitably complicated by energy dissipation from the studied system into the environment, Energy2D simulations allow students to easily discover these two fundamental laws.
2. **Heat Transfer**. This unit will cover the three mechanisms of heat transfer: **conduction**, **convection**, and **radiation**, which can be explored in three different ways: Energy2D simulations (e.g., convection shown in Figure 1a), temperature sensors (e.g., radiation shown in Figure 4), or IR cameras (e.g., conduction shown in Figure 1c). Students will learn the concepts in all three ways. These activities will not be simple repeats— the goal is to teach students how to use sensors and IR cameras to discover the same set of phenomena in the lab and how to connect sensor

Box 1: An Energy3D investigation: Which direction should your solar panels face?

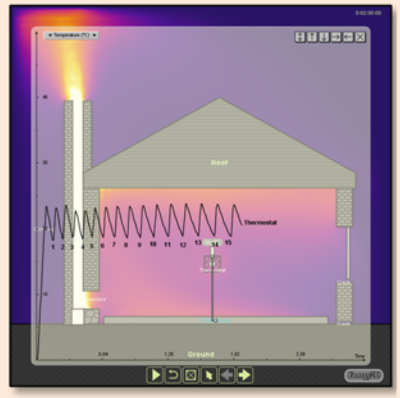


A recent study by Pecan Street Research Institute shows that, while solar panels produce the most electricity over the course of a year when facing south, there are benefits to facing solar panels west for reducing peak loads in climates where air conditioning drives peak demand such as in Texas (Konrad, 2013; Tweed, 2013). Suppose you are solarizing a house (shown above) in Boston where the summer is mild, which direction should you orient the solar panels? Use Energy3D to calculate the yearly, monthly, and daily outputs of a solar panel in different orientations. Pick a summer day and a winter day and compute the hourly outputs. Use these data to make your recommendation and write an analysis report to the home owner.

data and IR images with conceptual pictures animated by simulations. This unit will also cover the concept of emissivity of a material (the ability to emit energy by radiation), as understanding this concept is important to interpreting IR images correctly.

3. **Solar Energy**. The goal of this unit is to challenge students to utilize solar energy to reduce energy cost (HS-PS3-3). Students will learn the **Sun path** relative to a location on the Earth that drives the four seasons (MS-ESS1-1) and **the projection effect** that determines the density of solar energy shining on each surface of a building. Students will learn two strategies for harnessing solar energy: 1) **passive solar** designs are used to collect, store, and distribute solar energy; and 2) **active solar** technologies are used to convert solar energy into another form of energy such as electricity. Students will investigate these strategies with Energy2D or Energy3D (Box 1).
4. **Building as a System**. The goal of this unit is to teach students that a building is a system with a boundary known as the building envelope and an HVAC system maintains the thermal comfort for the occupants. The unit will **help students understand how different science and engineering concepts act together to affect home energy usage**. For example, they will learn with Energy2D simulations how energy is lost or gained through conduction, convection, and radiation, respectively, across the interface of the building envelope, and how this process is influenced by climate factors such as sunlight and wind. Energy2D can also show how the temperature in a house is regulated by a thermostat (see the image in Box 2). This modeling capacity will be extended in this project to allow students to learn cutting-edge home automation technologies such as the Nest Learning Thermostat (which was recently acquired by Google for $3.2 billion!).
5. **Home as a Lab**. The goal of this unit is to guide students to **discover thermal phenomena at home** and identify conduction, convection, and radiation in these phenomena. For example, students use a sensor to measure the temperature distribution in a room and find that the heat flux through a closed window is higher than through the wall. They are then challenged to distinguish the contributions of the three heat transfer mechanisms to the energy flow through the window. This unit will also provide simple experiments students can do with the thermostat. For example, students can test if a fireplace—an ancient way of warming up a house—is really a good idea today when the entire house is heated by a modern distributed heating system (Box 2).

Box 2: A home investigation: Fireplace to fight a polar vortex: Delightful or wasteful?



When wood burns, a fireplace creates an updraft force that draws the warm air from the house to the outside through the chimney. The loss of indoor air, in turn, draws the cold air from the outside into the house through small cracks in the building envelope. This is called the stack effect. So while you are getting radiation heat from the fireplace, you are also losing heat in the house at a faster rate through accelerated convection. As a result, your furnace has to work harder to keep other parts of your house warm.

Students can verify this effect on a cold night by recording for how long the furnace is running every hour when a fire is lit in the fireplace. Then put out the fire and shut the fireplace door. Record for how long the furnace is running every hour. Compare the results. Repeat this experiment a few times to get the averages. This idea is illustrated above with an Energy2D simulation.

6. **Home Energy Inspection**. This is the stage where students will **apply their knowledge and skills to "hunt" thermal defects at home**. Possible inspection sites will draw from the *Thermal Bypass Checklist Guide* (U.S. Environmental Protection Agency, 2008). For example, a thermal bridge can be found from an uninsulated balcony or a metallic fill pipe to an indoor heating oil tank. An IR camera will be a main diagnostic tool that students will use to rapidly scan the interior or exterior of a house to identify possible energy losses (Figure 1d). Students will also use temperature sensors to confirm IR results. Students will then write an energy assessment report to summarize their findings based on their sensor and IR results. This unit will follow industry standards such as *BPI 104: Envelope Professional Standard* (Building Performance Institute, 2010), whenever appropriate.

7. **Insulation, Weatherization, and Renewable Energy**. This is the stage where students will try (or propose) to **fix the thermal problems they have identified and check the results of their work using sensors or IR cameras** when possible. For example, students can weatherstrip doors or windows to reduce infiltration (air leakage) and take IR images before and after to provide evidence of improvement. If they find that the thermal flux through a window is excessively caused by radiation heat transfer, students can recommend their parents replace it with a low-emissivity window (Fisette, 1998). Students can also **use their engineering skills to design retrofit solutions on the computer and make suggestions to their parents**. For example, students will use Energy3D to sketch up approximate models of their houses and neighborhoods, set the location and orientation, and then compute the solar radiation on different sides of their houses in different seasons. The results can be used to evaluate the practicality of passive or active solar solutions such as adding sunspaces or rooftop solar panels. These virtual green retrofit solutions will be included in students' reports as the "recommendations to the client," in which they will use scientific data and reasoning to justify their recommendations.
8. **Green Building**. The goal of this unit is to **inspire students with the big picture of sustainable housing**. Specifically, this unit will focus on the contemporary concepts of zero-energy buildings—buildings with zero energy consumption over the course of a year, and off-the-grid buildings—buildings that produce and store energy enough to power themselves at any time. The task for students is to imagine a plan to achieve those high standards using what they have learned from the previous units.

RESEARCH PLAN

The research in this project will be structured around the three ITEST research questions RQ1-3 using the Social Cognitive Career Theory (Lent et al., 1994) as the theoretical framework.

Research Question RQ1 about Impacts on Students

We hypothesize that the proposed innovative technologies will create coherent sets of experiences in school and at home to support content learning and spur career interest. This can be tested by measuring the impacts of the technologies on the outcomes of science learning and career awareness using pre/post assessments. The **pre/post-tests for content learning** will include existing concept inventories about heat and energy (Jacobi, Martin, Mitchell, & Newell, 2003; Prince, Vigeant, & Nottis, 2012; Swackhamer & Hestenes, 2002) and items specifically designed to assess cleantech-related knowledge and skills such as interpreting IR images or designing green energy solutions. To properly score constructed responses in the pre/post-tests such as data interpretations or design rationales, we will develop three-level rubrics to rank students' demonstrated competence as novice, intermediate, and advanced. The **pre/post-questionnaires for career awareness** will draw from validated instruments such as the *STEM Career Interest Survey* developed for middle school students based on the Social Cognitive Career Theory (Kier et al., 2014), the *Educational and Career Interest Scale* developed for high school students (Oh et al., 2013), and the *General Self-Efficacy Scale* (Schwarzer, Bäßler, Kwiatek, Schröder, & Zhang, 1997). The questionnaire will measure four interrelated constructs: career interest, self-efficacy, outcome expectation, and personal performance and accomplishments. For example, a self-efficacy item can be "I can be an energy auditor if I have the right technology such as an IR camera," revised based on the General Self-Efficacy Scale to specifically address the role of technological education on career motivation.

Paired-samples t-tests will be used to analyze the pre/post data. The same analysis will be conducted for subgroups with different demographic backgrounds (e.g., gender, socioeconomic status, and ethnicity) and contextual backgrounds (e.g., student academic performance, type of class, teacher, and school) to detect any differential impacts. Student pre/post data will also be analyzed to classify students based on the patterns of change in their science competence and career awareness. A subsample of students representing each type of change will be randomly selected for a **semi-structured in-depth interview**. These interviews will capture students' subjective learning experiences, how they transfer knowledge and skills from classroom to home, their attitudes toward the technologies and curriculum, and how they perceive and respond to feedback from industry experts. The interviews will be audio-recorded and transcribed. The transcripts will be analyzed to identify characteristics of successful instructional models and processes of how these experiences generate impacts on student learning and career awareness.

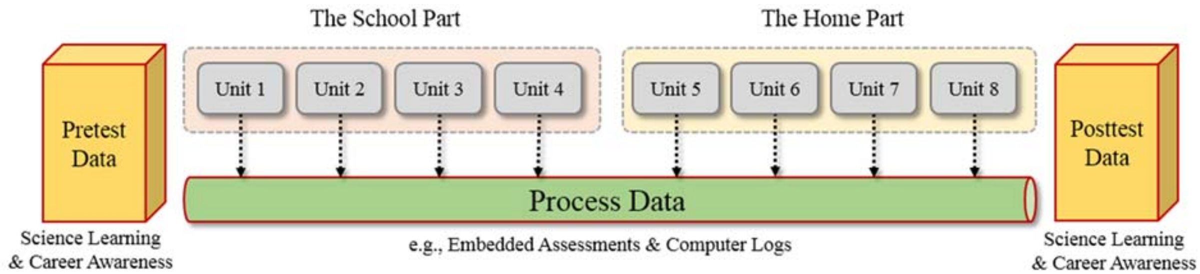


Figure 5. The main data sources for this research include the pre/post-test/questionnaire data that measure the outcomes in science learning and career awareness and the process data collected from embedded assessments and computer logs to represent student progress at each unit of the BSI Curriculum. Qualitative data sources from classroom observation and participant interviews are not shown here.

To understand how each aspect of the technology experiences affects the pre/post outcomes, we will **use process analytics to track the entire learning process and correlate the process data with the pre/post data** (Figure 5). Process analytics is a type of learning analytics and visual analytics spearheaded by the PI. Process analytics focuses on finding patterns and relationships from the fine-grained learner data logged by a learning technology, with the goal of understanding what learner-technology interaction is responsible for a learning outcome (Xie, Zhang, Nourian, Pallant, & Bailey, 2014; Xie, Zhang, Nourian, Pallant, & Hazzard, 2014). Process analytics will use algorithms to search for patterns and trends that are similar to those used in business intelligence for understanding and predicting consumer behaviors (e.g., Luckham, 2011; van der Aalst, 2011). For example, association rule mining (e.g., García, Romero, Ventura, Castro, & Calders, 2010) can be used to quantify the relationships between student data generated in school and at home, in order to understand the interplay between classroom and home learning. A key challenge for this project is to develop a comprehensive set of performance indicators from the heterogeneous datasets and artifacts collected by different tools from different environments to codify learning progress. The indicators related to HPXML-based home energy data will be rated by multiple industry experts (to improve the inter-rater reliability) using rubrics co-developed by CC and NSL. The indicators related to science and engineering learning based on embedded assessments will be rated by multiple CC researchers using rubrics co-developed by CC and pilot teachers. Indicators that can be derived from software or Web logs will be automatically analyzed using computer algorithms. To examine the validity and reliability of these performance indicators, in Years 1 and 2 we will randomly select one class from each teacher who implements the BSI Curriculum and observe how students learn in the classroom, using an observation protocol that maps to the indicators. We will compare the results from the observations with those from the indicators. Differences will be discussed and reconciled among researchers and teachers. Higher-level analyses on the student data quantified from the performance indicators will be conducted to identify deeper learning. For example, a question such as “How does a better understanding of a science concept underlying a home energy problem contribute to finding a solution?” can be answered by examining if there is any correlation between students’ performances on the test items for the concept and on the actual problem-solving tasks.

Research Question RQ2 about Impacts on Teachers

We will use **pre/post-questionnaires** and **in-depth semi-structured interviews** to collect data from teachers for finding effective ways to engage them in using technologies. Pre/post-questionnaires will be developed to measure teachers’ attitude changes towards the technologies, their expectations of student learning outcomes, and their perceptions of the instructional partnership with industry experts. The questionnaires will ask teachers to compare the instructional model against their traditional ways of teaching the same content. The questionnaires will be piloted with the participating teachers in the first year to ensure its validity and reliability. All participating teachers will complete the pre-questionnaire at the beginning of the project as a baseline. The post-questionnaire will be administered after they have implemented the project materials. This post-questionnaire will be repeated for teachers who are involved in this project the next year to capture changes due to increased familiarity with the technologies and curriculum. The responses to the questionnaires will be analyzed to classify teachers based on the patterns of changes. **Association analysis techniques** such as Pearson's chi-squared test will be performed to explore how teachers' demographic and professional backgrounds (e.g., gender, teaching experience, and pedagogical beliefs) influence their engagement and attitudes. A subsample of teachers representing each type of change will be randomly selected for an in-depth semi-structured interview. They will be asked to identify factors that influence their attitudes toward the application of innovative technologies and the instructional partnership with industry, to describe specific instances that alter their beliefs, and to report their efforts to adjust the curriculum to accommodate the particular needs of their students. The interviews will be audio-recorded and transcribed. The transcripts will be analyzed to identify characteristics of successful instructional models and processes of how these experiences transform teachers' attitudes.

Research Question RQ3 about Industry Contributions

In the pre/post-questionnaires and interviews for both teachers and students, we will also include questions that address the effects of industry participation on learning, teaching, and career awareness. For instance, are there any changes in the attitudes of students and teachers that can be attributed to a career prospect in the learning goals endorsed by industry? What false beliefs and faulty self-efficacy of students about cleantech careers can the familiarity with industry technologies and online interactions with industry experts modify? What part of the instructional partnership with the industry do teachers feel is most helpful?

Broader Impacts

This project will promote the energy literacy (U.S. Department of Energy, 2012) and technical competency (Advanced Technology Environmental and Energy Center, 2011) of more than 2,000 students from diverse socioeconomic backgrounds, and inspire an even greater population as the family members of these students also become engaged. The technical authenticity of this project will increase participants' appreciation of the importance of cleantech from a purely scientific perspective. In the long run, this project will contribute to home energy savings and cleantech industry growth in Massachusetts. The strategies of this project will provide technology-enhanced models of extensive education-industry collaboration that may be transferable to other states. Using open-source software that we have developed and affordable hardware from various vendors ensures the scalability of the free, Web-based BSI Curriculum.

Project Evaluation

This project will be independently evaluated by Sun Associates, which specializes in measuring the impacts of technology on education. To complement the educational research of this project as described above, the external evaluation will focus on the operation, management, and impacts of the project. Summatively, Sun Associates will observe activities and document outputs and outcomes of this project. Formatively, Sun Associates will monitor project progress and provide project staff with inputs on improving their work to ensure positive outcomes. The evaluation will address two primary questions: 1) **To what extent has the project achieved its goal?** and 2) **To what extent has the project engaged students, teachers, and industry?** Sun Associates will focus on the following avenues of evaluation: a) **Create benchmarked performance indicators for overall project assessment**. At the beginning of the project, Sun Associates will work with project staff and the Advisory Board to develop a benchmarked set of project performance indicators based on the two evaluation questions defined above, as well as the project goal and objectives. Arranged into a rubric, the indicators will provide clear criteria for project success (summative evaluation) and benchmarks used throughout the three project years to show how the project qualitatively and quantitatively improves its performance (formative evaluation). b) **Evaluate the school activities**. Sun Associates will develop an indicator rubric that assesses the project activities in school. The participating teachers will provide inputs for evaluating the effects of the BSI Curriculum and the supporting technologies based on their experiences in using them with their students. A number of instruments including surveys, questionnaires, and interviews will also be developed and used to collect student opinions about the activities. c) **Evaluate the home activities**. This part will be similar to the evaluation of the school activities. But it will include the inputs from the NSL experts and, when applicable, the parents or guardians. Their opinions will provide an additional lens to evaluate this project objectively. In addition to regular formative reporting to the project staff, Sun Associates will report summatively via an annual report submitted to the project, the Advisory Board, and the NSF. The report will also include recommendations for improvements.

THE ADVISORY BOARD

An Advisory Board consisting of six members will oversee this project. The board will meet twice with project staff to review the project progress, evaluate the scientific and technical quality of the project, and guide future research. In addition, project staff will also take advantage of the members' expertise in one-on-one sessions throughout the project years. The members are: **Dr. Sanjay Kaul** is Professor and Chair of the Department of Industrial Technology at Fitchburg State University. His research focuses on energy engineering and energy management. He has published several books on renewable energy and was a Fulbright Senior Specialist. **Dr. Janice Mokros** is Managing Director of Maine Mathematics and Science Alliance (MMSA). Janice is a developmental psychologist and mathematics educator who has led several projects at MMSA, including an NSF project on energy education. **Gary Orlove** is the Curriculum Manager at the Infrared Training Center of FLIR Systems. FLIR is a world leader in IR technology. An infrared thermographer since 1975, Gary is also a director of the International Association of Certified Thermographers. **Dr. Chris Rogers** is Professor at the Department of Mechanical Engineering and Co-Director of Engineering Education and Outreach at Tufts University. His work involves STEM integration using hands-on engineering design projects. **Dr. Brent Stephens** is Professor of Architectural Engineering at Illinois Institute of Technology. His research is dedicated to investigating problems and solutions related to energy supply, consumption, conservation, and sustainability within the built environment. **Larry Weathers** is K-12 Science Director at Arlington Public Schools. He taught K-16 STEM for over 40 years, received a Presidential Citation from the White House for Excellence in Science Teaching, and has been inducted into the Massachusetts Teaching Hall of Fame.

SENIOR PROJECT STAFF

Dr. Charles Xie will serve as the PI at CC. A computational scientist and an infrared thermographer, he has 15 years of research and development experience in STEM education. Charles has developed several interactive, visual science and engineering simulation tools used by over a million students and has authored 12 peer-reviewed papers in STEM education journals. He is also leading cutting-edge research on process analytics for unpacking complex student learning. **Joyce Massicotte** will serve as the Co-PI at NSL. She is the manager of NSL's educational programs. She will ensure optimal integration of NSL's industry expertise into this project to promote science education and workforce development. Joyce holds a Master of Science in Resource Administration and Management from the University of New Hampshire. **Dan Barstow** will serve as the Co-PI at VHS. He is a nationally regarded expert in climate and energy education. He founded and directed the Center for Earth and Space Science Education at TERC and was President of the Challenger Center for Space Science Education. Dan was a member of the National Academy of Science panel on America's Climate Choices, and PI of Windows on Earth, creating software used by astronauts on the International Space Station. **Dr. Saeid Nourian** will be responsible for developing integrated software solutions for this project. He has done extensive research in virtual reality and computer graphics. He is the lead developer of Energy3D. He holds a Ph.D. in computer science from the University of Ottawa. **Dr. Jie Chao** will serve as a senior educational researcher. She has led multiple research projects on how innovative learning technologies can enhance conceptual understanding in science and engineering. Jie holds a Ph.D. in Instructional Technology in STEM education from the University of Virginia.

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