INFUSING TECHNOLOGY INTO ENGINEERING EDUCATION

Charles Xie[1], Edmund Hazzard, and Saeid Nourian

The Advanced Educational Modeling Laboratory

The Concord Consortium, Concord, MA 01742, USA

Abstract: Technology is transforming science education. Likewise, it has the potential to bring transformative changes to engineering education. In this paper, we present a set of cutting-edge technologies we have developed as novel cognitive and design tools. We propose several mechanisms based on these tools that may help solve critical problems in design-based learning for engineering education. Our work focuses on the topic of energy and power in thermal systems, which is an important engineering field in the green economy.

INTRODUCTION

Engineering education in the U.S. must respond to the challenge of globalization (National Science Board, 2007). While the shortage of qualified engineers may not be as severe as often cited (Gereffi, et al., 2005), the trend of continuous outsourcing of engineering jobs—following the large-scale outsourcing of manufacturing jobs that has fundamentally altered the nation's industrial structure—is evident (Bradsher, 2010). The health of the U.S. economy depends substantially on how the country's education system raises the bar for engineering education. American engineers must acquire higher-level skills and provide greater value to retain their global leadership in a flat world (Friedman, 2005). Innovative academic programs and curricula need to be engineered to launch students to a higher starting point that will enable them to compete favorably in their future scientific and engineering careers in the global market—probably early in their education (Cunningham, 2009; Hu, 2010; Rogers & Portsmore, 2004). Technology holds an important key to this imperative educational overhaul (U.S. Department of Education, 2010; Zucker, 2008).

Engineering and technology are closely interrelated. On the one hand, technology is often the result of successful engineering. On the other hand, engineering advances through the application of technology. Thanks to the advancement of technology, in particular computer and information technology, engineering tools have become more powerful, more accurate, and more cost-effective. Development of new technologies has caused paradigm shifts of engineering principles and practices that frequently redefine the frontiers of engineering. Educators need to be aware of these constant shifts and updates in order to orient students for their future careers. One obvious way to modernize the curricula and teaching practices is to infuse cutting-edge technology into engineering education. Technology has the potential to transform engineering curricula and pedagogies to meet the challenge of teaching 21st century skills (Aronowitz, 2009). Technology-enhanced engineering education offers hope for producing new generations of creative engineers and scientists who will be capable of opening new horizons in industry and leading the economy to new heights.

Funded by the National Science Foundation, we are developing innovative educational technology for teaching and learning engineering design and studying how technology can enhance engineering education at the secondary level. We chose to focus on the topic of energy and power in thermal systems, as it is an important engineering field in the green economy and relevant to students' everyday lives. In this paper, we will present these new educational tools, suggest how they may empower high school students to undertake scientific discoveries about heat transfer and engineering designs for energy-efficient houses, and outline a theoretical framework that guides our curriculum development, educational research, and

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[1] To whom correspondence should be addressed: qxie@concord.org

classroom implementation. Some of the tools were pilot-tested in the spring of 2010 at several high schools in Massachusetts. The results of these pilot tests and future field tests will be analyzed and published elsewhere.

DESIGN-BASED LEARNING: IMPORTANCE AND CHALLENGES

Engineering design is a systematic, science-based process in which designers create, test, and evaluate concepts for devices, systems, or processes whose form and function achieve clients' objectives or meet users' needs while satisfying a specified set of constraints (Dym, Agogino, Eris, Frey, & Leifer, 2005). There is a consensus among educators that design-based learning is essential for *all* students in engineering education (Hacker & Burghardt, 2008; Katehi, Pearson, & Feder, 2009; Kolodner, et al., 2003; Mehalik, Doppelt, & Schunn, 2008; Sadler, Coyle, & Schwartz, 2000; Schunn, 2009). The Standards for Technological Literacy (International Technology & Engineering Educators Association, 2007) emphasize its importance: "Design is regarded by many as the core problem-solving process of technological development. It is as fundamental to technology as inquiry is to science and reading is to language arts."

Using design challenges to teach engineering, however, does not automatically lead to effective learning. In some design-based projects, students are simply instructed to follow prescribed procedures, solve problems using trial and error, and often left to wonder about what in essence they were supposed to learn. Many studies have revealed that this kind of laboratory experience does not result in a significant learning (Burghardt & Hacker, 2004; Singer, Hilton, & Schweingruber, 2005). It is argued that, to remedy this, integrating science into engineering design can help students develop some basic scientific understanding that can then be applied to making a more effective design (Zubrowski, 2002).

Technology such as sensors, infrared imaging, and modeling and simulation software are tools employed by professional engineers. These tools are converted into cognitive tools in this project to overcome the problem of superficial learning in a complex, open-ended design challenge project. Computer simulation and infrared imaging are excellent cognitive tools because they extend thinking beyond perception by providing rich visualizations of invisible physical processes that would otherwise go unnoticed. Integrating these tools into engineering design in the classroom will likely increase students' curiosity and interest because they render an intriguingly distinct view of common phenomena in everyday life. We propose novel ways of using them to deepen students' understanding of engineering principles and the fundamental science behind them. We also theorize that a curricular integration of a simulation tool and a hands-on tool in a design process can result in a cognitive resonance—a mechanism that can reinforce understanding of a concept through observing its occurrence in multiple forms, particularly in a computational form and an experimental form that explain each other. Finally, we suggest that computer modeling can supersede the pencil-and-paper method to offset many design difficulties, allow students to concentrate on their designs, and help them achieve the performance goals.

Our research and development centers on design-based learning through a hands-on project in which students are challenged to create an energy-efficient scale model house. Several design-based projects involving building a scale model house exist (Coyle, 2001; Host-Jablonski, 2000; Museum of Science, 2008; Thames & Kosmos, 2010). Our project is based upon these well-conceived projects and products, but our main efforts are focused on using technology to integrate science into engineering design, improve the design-based learning process, and push the envelope of content depth and skill level. In the following sections, the educational applications of these technologies will be discussed from two perspectives: technology as **cognitive tools** and technology as **design tools**.

TECHNOLOGY AS COGNITIVE TOOLS

A design challenge, regardless of its level of sophistication, can only teach based on what students see, hear, and touch during the design activity. Many important learning goals in engineering, however, rest on the application of abstract concepts such as heat transfer, stress, airflow, reaction rates, or electromagnetic signals that are often invisible, inaudible, and intangible. For instance, the Massachusetts engineering content standards require that high school students be able to explain how tension, compression, shear, and torsion relate to the selection of materials in structures and give examples of how conduction, convection, and radiation are considered in choosing materials for buildings and designing a heating system (Massachusetts Department of Education, 2006). Concepts like these are not trivial to teach and are not necessarily covered adequately by prior science courses. But in a design challenge, students are expected to both learn and apply them to make something that works in a short time. To cross such a steep learning curve, an engineering course must "open the black box" for students to see how these concepts and the related principles are put to work in a design so that they can deepen their conceptual understandings while learning the engineering applications of the concepts and principles.

In the research fields of science and engineering, many technologies have been invented and perfected for making scientific discoveries and solving engineering problems. Some of these technologies have enormous potential to act as a "black box opener" for education. They can provide invaluable cognitive tools that support, guide, and extend students' thinking processes (Jonassen, 1994), in a way that is not dissimilar to their use in research. These tools support constructivist learning by permitting students to acquire knowledge themselves in the same way that scientists and engineers employ them.

In this section, we present two technologies—infrared imaging and computational fluid dynamics—that were originally intended for research and development but can be harnessed as powerful cognitive tools to transcend the limitations of human perception and calculation abilities. Appropriate, thoughtful applications of these tools can help students predict and visualize how energy and matter flow in a complex system such as a house and afford them the opportunity to internalize these abstract concepts and apply them to their designs. Salient visualizations of these abstract concepts using technology in the midst of a complex engineering design project serve to encourage a few reflective moments[2] to explore the concepts before students jump to the next busy task. Without this impetus to pause and reflect brought by technology, the concepts may remain simple hunches or vague notions to most students, preventing them from thinking more scientifically and creatively to truly achieve the learning goals.

In the following, we will briefly demonstrate the power of these cognitive tools by presenting a few examples.

Discovery Learning Using Infrared Imaging

Based on detecting infrared (IR) radiation emitted by the target, IR imaging can show the temperature distribution of a system without touching it. As a picture is worth a thousand words, an IR camera has great potential for teaching heat transfer, which is otherwise unintuitive due to the invisibility of heat and temperature.

The educational applications of IR imaging were first discussed by German physicists in 2001 (Möllmann & Vollmer, 2007; Vollmer, Möllmann, Pinno, & Karstädt, 2001). At that time, IR cameras were prohibitively expensive. Thanks to the growing needs of building energy inspection and construction quality assurance using IR thermography in the past decade (Kavoussi, 2010), the price of IR cameras has plummeted and they have become easier to use (Snell, 2010). An affordable IR camera that allows students to *see heat flow in real time* is now available[3]. This focus-free camera automatically generates thermograms of satisfactory quality with a temperature sensitivity of 0.1°C. It is as easy to use as a typical digital camera. As it is a no-touch tool, it is safe to use in the classroom. Although the size of its microbolometer array is only 80×80 pixels, it works very well for most lab bench experiments that do not need wide angles.

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[2] Note that these reflective moments should not be confused with the reflection time when an instructor intervenes and requires students to slow down and reflect.

[3] http://www.amazon.com/Extech-i5-Thermal-Imaging-Camera/dp/B003B3N60E

Figure 1 shows the apparatus of a conduction experiment. A metal strip and two paper strips are laid out on a foam board base, as illustrated. A piece of paper covers up the metal and paper strips entirely. The assembly is taped together tightly to ensure good contacts. A hot water jar is placed at different locations to heat the apparatus and then removed for IR observation. In the contact area between the bottom of the jar and the cover paper of the apparatus, heat diffuses into the metal and/or paper strips underneath and in turn warms up the cover paper above them when it spreads out. An IR image of the cover paper shows how heat flows beneath it. The difference of emissivity between metal and paper is not an issue, since the IR emission comes from the cover paper that has identical emissivity everywhere.

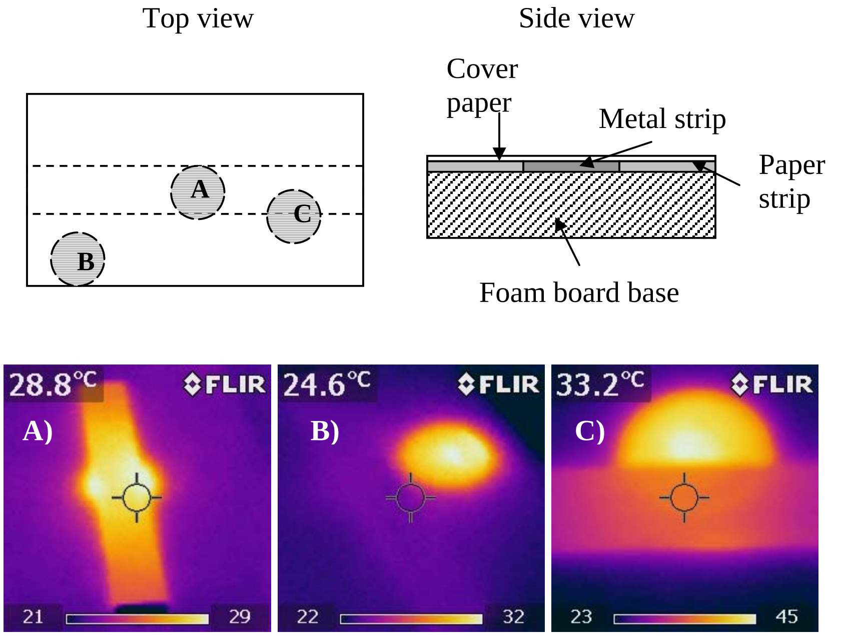

Figure 1. Using an infrared camera to visualize heat conduction on a plate consisting of areas with different thermal conductivities. A hot water jar was used as the heat source. Thermograms were taken when: A) the jar was placed above the center of the metal strip, B) the jar was placed entirely above a paper strip, and C) the jar was placed half on the metal strip and half on a paper strip. In all three cases, the jar was removed before the thermogram was taken. Thermogram C is a close-up shot.

When the jar is placed over the center of the metal strip, the thermogram clearly reveals the shape of the underlying metal strip, indicating that heat conducts quickly in metal (Figure 1A). When the jar is entirely over a paper strip, the thermogram shows a circular area of concentrated heat slightly larger than the cross section of the jar, indicating that heat conducts slowly in paper (Figure 1B). If the jar is placed at such a position that half of it sits over the metal strip and the other half over a paper strip, an interesting pattern emerges (Figure 1C).

The experiment described above presents an example of how students can discover knowledge about heat conduction using IR imaging as a cognitive tool. Compared with the simple, traditional way of teaching heat conduction by having students touch different materials and feel their warmth or cold, the IR tool uncovers a direct, impressive view of heat flow and invites students to explore more. The “sunset” image in Figure 1C prompts students to think about what causes the formation of the pattern. The experiment can be made more engaging by giving students plates with multiple metal and paper strips of different shapes, covered by a piece of dark paper, and having them discover their locations and shapes. If time permits, students can design plates of their own to achieve desirable thermal patterns. These extended activities can maximize the cognitive power of IR imaging in teaching heat conduction.

The IR tool has been proven to be very versatile and can be used to teach many more concepts besides conduction (Xie & Hazzard, 2010a).

Interactive Computational Fluid Dynamics

Simulation-based engineering and science are increasingly important in accelerating research and development because of the analytical power and cost effectiveness of computer simulation (Glotzer, et al., 2009; NSF Blue Ribbon Panel on SBES, 2006). Advanced simulation tools based on solving basic equations in physics are routinely used to tackle complex problems and to search for optimal solutions in many engineering practices.

Computational fluid dynamics (CFD)[4] is one such modeling method that has been widely used in engineering design. We have developed a 2D CFD simulator called *Energy2D* that has shown great potential in teaching many important engineering concepts and principles related to heat and mass flow (Xie & Hazzard, 2010b). The software—the result of technology transfer from CFD research to education—is based on fast algorithms we invented to solve the Heat Equation (Xie, 2010b) and the Navier-Stokes Equation (Xie, 2010a). *Energy2D* can simulate conduction, convection, and radiation for complex 2D structures in real time (see Figure 2). This is an important feature that—unlike many simulation tools not explicitly designed for education—allows users to interact with the simulation while it is running and see the results instantaneously. Students thus have a powerful computational laboratory at their fingertips for experimenting with a large variety of phenomena, which is far better than a worksheet for crunching numbers to calculate heat transfer.

Sunlight: ● On ○ Off Graph: ○ On ● Off

Figure 2. An Energy2D applet that shows a pattern of convective heat flow resulting from solar heating of a dark floor through glazing. The rays represent sunlight. The color represents temperature—the more bluish, the colder. The vectors represent the velocity vectors of the air parcels at their locations.

Like IR imaging, a CFD tool can render stunning visualizations of temperature distribution and heat flow on a computer screen. And it has several extra strengths. First, it offers more information than just the temperature distribution field. For example, it can show the velocity field of a fluid. Second, as it is a virtual model, it allows students to explore what-if scenarios that are not feasible in the classroom. For instance, what would happen to the heat flow within the house shown in Figure 2 if the air were very viscous (i.e., if the convection effect were weakened)? Several studies on the impact of computer simulation upon student learning in engineering laboratories found positive results (Campbell, Bourne, Mosterman, & Brodersen, 2002; Koretsky, Amatore, Barnes, & Kimura, 2008; Walrath, 2008; Wiesner & Lan, 2004), possibly due to all these affordances.

An interactive CFD tool is powerful, but its educational value will be limited to exploring covariations among factors if it only allows students to change certain parameters outside the context of an engineering design. The educational potential of this

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[4] Computational heat transfer is considered in this paper as part of computational fluid dynamics, though not all heat transfer processes involve fluid flow.

engineering tool can be fully realized only when it is integrated into an engineering design process as a cognitive tool. Two integration strategies can be drawn from how professional engineers use modeling tools to solve real problems. The first strategy is “explaining with simulations,” a procedure that challenges students to create a simulation that fits the real data they acquired from a hands-on experiment about their designs. In this case, the simulation activity acts as an enhancement to the hands-on activity for students to understand how a design works. The second strategy is “predicting with simulations,” a procedure that challenges students to use a simulation tool to come up with a design before realizing it in a hands-on lab. In this case, the hands-on activity acts as an enhancement to the simulation activity for students to confirm their computer designs. Both pedagogies require students to relate their hands-on activities with their simulations and encourage them to explain their lab results based on the correlation between theory and practice. By interweaving simulations with hands-on activities during a design challenge, students are given multiple chances to reflect, think, and solve problems with the provided cognitive tools.

Furthermore, the observation of the agreement between a hands-on experiment and a simulation delivers convincing explanatory learning experience that can deepen students’ conceptual understanding. The explainability of a process or a design is utterly important in science and engineering. Educationally, the cognitive resonance between hands-on and simulation is one of the most profound teaching moments. It is not just a coincidence or an alignment of artifacts. It is the result of the orchestration of many concepts. These concepts are elusive in a hands-on lab but can be represented by variables in a simulation. Cognitive resonance can ignite an understanding of how different concepts work together to explain an experimental result and, therefore, contribute to the development of a solid mental model.

TECHNOLOGY AS DESIGN TOOLS

Several studies have shown that word processors are valuable tools for helping students develop writing skills (Goldberg, Russell, & Cook, 2003; Jeroski, 2003). This is not a surprising result because word processors make composing far easier and more flexible than pencil and paper.

Likewise, technology can enhance engineering design in a similar way. Many engineering design challenges involve creating 3D structures. It is not easy to design a complex 3D structure with pencil and paper (Figure 3). Fortunately, modern software technology has provided a much better solution for learning 3D design (Cheng, 2007). For example, Google’s *SketchUp* has been widely used as a 3D computer-aided design (CAD) tool at schools. Its revolutionary What-You-See-Is-What-You-Get (WYSIWYG) 3D graphical user interface makes it easy to draw 3D structures on the computer screen.

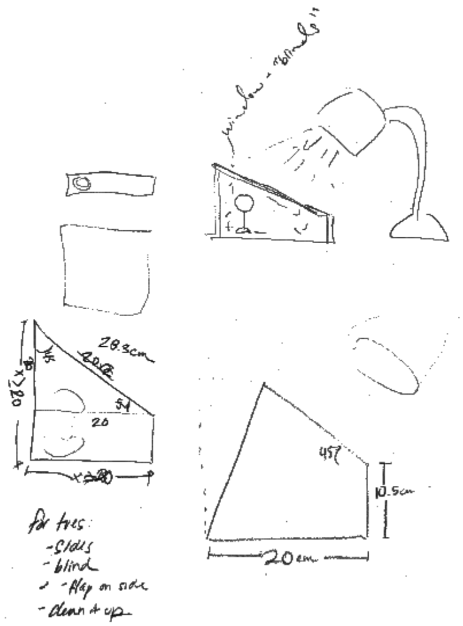

Figure 3. A sketch of a solar house drawn by a student who participated in our pilot test to explain her design to her teammates.

We hypothesize that a CAD tool such as *SketchUp* helps students develop their designing skills because 1) it renders a realistic view of the design while the user is working on it (WYSIWYG); 2) it invites revisions by making it easy to tweak a design; 3) it does all the geometric calculations automatically, thus saving users substantial time on laborious mathematical work and enabling them to focus on their designs. In a sense, a CAD tool replaces the tedious, intimidating, and perhaps unproductive procedures[5] in engineering design with interesting, easy, and productive activities.

While the above enhancements resulting from the use of CAD tools already have tremendous implications to engineering education, we are adding even more powerful features to make their educational values even greater. These novel features, to be introduced below, are built into our *Energy3D* software.

Ease of Design

Similar to *SketchUp*, our CAD tool *Energy3D* can be used to construct a 3D building in a WYSIWYG manner. While *SketchUp* is a general CAD tool, *Energy3D* is developed only for constructing buildings. Our goal is to empower the user to create and edit a building as easily as possible. With *Energy3D*, the user can construct a house using a complete set of building blocks such as foundations, walls, doors, windows, roofs, and floors. Any building block can be added, reshaped, moved, or deleted in ways permitted by the corresponding rules applicable to its type. Adding a non-flat roof, a difficult task in *SketchUp*, is simplified in *Energy3D*. When the user selects the "Roof" mode and clicks on a roofless construct, a roof will be automatically added to cover the existing walls with a reasonable overhang. The shape and size of the roof can then be adjusted.

Two mechanisms were developed to further simplify the user interface of 3D construction in *Energy3D*. The first is a grid mode in which the user can add or modify a construction element on a grid. This mode makes it easier for the user to set or measure the dimension of an element. The second is a snap mode that can infer the user's intent and automatically connect the piece being manipulated to existing ones seamlessly and precisely.

Design under Constraints

An important feature of *Energy3D* is the ease of handling constraints. An engineering design challenge always includes constraints. For example, students will be given only a certain amount of constructional materials to build a scale model house. On the one hand, exceeding the limit will result in an incomplete house that may score poorly. On the other hand, leaving too much material unused at the end may be an indication of a bad design. Creating the best design requires planning and calculations that are not easy for novice designers, because the constraints are often at a system level and, therefore, must be dealt with systematically. Most students have not learned backward design. It is not obvious to them what to do at each step of a design process with individual parts that must add up together correctly at the end to meet a design goal.

Energy3D offsets this design difficulty by providing students with a simple tool to deal with constraints. Students need not worry about constraints before they complete a design of a house. Once completed, the computer model of the entire house can be resized easily and the material cost for each size will be dynamically calculated and reported to them. Thus students can optimize the material costs by adjusting their designs. In this way students are able to *concentrate on designing first* without being distracted by

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[5] Arguably, an engineering course should focus on the engineering design part, instead of mathematics, to make functioning artifacts in a given amount of time. If a design involves complex geometry, such as a house in our project, students may spend a lot of time on algebra and trigonometry, compromising the engineering learning goals such as energy efficiency and renewable energy. This is not to say the application of mathematics is not an important skill to learn in an engineering project. But due to the limitation of classroom time for engineering at the secondary level, an engineering project has to choose its focus.

constraints all the time. This is similar to the case of using a word processor—the writer can defer the adjustment of format to meet a publisher's requirement until after an article has been composed.

Integration with Hands-On Activities

Another important feature that is missing in *SketchUp* but key to our project is a smooth integration with hands-on activities. In our project, students are required to build scale model houses. Hence, *Energy3D* must allow transfer from a computer model to a physical model. Having designed a house on the computer, the user can use *Energy3D* to generate a "blueprint" for making physical models.[6] *Energy3D* automatically deconstructs a 3D structure into 2D pieces, figures out which pieces are on the same 2D plane, generates a layout of all the planes, calculates the necessary lengths and angles, and prints them (Figure 4). Every piece is numbered and annotated with calculated geometric information adequate to guide students to cut it from provided constructional materials such as paper or foam board. The entire deconstruction process is animated so that the user has an intuitive understanding of the relationship between a house and the pieces in the blueprint.

Students also have an option of fitting designs to the dimensions of constructional materials. For example, one option is to assemble a house using printer paper. If students select this option, *Energy3D* will automatically rescale every piece to guarantee that the largest piece can fit an A4 page and all the others will be proportionally rescaled accordingly. In this case, the texture and all the marks on a piece will be printed out, making it possible for students to construct a physical scale model that looks just like its computer counterpart (Figure 5).

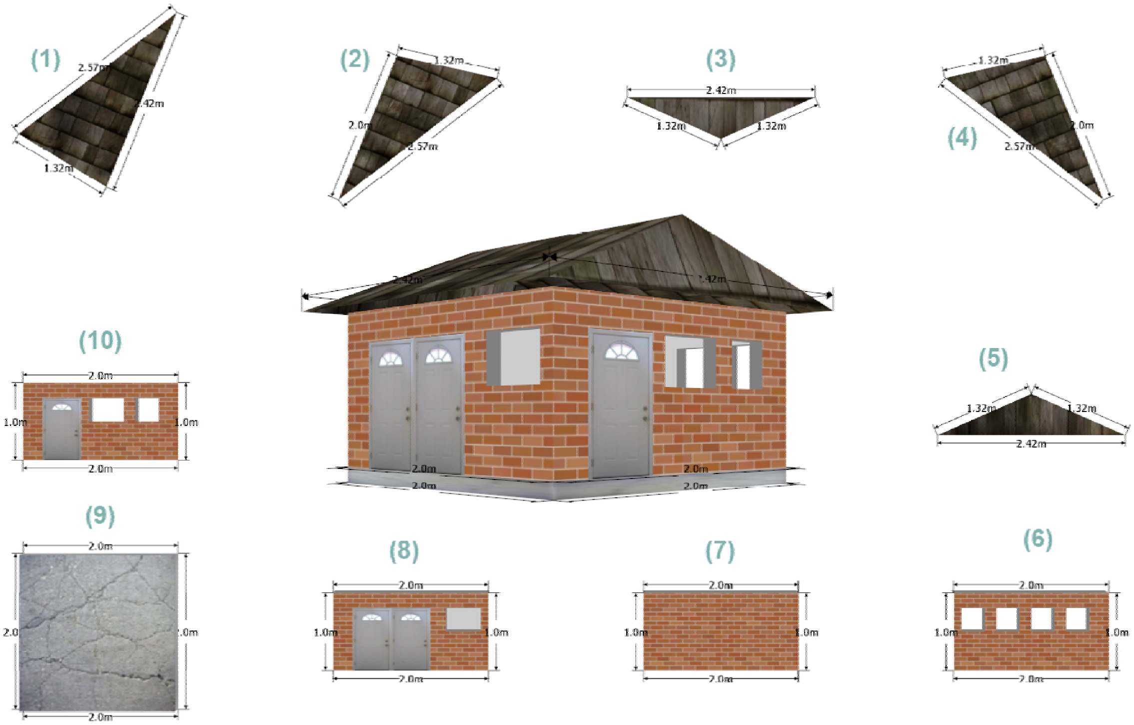

Figure 4. A screenshot of the "blueprinting" functionality of Energy3D. At the center is the 3D house that can be rotated. Surrounding it are the 2D pieces that are annotated and can be printed out for cutting and assembling.

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[6] This idea is similar to Fab@School (http://www.youtube.com/watch?v=Qzlcuk1tmhE).

If students are not sure where a piece is located during assembly, they can go back to *Energy3D* and click on the corresponding virtual piece in the 3D computer model, which will then be highlighted to indicate its position. Thus, the software tool remains useful during the hands-on construction. If any revision is needed after a physical scale model has been constructed, *Energy3D*'s blueprint feature can help students evaluate whether a modification is feasible by calculating how many pieces will need to be changed and whether there will be enough materials to make the changes.

Beyond Geometric Modeling

Many CAD tools such as *SketchUp* are mainly geometric modeling tools. They do not perform calculations to evaluate the mechanical, physical, and environmental consequences of a design. This limits their values as tools for teaching and learning science and engineering. Engineering is not only about designing something that looks aesthetically pleasant, but also about testing if the design actually works to meet the client's needs during operation. A complete engineering project is an iterative process of design, construction, testing, and analysis until all client requirements are satisfied in an optimal way.

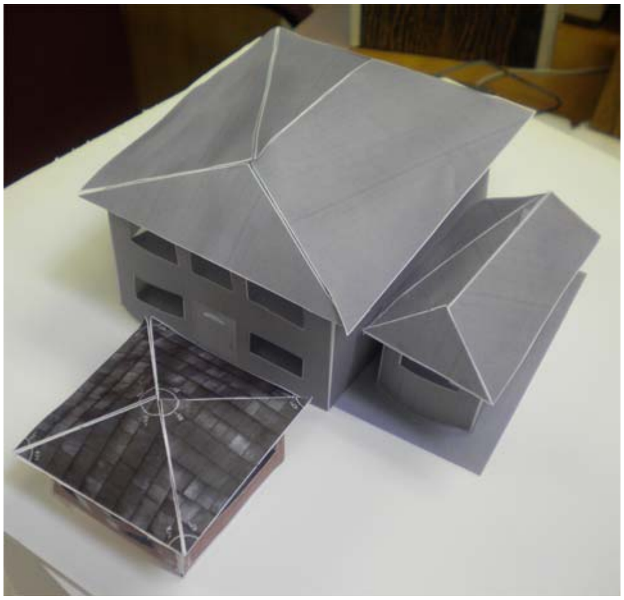

Figure 5. Two scale model houses assembled from Energy3D's blueprint outputs.

An ideal educational tool should support the full engineering cycle. Such a tool extends engineering education beyond conventional CAD based on only geometric modeling and can be considered as a more comprehensive computer-aided engineering (CAE) system. An educational CAE system should allow students to design a virtual structure, test if it works, and analyze why it succeeds or fails. For instance, if the structure is a house, the user will be interested in exploring questions such as "will it fall apart if built?", "will it be warm enough in winter?", and "can it survive an earthquake of 8.0 on the Richter scale?"

Answering these questions requires building a physics-based simulation engine that is capable of handling structural mechanics and/or heat transfer. Several plugins to *SketchUp* that add the capacity of building performance analysis exist.[7] However, these plugins were primarily designed for professionals. Their steep learning curves prevent them from being effectively used in the classroom. For example, the US Department of Energy's *OpenStudio* requires the user to be familiar with *EnergyPlus*'s command syntax in order to prepare a building simulation. An *EnergyPlus* simulation runs outside *SketchUp*, no real-time visualization back in *SketchUp* is rendered, and the results are viewed in unintuitive data sheets. This kind of interplay between multiple different tools is often confusing and poses difficulty to novice learners.

Our vision of an educational CAE system was inspired by the recent movement of serious games (Aldrich, 2005; Gee, 2007). A successful example is *FoldIt*,[8] a simulation game that engages users to manipulate protein structures to search for lowest-energy conformations and understand how proteins fold. As the player is tinkering with a protein structure, game scores are reported based on the total potential

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[7] http://sketchup.google.com/download/plugins.html
[8] http://fold.it

energy calculated in real time by a biophysical simulation engine behind the scene. By analogy, a game for building engineering can calculate—in real time—a number of indices such as material costs, energy consumption, and carbon footprint to measure the greenness of a building being designed, which drives the game play. Instructions, assessment, and learning goals in science and engineering can be embedded in the game play. This type of serious game falls into the category of construction and management simulation (CMS) that is increasingly used in job training (Rollings & Adams, 2003). Successful examples of CMS games such as *SimCity*[9] and *CityOne*[10] provide valuable additional guidance to our development.

Motivated by these visions, we are building an energy simulation engine into *Energy3D* that will inform students of the energy and environmental consequences of their designs. In *Energy3D*, a complex building is viewed as a network of nodes, each of which represents a physical volume in the building corresponding to a room, a wall, a renewable energy unit, a heating, ventilating, and air conditioning (HVAC) component, and so on (Clarke, 2001). Conservation equations are applied to each node that is in thermodynamic contact with others. These equations model the nodal conditions such as temperature and inter-nodal heat and mass transfers. The entire set of equations is solved simultaneously for successive time steps to predict the states of the nodes. Integrating energy inputs and outputs over all nodes yields the overall energy performance of the entire building. This engine will provide additional educational advantages to *Energy3D* and greatly broaden its educational applications (Figure 6).

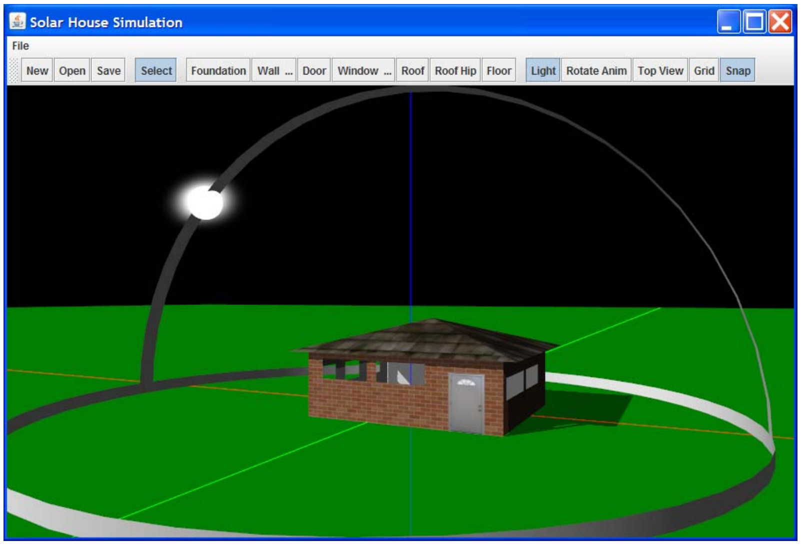

Figure 6. The heliodon wizard in Energy3D allows the user to study solar heating and shading of a house.

CURRICULUM, IMPLEMENTATION, AND RESEARCH

To test this assortment of cutting-edge educational technologies, we have developed four curriculum units to teach the engineering subject of energy, power, and heat transfer in buildings. These units are: 1) "Fundamentals of Heat Transfer," 2) "Heating and Cooling in a House," 3) "Natural Heating," and 4) "Natural Cooling." These units cover basic concepts in thermodynamics and heat transfer, engineering principles in building design, and energy efficient/passive houses, and lead to a capstone project of creating a green scale model house, for which students are expected to apply the scientific and engineering principles they have learned.

Many known issues with pre-college engineering education (Svihla & Petrosino, 2008) have been carefully considered in the project. The curriculum units can be plugged into a typical engineering course in high schools as they conform to content standards in Massachusetts and cover the same scope of content that is already taught in secondary schools (e.g., the *Engineering the Future* curriculum developed by the Boston Museum of Science is widely used at high schools in Massachusetts). Conversely, they can be

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[9] http://simcitysocieties.ea.com
[10] http://www-01.ibm.com/software/solutions/soa/innov8/cityone/index.html

used in a physics course to replace the module for heat and temperature to make the subject more engaging. The activity of designing a scale model house is more connected to everyday life and will likely promote students' interest and performance in the classroom (Hulleman & Harackiewicz, 2009). The topic is also particularly relevant today since energy science and technology are vitally important to a sustainable future and the message has been clearly conveyed to young students on many occasions. Therefore, this project has a good chance to interest and motivate *all* students, which will in turn provide excellent research opportunities for us to investigate the effectiveness of technology on engineering education.

We have conducted small-scale pilot tests of our technologies and curriculum units at three high schools in Massachusetts in the late spring of 2010, involving approximately 200 students (Figure 7). The results of these pilot tests provided important feedback and information for us to improve our technologies, pedagogies, and curricula. Preliminary exit surveys about *Energy2D* simulations showed most students responded very positively to the visualization of heat transfer and the ability to tweak the simulations, confirming the cognitive value of the tool.

A rigorous research plan based on the theoretical framework outlined in this paper is being developed. A pre-test about high school students' understanding of heat and temperature and their engineering applications has been administered to more than 100 students to provide baseline data. A control study has been devised to investigate the effect of computer modeling and simulation as the treatment. A larger-scale field test is planned for the winter of 2010, in which we will collect formal research data for performance assessment. Results of these tests will be published later.

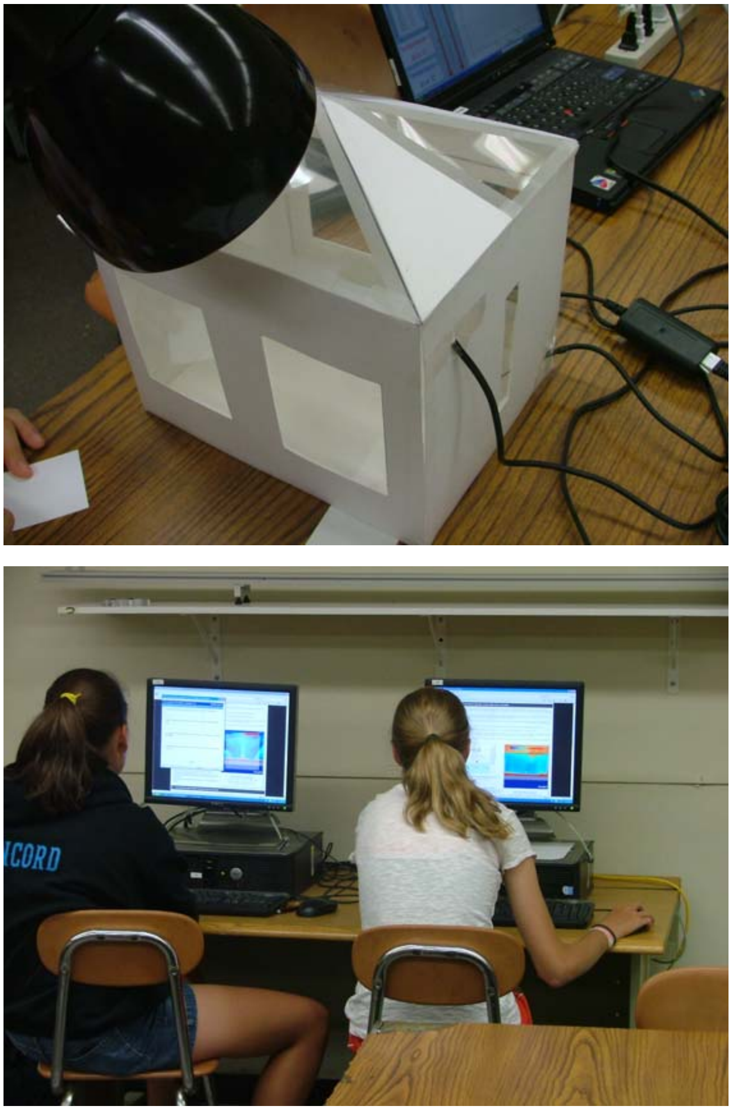

Figure 7. High school students worked with our hardware and software during the pilot tests in 2010. Upper: A group of students ran a solar heating test using temperature sensors on a scale model house they built collaboratively. Lower: Students ran Energy2D simulations in a computer lab to study heat transfer.

CONCLUSION

Engineering education in the 21st century should take advantage of 21st century technology. This paper expounds the idea of using technology as both cognitive tools and design tools to improve design-based learning. Many examples of learning opportunities resulting from the adoption of cutting-edge technologies are described and the corresponding research hypotheses are proposed wherever applicable. This paper laid down a theoretical and technological foundation for our research study that will probe into a number of critically important issues in science, engineering, and technology education. The presented insights about the application of technology may also be valuable to other engineering education projects that are unfolding across the nation as the topic of technical education is once again gaining importance in the nation's top agenda.

WEB LINK

http://energy.concord.org

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