Use of Interactive Computer Models to Promote Integration of Science Concepts Through the Engineering Design Process

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Abstract: During a *Solar Ovens* project in which middle school students design, build, and test solar ovens, students should also engage with science content to strengthen their designs. We integrate these two areas by using an interactive computer model to show how design decisions impact energy transformation inside a solar oven. This study investigates how students use a computer model to connect design decisions and science concepts at different points during a design project. Students engaged in either *planning* or *reflecting* by using the model before building or after, respectively. Students in the *planning* condition used the model in an exploratory manner, while students in the *reflecting* condition used the model to confirm the results of their physical solar ovens. Results suggest that using the model is helpful during both phases, but using the model during the *planning* phase helped students to better integrate their ideas about energy.

Keywords: science, engineering, computer models, technology, knowledge integration

Introduction

This research investigates how an interactive computer model could help students understand the interplay between science principles and engineering design decisions while carrying out a hands-on design project in a classroom setting. Often when students build a physical model they neglect the scientific basis for their decisions (Crismond, 2001). We address this challenge by engaging students in using a computer model that connects the science principles to their design decisions, consistent with the Next Generation Science Standards (NGSS) emphasis on science and engineering practices (NGSS Lead States, 2013). Interactive computer models can help students connect science principles and design decisions by making mechanisms such as energy transformation visible (Snir, Smith, & Grosslight, 1993; Wilensky & Reisman, 2006). Our research explores the effectiveness of the computer models, including whether they introduce confusions rather than supporting links between design decisions and energy concepts.

We used the knowledge integration framework to create a unit about solar ovens, with the goal of connecting design decisions and scientific principles (Linn & Eylon, 2011). The knowledge integration framework has proven useful for design of instruction featuring dynamic visualizations (Ryoo & Linn, 2012) and virtual design activities (Chiu & Linn, 2011; McElhaney & Linn, 2011). The framework supports linking of ideas by first eliciting all the ideas students think are important, then engaging them in exploring their ideas. When students build a physical artifact they can often only test a few of their ideas due to time and material constraints. Modeling allows students to explore many more ideas.

Besides testing the overall advantage of modeling for knowledge integration, we also investigate whether it is more effective to use modeling to connect design decisions and principles prior to building a physical model or following the model construction and testing. Modeling before building the physical oven could help students distinguish among alternatives such as whether to line the inside of the solar oven with black paper or with foil. Modeling after building a physical model could enable students to test conjectures that arose during the construction of the oven. The computer model we designed illustrates the flow and transformation of energy in a solar oven and allows students to make design choices and compare multiple designs

Methods

Participants and procedures

Two teachers from one middle school serving a diverse population (42% reduced lunch, 13% ELL) participated in this study. A total of 252 sixth grade students participated in this study, completing a pretest, the curriculum unit, and a posttest. The pretest was conducted one day before beginning the unit, and the posttest one day after

finishing the unit. Both the pretest and posttest were administered to students individually. Pairs of students were assigned to collaborative workgroups by their teacher to work on curriculum. Workgroups were randomly assigned to a condition (*planning* or *reflecting*) by the software and received the same activities in different orders.

Curricular materials

This study was implemented in a curriculum module entitled *Solar Ovens and Solar Radiation* (referred to as *Solar Ovens* in this paper). The goal of the unit was to familiarize students with the way energy transforms from solar radiation to heat through a hands-on project and interactive models, covering the modeling aspect of the Science and Engineering Practices of the NGSS, as well as the standards associated with energy, specifically standards related to the transfer of thermal energy (NGSS Lead States, 2013). Students engaged with the curriculum in WISE (Web-based Inquiry Science Environment), utilizing a variety of instructional and assessment tools (Linn & Eylon, 2011).

Table 1: *Solar Ovens* Curriculum. Students used the model EITHER for planning or for reflecting.

Activity	Description & Items of Interest
Introduction to Solar Ovens	Elicit initial student ideas about energy transformation
Solar Radiation and the atmosphere	Energy comes as radiation from the sun; energy can be absorbed or reflected. Students use a simulation to investigate energy.
Solar Radiation and Greenhouse Gases (GHGs)	Describes how energy interacts with greenhouse gases. Students use a model to investigate how addition of GHGs impacts energy.
Model for planning condition	**Students use an interactive model to investigate how radiation works in a solar oven [*Trials* item]**
Design, Build, Test 1	Design oven under budgetary constraints using a draw tool, build, test under a heat lamp using a temperature probe to collect data
Design, Build, Test 2	Students reflect on what was learned from the first iteration; use new budget constraints to repeat process [*Learn* item]
Model for reflecting condition	**Students use an interactive model to investigate how radiation works in a solar oven [*Trials* item]**
Reflect	Students describe how their solar ovens work using energy from the sun; make connections between solar ovens and the atmosphere [*Atmosphere* item]

Table 1 displays the general layout and features of the *Solar Ovens* curriculum unit. In this study we highlight those steps after the conditions diverge, specifically the embedded *Trials, Learn,* and *Atmosphere* items. In the *Trials* item students were asked to run at least three trials on the solar oven model, then write about what settings they used, how hot the oven got, and how long it took for the oven to get that hot. In the *Learn* item, which occurred between the two Design, Build, Test (DBT) iterations, students were asked what they learned from their first trial and how they will improve their design during the second iteration based on what they learned. In the *Atmosphere* item, students were asked to compare and contrast how radiation works in the atmosphere and in a solar oven.

The solar oven model was designed using NetLogo (Wilensky, 1999) (Figure 1). Each time students viewed a model, they made a prediction, interacted with the model to test their prediction, and wrote about whether their prediction was correct or incorrect and why.
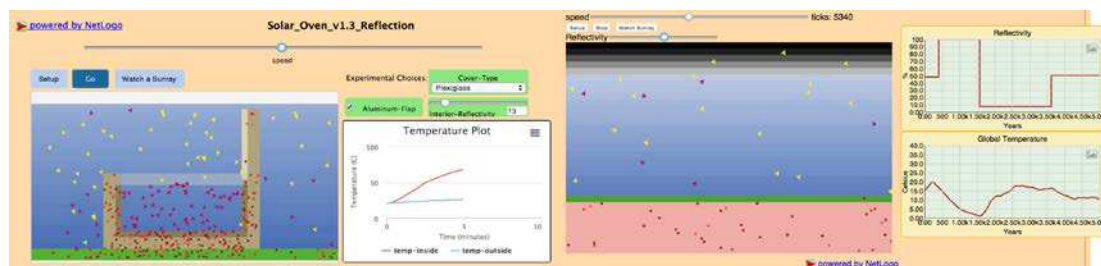

Figure 1: Screenshot of solar oven model (left) and solar radiation and the atmosphere model (right)

Test materials

The pre- and posttest assessments measured student ability to link concepts about energy. Typically the items offered a choice among options and asked for a written explanation of the choice, consistent with the knowledge

integration emphasis on linking ideas. For example the, *Car on a Cold Day (Car)* asked students to explain what would happen to a car left in the sun during a cold day. In another item, *Laura's Car,* students were asked what color interior and exterior Laura should have on her car in order to keep it the coolest on a sunny day (*Laura1*), and to explain whether or not Laura should use a sun shield to keep her car cool (*Laura2*). Students were also shown two pictures, of greenhouse gases in the atmosphere and of a greenhouse, and asked to compare them in *Greenhouse Gases 1 (GHG1)*, then asked to compare the atmosphere and a greenhouse with a solar oven in *Greenhouse Gases 2 (GHG2)*. One item, *Model,* asked students to use a basic solar oven model to answer help a fictional student determine whether a tall, skinny box or a short, wide box would heat up faster. The pretest is made up of the *Car, Laura1, Laura2, GHG1,* and *GHG2* items, while the posttest is made up of these same items with the addition of the *Model* item.

Analysis approach

To measure knowledge integration, the items were scored using knowledge integration rubrics to assess links between multiple normative science ideas (Linn & Eylon, 2011; Liu et al, 2008). The knowledge integration rubric for *Cars* shows how links are scored (Table 2).

Table 2: KI scoring rubric for "Car on a Cold Day" pre/post open response item

Score	Level	Examples
0	**No Answer**	
1	**Off Task**	*I don't know.*
2	**Irrelevant/Incorrect**	*The inside air and the outside air are the exact same temperature because the sun is not enough to heat the inside if the car.*
3	**Partial** Normative isolated ideas without a valid link	*The solar radiation would go through the metal and would stay in the car when the outside air wouldn't be able to get inside.*
4	**Basic** Elaborate a scientifically valid link	*it would be warmer than the outside air because if the car hasn't been driven for a week and its been in the sun the whole time the car will absorbe the heat and scence there is know way the heat can get out of the car the heat will just keep building up.*
5	**Complex** Elaborate two or more scientifically valid links	*The sun produces solar radiation which heats up the car and the infrared radiation gets trapped in the car which leads to the temperature rising.*

The *Learn* and *Atmosphere* items were scored using knowledge integration rubrics, while *Trials* was evaluated using an adjusted knowledge integration rubric. *Trials* was evaluated for use of numerical evidence, mention of energy transformation mechanisms, and completion of *Trials*, with students earning one point for each piece included in their response for a possible total of three points.

Results

Students in the *planning* condition outperformed students in the *reflecting* condition on posttest [*planning:* M=15.54, SD=0.32; *reflecting:* M=14.83, SD=0.26]. A t-test of pooled pre- and posttest data across conditions (*Car, Laura1, Laura2, GHG1, GHG2* items*)* revealed a significant effect of testing session [$t(473) = -5.81$, $p < 0.001$], demonstrating that across both conditions students made gains from pre- to posttest. A regression model showed that posttest scores were significantly influenced by condition when controlling for pretest scores [$F(247) = 27.11$, $p=0.05$], suggesting a benefit from interacting with the model earlier during the unit.

These results suggest that interacting with the solar oven simulation before DBT might be most beneficial, if time constraints allow for only one modeling phase. Additional support for this claim comes from the *Model* posttest item. Students in the *planning* condition performed slightly better than students in the *reflecting* condition [$t(240) = 1.88$, $p < 0.06$]. This is surprising since students in the *reflecting* condition would have the added benefit of interacting with a similar computer model recently (during the end of the unit), while approximately one week had elapsed for students in the *planning* condition since they interacted with the embedded model.

Students in the *planning* condition also performed better on scored items embedded in the unit [*Learn:* $t(248) = 2.43$, $p < 0.02$; *Atmosphere:* $t(248) = 1.83$, $p < 0.06$; *Trials*: $t(248) = 4.10$, $p < 0.001$]. Higher scores on the *Learn* and *Atmosphere* items, which were scored using a knowledge integration rubric, indicate that students were able to add more normative ideas and connect their ideas together. Higher scores on the *Trials* item indicates students used the model to run trials of their existing or future ovens, wrote about the results using numerical

values, and connected the energy concepts with their design choices. A regression model also showed that posttest score across conditions was by influenced by score on the *trials* item, when controlling for pretest score [$F(247)$ = 30.57, $p < 0.02$], indicating that students who scored higher on the *trials* item were more likely to score highly on the posttest.

Conclusions and implications

This study shows how students use computer models in conjunction with hands-on activities. This combination allows students to connect science concepts to their design decisions.

During the Solar Ovens unit, the modeling activity strengthened the links between the science concepts and design decisions, offering students a space to plan and test their designs in the *planning* condition, or to confirm their results and make further connections after they engaged in design process (*reflecting* condition).

Students who used the interactive model for *planning* during the unit were more likely to make gains on the integration of energy concepts between pre- and posttest. Many students in the *reflecting* condition used the model for very simple confirmatory analysis of models they had already built, which was not as helpful as using the model during the *planning* phased to connect science and design ideas.

In future studies we plan to explore patterns of student interactions with the model by collecting log data. The log data will consist of the clicks students make within the model and the time at which they make them. Using this data, we will also be able to evaluate the amount of time students spent on the model, how that differs by student pair, and how systematic or unsystematic students explorations with the model are. Some early research has been done on analysis of student log data from interactive computer models, showing that this is a feasible addition to our research on student use of computer models (Conati et al, 2015).

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