Solar Cookers - High School Sample Classroom Task

Introduction

People all over the world cook using electricity, gas, coal, and wood as a heating source. With decreasing access to the natural resources required for use as a fuel, many people are now turning to an alternative solution that uses the sun. The most basic design of the solar oven is one of a box with a hole in the top covered by a transparent material. The sunlight enters the box through the window and hits the surface of the inside of the box (painted black), which transforms the solar energy to thermal energy, increasing the temperature on the inside of the box. How well the heat stays in the box depends on the materials and design of the box.

In this task, the students use a simplified equation to create a computational model (in this case, a spreadsheet) to test the effects of changes in various elements on the temperature in the oven by keeping all variables constant in each simulation and changing only the variable being tested; the students plot and compare the data for each simulation. The simplified equation relates the thermal energy (as measured by the change in the temperature of the box) to the amount of solar energy hitting the walls of the box (affected by solar flux and the area of the window in the box) and to the other design components of the box (area, efficiency of box design, and thermal resistance of the box material). Using their designs, equations, and simulations, students also engage in the design and engineering process as they build and revise their own solar ovens using principles of energy transformation and transfer within the solar box system and the results of their simulations.

This task was inspired by:

- *National Air and Space Administration's "Build a Solar Oven" activity: www.nasa.gov/pdf/435855main_BuildaSolarOven_6to8.pdf*
- *Fernandez-Burgos, M., Tracy-Wanck, S., Schmidt, J., Hastings, H., & Gorham, H. (2008). Solar cooker earth analog and comparison of design efficiency. Available at: http://jvarekamp.web.wesleyan.edu/CO2/Solar%20Cooker%20Paper.pdf*

Standards Bundle

(Standards completely highlighted in bold are fully addressed by the task; where all parts of the standard are not addressed by the task, bolding represents the parts addressed.)

CCSS-M

MP.1	**Make sense of problems and persevere while solving them.**
MP.2	**Reason abstractly and quantitatively.**
MP.3	**Make viable arguments** and critique the reasoning of others
MP.4	**Model with mathematics**
MP.5	**Use appropriate tools strategically.**
HSN.Q.1	**Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.**
HSN.Q.2	**Define appropriate quantities for the purpose of descriptive modeling.**
HSA.CED.3	**Represent constraints by equations** or inequalities**, and by systems of equations** and/or inequalities**, and interpret solutions as viable or nonviable options in a**

modeling context.

HSA.CED.4 **Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.**

HSF.LE.1b **Recognize situations in which one quantity changes at a constant rate per unit interval relative to another.**

HSG.MG.3 **Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost;** working with typographic grid systems based on ratios).

HSS.ID.6 **Represent data on two quantitative variables on a scatter plot, and describe how the variables are related.**

HSS.ID.6a **Fit a function to the data**; use functions fitted to data to solve problems in the context of the data. Use given functions or **choose a function suggested by the context. Emphasize linear, quadratic, and exponential models.**

HSS.ID.6c **Fit a linear function for a scatter plot that suggests a linear association.**

<u>NGSS</u>

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-PS3-2 **Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as either motions of particles** or energy stored in fields**.**

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

HS-ETS1-3 **Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.**

<u>CCSS-ELA/Literacy</u>

W.9-10.2 **Write informative/explanatory texts to examine and convey complex ideas, concepts, and information clearly and accurately through the effective selection, organization, and analysis of content.**

WHST.9-10.2 **Write informative/explanatory texts, including the narration of** historical events**, scientific procedures/ experiments, or technical processes.**

W.9-10.2.a & WHST.9-10.2.a

Introduce a topic**; organize complex ideas, concepts, and information to make important connections and distinctions; include formatting (e.g., headings), graphics (e.g., figures, tables),** and multimedia **when useful to aiding comprehension.**

W.9-10.2.d **Use precise language and domain-specific vocabulary to manage the complexity of the topic.**

WHST.9-10.2.d **Use precise language and domain-specific vocabulary to manage the complexity of the topic and convey a style appropriate to the discipline and context** as well as to the expertise of likely readers.

W.9-10.2.e & WHST.9-10.2.e

Establish and maintain a formal style and objective tone while attending to the norms and conventions of the discipline in which they are writing.

W.9-10.2.f & WHST.9-10.2.f

Provide a concluding statement or section that follows from and supports the information or explanation presented (e.g., articulating implications or the significance of the topic).

W.9-10.7 & WHST.9-10.7

Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, **demonstrating understanding of the subject under investigation.**

Information for Classroom Use

Connections to Instruction

This task is aimed at students who have completed Algebra 2 and have either completed Geometry or are currently taking Geometry (10th or11th grade). This task would fit within an instructional unit on energy, including solar energy, the production and transfer of thermal energy (thermodynamics), and/or sustainability in an integrated science course, a physical science course, or a physics course. The calculations and plotting within this course could be used in an integrated math/science course to check student understanding following a unit on solving equations with one variable or describing trends in the data as functions.

The model in Task Component A could be used as a check for understanding of energy transformation and transfer within a system. Because the calculations in the simulation are used to make decisions and support explanations in the other task components, the initial development of the computational model in Task Component C should be formative, followed by Task Components E and G as subsequent opportunities for students to demonstrate the use of the computation simulation. Task Component D serves as an opportunity for students to demonstrate their ability to interpret the data using the functions and plots. Task Components B and F allow students multiple opportunities to check for understanding on the associated science and math concepts through the design, test, and redesign of the solar oven- please not that careful attention must be given to safety concerns, and any necessary safety related constraints should be paramount in the design. Task Component H could serve as the ultimate check for understanding of the design process, but should be closely monitored by the teacher for safety reasons. To save time, or given regulations preventing the building and testing of solar ovens, the design parts of the task (Task Components B, F, and H) could be removed, but by doing so the NGSS and CCSS-M standards associated with those task components, such as HS-PS3-3, as listed in the alignment description section will be less completely addressed.

This task provides the opportunity for an interdisciplinary collaboration with ELA/Literacy in the assessment of conducting and reporting on research. As students progress through the components of this task, A through H, they will be conducting and reporting the results of sustained research, using writing to inform or explain as a part of this process. The writing produced can, at the conclusion of the task components, be organized and formatted as demonstration of conducting research. Students can be assessed formatively on various aspects of writing to inform or explain (describing, discussing, comparing, reporting) on Task Components B, C, D, E, F, G, and H. This task has been aligned with the ELA/Literacy standards for the 9–10 grade band. Teachers using this task in grades 11 or 12 should consult the corresponding CCSS for the 11–12 grade band.

Accommodations for Classroom Tasks

To accurately measure three dimensional learning of the NGSS along with CCSS for mathematics, modifications and/or accommodations should be provided during instruction and assessment for students with disabilities, English language learners, and students who are speakers of social or regional varieties of English that are generally referred to as “non-Standard English”.

Approximate Duration for the Task

The entire task could take 6–12 class periods (45–50 minutes each) spread out over the course of an instructional unit, with the divisions listed below:
Task Component A: up to 1 period, depending on whether parts are done outside of the classroom.
Task Component B: 1–3 class periods, but may vary depending on time needed for oven to heat up
Task Components C, D, and E: 2–4 class periods, depending on whether parts are done outside of the classroom
Task Component F: 1–2 class periods, but may vary depending on time needed for oven to heat up
Task Component G: 1–2 periods, depending on whether parts are done outside of the classroom.
Task Component H: 1–2 class periods, but may vary depending on time needed for oven to heat up
(Note: Time for the task could be reduced for this task if the design and design test parts are not included, but removal of these parts will affect the assessment of the standards - see the “Connections to Instruction” section.)

Note that this timeline only refers to the approximate time a student may spend engaging in the task components, and does not reflect any instructional time that may be interwoven with this task.

Assumptions

The teacher will need to familiarize him/herself with the design elements of solar ovens (see examples in supplementary resources) and the components that go into the ΔT equation before assigning the task. It is highly recommended that the teacher build and test a solar oven, and run the computational simulation first before assigning the task. Teachers should be prepared to address the safety concerns related to testing a solar oven.

The students will need to have familiarity and comfort with using a spreadsheet program, including building functions within a cell to link the changes in one variable to the changes in the other variables and plotting data on scatter plots. Students will also need to have covered and understand solar and thermal energy well enough to create the energy model and knowledgably build and refine a simple solar oven. Students should be aware of the safety concerns of building a solar oven, such as skin burns and material combustion dangers from high temperatures before attempting to test their ovens.

Materials Needed

- Students will need access to a spreadsheet computation program to create the computational model.
- Student and teachers will need access to proper safety materials including a fire extinguisher and a first aid kit when testing the oven designs.
- Depending on the sophistication of the oven built by students and the resources available, the student will need the following at minimum:
  - a box for the oven
  - material to make the inside surface of the oven dark
  - transparent material for the window of the oven (can be optional)
  - material for reflectors, including aluminum foil for the surface of any reflectors

- materials, such as tape/glue, to put the box together
- string, sticks, etc., to arrange the box relative to the sun and to keep reflectors positioned
- a thermometer to read the temperature inside the box.

Supplementary Resources

- Thermal conductivity of materials: www.engineeringtoolbox.com/thermal-conductivity-d_429.html
- University of Arizona College of Optical Science "Approaches to Designing a Solar Oven": http://azmesa.arizona.edu/sites/azmesa.arizona.edu/files/Solar%20Oven%20Design.pdf
- Thermal Resistance and Thermal Conductance: www.ctherm.com/products/tci_thermal_conductivity/helpful_links_tools/thermal_resistance_thermal_conductance/
- Fernandez-Burgos, M., Tracy-Wanck, S., Schmidt, J., Hastings, H., & Gorham, H. (2008). Solar cooker earth analog and comparison of design efficiency. Available at: http://jvarekamp.web.wesleyan.edu/CO2/Solar%20Cooker%20Paper.pdf
- Cavalcanti, E. J., Maranhão, S. S. A., Motta, H. P. (2011). Evaluation of the efficiency of a solar box cooking by recyclable material. Available at: www.sigaa.ufrn.br/sigaa/verProducao?idProducao=744425&key=42da9327f2035bf1e58330c67eb09efb
- Information on solar flux values: www.newport.com/Introduction-to-Solar-Radiation/411919/1033/content.aspx
- Links for building a box solar oven:
  www.hometrainingtools.com/a/build-a-solar-oven-project
  www.nasa.gov/pdf/435855main_BuildaSolarOven_6to8.pdf
  www.wikihow.com/Make-and-Use-a-Solar-Oven
  http://herbangardener.com/2010/07/15/how-to-build-a-solar-oven/

Assessment Task

Context

When humans first began cooking, we entered an exciting culinary and health-related time: cooking renders many foods edible that would be otherwise dangerous, while also rendering nutrients within our food more easily digestible. People all over the world cook their meals using a variety of heat sources, including electricity, gas, coal, and wood. With decreasing access to the natural resources required as fuel sources, many people are now turning to an alternative solutions that utilize easily accessible, renewable energy resources, such as solar energy. As a result, solar ovens are becoming more prevalent in many parts of the world as a relatively inexpensive and renewable option.

The design of a solar oven is based on the principles of heat conversion from solar energy to thermal energy as well as the principles behind conduction of heat through materials. At the most basic, a solar oven is a box with a hole cut in the top to let light in. The light will hit the inside surface of the box and be transformed from solar energy to thermal energy. The surface of the inside of the box is painted or altered in some way to increase the amount of solar energy that is transformed to thermal energy. A transparent material covers the window to let the solar energy in and to prevent the thermal energy from leaving. Once the solar energy is transformed to thermal energy, it needs to be kept in the box and prevented from leaving so that the inside of the box can reach high enough temperatures for cooking. Some materials let heat conduct through easily and others are insulators and prevent significant heat conduction. The material from which the box walls are made and the thickness of the walls of the box are important components for keeping as much thermal energy in the box as possible. So, the design of the solar oven requires components that maximize the amount of solar energy entering the box, maximize the conversion of solar to thermal radiation at the inside surface of the box, and prevents as much heat as possible from leaving through the walls of the box.

These design components are included in the simplified equation below that relates the thermal energy (measured by the change in the temperature of the box) to the amount of solar energy hitting the walls of the box (affected by solar flux and the area of window in the box) and to the other design components of the box (surface area of walls, efficiency of box design, and thermal resistance):

<u>Change in Temperature within the Solar Oven</u>
Symbol Equation: $\Delta T = (R)\,(\eta_o)\,(H_{sn})\,(A_W/A_B)$
Word Equation: *(change in temperature) = (thermal resistance of box material) x (efficiency of design) x (solar flux) x (area of rays hitting oven ÷ area across which heat is lost)*

<u>Relationship between Thermal Conductivity and Thermal Resistivity</u>
Symbol Equation: $k = L/R$
Word Equation: *(thermal conductivity of a material) = (distance the thermal energy has to travel) ÷ (thermal resistance of box material)*

<u>Symbols/Units</u>:
- ΔT- temperature difference between the inside and outside of the box; °C
- R- thermal resistance of box material, $(m^2 °C)/W$
- W- area of the window (m^2)
- L- thickness of box walls, m
- k- thermal conductivity of box material; W/(°Cm)
- η_o- efficiency value of oven; 0 to 1 scale, with 1 being the most efficient
- H_{sn}- solar flux; (W/m^2)

A_W- area that solar rays are hitting the oven, area of the window; m^2
A_B- area across which heat is lost, surface area of the box; m^2

The solar flux (H_{sn}) represents the rate of transfer of solar energy through an area; in other words for this situation, how much solar energy is available at the surface of the Earth. This number is higher on sunny days and lower on cloudy days,
when the particles in the air disperse much of the solar energy. This number also varies depending on the season, the distance of the box from the equator, and the elevation of the the box. The solar flux varies between 0 and a maximum of approximately 1100 W/m^2.

The efficiency value (η_o) is a number that represents how effective the box is at converting solar energy into heat energy. A value of 0 represents no conversion of solar energy to thermal energy, while a value of 1 represents a complete conversion of solar energy to thermal energy. This value factors in the solar flux in terms of how well the solar energy enters the box: because direct sunrays entering perpendicular to the box allow for the maximum amount of energy to be converted, due to the fact that maximum amount of solar energy will be directly entering the surface area of the box at a 90° angle. With an angle of incidence resulting from of indirect sunrays entering the box, at an angle less than 90°, less sunlight will be directly hitting the surface of the box, and therefore less solar energy can be converted than in the direct case. The efficiency value also factors in how much of the available solar energy is actually converted to thermal energy at the surface of the box, a conversion that at best is usually no more than 90% efficient.

When designing a solar oven, all of the factors listed and discussed above must be considered. In addition, there are also human constraints to be considered that relate to how the oven will be used by people, where the ovens will be used, how expensive the oven will be to make, etc. Because ovens are designed and tested in different settings (geographic and cultural) around the world, engineers and scientists are coming up with designs that work well and are actually used by the people who need them most.

In this task, you will use the equations listed above to create a computational model to better understand the parameters that affect the maximum temperature a solar oven design could achieve, and then guided by your simulations, design, build, test, and redesign a solar oven of your own.

Task Components

A. Draw a series of models of an empty solar oven, using labels and arrows to show the transformation and movement of energy at two different scales: one depicting the molecular-level-scale and one depicting a macro-scale. In your molecular scale model, use molecular-level representations of part of the internal wall of the oven to show the transformation of solar energy to thermal energy, including any changes in molecular motion. Be sure to identify the features of this surface that maximize the transformation of energy in the solar oven and illustrate the change in form of energy at the molecular level. In your macro-scale model of the entire oven, use your model to show the relative magnitude and direction of movement of the energy inputs, outputs, and energy transformations though the movement of molecules and matter within the oven and between the oven and the surroundings, and showing that all energy is conserved.

B. Design and construct a simple solar oven that will maximize the change in temperature within the oven. First, create a design plan that includes a scale drawing of your oven and that takes into account the scientific principles and energy changes outlined in your model in Task

Component A. Discuss the reasoning behind the components of your design as they relate to your understanding of energy conversion from solar to thermal energy. Test your oven design by determining intervals for temperature collection, and collecting peak temperature data at those determined intervals for your oven until the temperature stabilizes. Calculate the change in temperature between the inside of your oven and the temperature outside of your oven. *SAFETY NOTE: Be aware that while testing your solar oven, the temperatures inside the oven will become elevated and may cause burns or may cause the oven materials to combust.*

C. Using the equations provided, write an equation for the change in temperature within the solar oven due to solar energy, using thermal conductivity and the thickness of the box walls in place of thermal resistance. Be careful to keep track of your units. Use the equation that you constructed to create a computational model using a spreadsheet program to calculate the change in temperature in the solar oven as the values in the equation are changed. For each of the following, run a simulation for a range of values changing only that variable. Pick reasonable values for all unchanging variables and do not change them throughout each simulation.

a. change in temperature when the size of the box (A_B) is changed
b. change in temperature when the size of the window of the box (A_W) is changed
c. change in temperature when the solar flux is changed (min/max range of 100-1100 W/m^2)
d. change in temperature when the wall material type (conductivity-k) is changed (0.024 & up)
e. change in temperature when the wall material thickness (L) is changed
f. change in temperature when the efficiency of the solar box design (η_o) is changed (0.1-0.9)

Record the change in temperature relative to the change in the variable during each simulation and create a scatterplot for each set of the data. Be sure that each of your scatter plots has appropriate scales, axis labels, unit labels (where applicable), and titles. Communicate (written or orally) a narrative describing the system you are modeling in your simulation, including initial conditions, justifications for any values you chose, and how the changes you are making digitally would translate to a physical construction.

D. Compare your scatter plots showing the change in the parameters of the equation relative to the temperature of the oven. Determine the type of function (linear, exponential, etc.), if any, that would best describe the change in temperature relative to the change in each variable. Construct an explanation for what the function types that describe the data tell you about how the temperature in the oven changes with a change in each parameter. Describe whether or not the changes are proportional and if there are ranges in the values where the change in temperature may be greater than the temperature change for other ranges in the data. Also, describe any similarities or differences between the function type and the type of variable.

E. Change the variables in the equation in your spreadsheet to create the greatest temperature change within the solar oven box. Report the variables you have chosen and the resulting temperature change. The variables you choose must follow the listed criteria:

- The length of the longest side of your box must not be greater than one meter.
- The length of the longest side of your box must not be less than 0.25m
- The solar flux cannot exceed 500 W/m^2
- The efficiency value of the solar oven design cannot exceed 0.6.
- The thickness of the box walls must be between 0.01and 0.05m.
- A_W cannot exceed the surface area of the box.

Consider whether the values you have chosen for each variable are reasonable given environmental and societal considerations related to the design of solar ovens. These might include factors such as the portability of the ovens, the availability and cost of materials to make the ovens, the durability of the ovens, the ability to fit pots and other cooking vessels inside the oven, etc. Describe any tradeoffs you might need to consider and show how the values of your variables change to reflect these tradeoffs. Describe how these considerations affect the predicted temperature change inside the box.

F. Using what you have learned from working with your spreadsheet calculations and the temperature data you collected during your first test, refine the design of your solar oven and update your design plan to further maximize the change in temperature within the oven and to meet the constraints you identified. Discuss the reasoning behind the components of your design as they relate to the components of the equation and your spreadsheet calculations. Test your redesigned oven. Using the same criteria as stated in part B, collect peak temperature data for your oven and calculate the change in temperature between the inside of your oven and the temperature outside of your oven. Compare the two temperature values and discuss why you think the changes you made lead to the change in the temperature values. In your discussion, consider the spreadsheet calculations you made in Task Component E. How were these calculations useful for predicting the change in temperature values you observe here? Were there limitations to the usefulness of your equations? Specifically describe which variables were the most uncertain or most difficult to choose values for, given your design.

G. Reflectors can be added to a solar oven box to increase the amount of solar energy captured. The reflectors work by increasing the area of solar energy that is captured beyond the maximum size of the window. This can be factored into your spreadsheet calculations by increasing the area of the window (A_W) to a number greater than the surface area of the top of the box. Run a simulation as you did in Task Component C, but this time find the change in temperature when reflectors of various area are added to the box (extra area added to A_W greater than the surface area of the top of the box). Plot the change in temperature and A_W values on a scatter plot and describe the shape of the data.

H. Using all you have learned in previous task components, update your design plan and make one final revision to your solar oven design. Test your redesigned oven. Collect peak temperature data for your oven and calculate the change in temperature between the inside of your oven and the temperature outside of your oven. Compare the temperature values from all the trials, and make a final statement for which design elements you think were most valuable in converting solar energy to thermal energy and maintaining the heat within the solar oven. Explain the reasoning behind your answer in terms of the energy conversion and the movement of heat between the box and the surroundings.

Alignment and Connections of Task Components to the Standards Bundle

Task Component A asks the students to create models of an empty solar oven that depict the molecular scale and the macroscopic scale showing the transformation of solar energy to thermal energy and the movement of energy within the oven and between the oven and the surroundings. This partially addresses the NGSS performance expectation of **HS-PS3-2** by addressing and integrating parts (individual bullets from the Appendices) of the core idea of **PS3.A: Definitions of Energy**, part of the practice of **Developing and Using Models**, and part of the crosscutting concept of **Energy and Matter**.

Task Components B, F, & H ask the students to design a solar oven, build the solar oven, test the solar oven, and then to redesign, reconstruct, and retest the solar oven given the calculations done in other task components. This partially addresses the NGSS performance expectation of **HS-PS3-2** and part of the associated practice of **Constructing Explanations and Designing Solutions**. This also partially addresses part of the NGSS core idea of **ETS1.A: Defining and Delimiting Engineering Problems**, part of the practice of **Planning and Carrying Out Investigations**, and part of the crosscutting concept of **Structure and Function**. By using measuring tools and geometric principles in the design and redesign process, the students understanding is checked on part of the CCSS-M content standard of **HSG.MG.3** and CCSS-M practice of **MP.5.** By making and supporting their claim for which design elements were the most valuable in converting solar energy to thermal energy and maintaining the heat within the solar oven, students address part of the NGSS practice of **Engaging in Argument from Evidence**. Furthermore, students demonstrate their performance of **MP.3** as they make and explain these claims. Discussing the relationships between their design and their understanding of energy conversion in **Task Component B**, comparing two temperature values in **Task Component F**, and comparing the temperature values from all trials in **Task Component H**, partially addresses **W.9-10.2**, **W.9-10.2.a**, **W.9-10.2.d**, **W.9-10.2.e**, **WHST.9-10.2**, **WHST.9-10.2.a**, **WHST.9-10.2.d**, and **WHST.9-10.2.e**,, writing to inform or explain

Task Components C, E, & G ask students to use the given equations to create a computational spreadsheet model they then use to find the change in temperature within a solar oven given the change in the components of the equation, including within defined constraints. This partially addresses parts of the NGSS practices of **Using Mathematics and Computational Thinking (as it relates to HS-PS3-1)** and **Developing and Using Models**; parts of the NGSS core ideas of **ETS1.C: Optimizing the Design Solution, ETS1.B: Developing Possible Solutions**, and **PS3.B: Conservation of Energy and Energy Transfer (via HS-PS3-1)**; parts of the NGSS crosscutting concepts of **Systems and Systems Models**, **Structure and Function**, and **Cause and Effect**; and the CCSS-M practices of **MP. 2** and **MP.4**. By combining the two given equations to make one equation, students are asked to partially address the CCSS-M content standard of **HSA.CED.4**. By keeping some variables in the equations constant and solving for one variable by changing the inputs, students partially address CCSS-M content standards of **HSN.Q.1, HSN.Q.2,** and **HSA.CED.3.** Without a demonstration of the ability to manipulate equations and solve for different variables, the science and engineering standards and dimensions could not be addressed, whereas the science equations and engineering context provide real life contexts for students to demonstrate proficiency on the math standards and practices.

Task Components C, D, E, & G also ask students to plot the data derived from the spreadsheet calculations, draw lines of best fit, describe the type of function that would fit the data, and then to comment on what the functions (linear, exponential, etc.) indicate about the change in temperature with the change in one variable over the change in another variable. This partially addresses CCSS-M content standards of **HSN.Q.1, HSF.LE.1b, HSS.ID.6, HSS.ID.6a,** and **HSS.ID.6c,** CCSS-M practices of **MP. 2** and **MP.4**, and parts of the NGSS practices of **Analyzing and Interpreting Data** and **Using Mathematics and Computational Thinking.** The plotting and modeling of the data as functions enhance the assessment of the science standards through a more complete description of the effect the change in the design components has on the temperature in the oven, while the data produced provides practical examples for the comparison of different mathematical functions. By asking students to compare, discuss, describe, or report their findings, **Task Components D and E** partially address **W.9-10.2**, **W.9-10.2.a**, **W.9-10.2.d**, **W.9-10.2.e**, **WHST.9-10.2**, **WHST.9-10.2.a**, **WHST.9-10.2.d**, and **WHST.9-10.2.e**, writing to inform or explain. By asking students to run simulations, change variables, and collect data to answer a research question, **Task Components C, D, E,** and **G** also partially address **W.9-10.7** and **WHST.9-10.7**, conducting research projects.

Together, **Task Components C, D, E, & G** fully address the NGSS performance expectation of **HS-ETS1-3**. Part of the core idea of **ETS1.B: Developing Possible Solutions**, part of the practice of **Constructing Explanations and Designing Solutions**, and part of the **Influence of Science, Engineering, and Technology on Society and the Natural World** are fully addressed and integrated when students create and use the computational spreadsheet model to test potential solutions for the solar oven design given specific criteria and constraints (practical, societal, environmental, etc.).

Together, **Task Components A, C, D, E, F & G** fully address the NGSS performance expectation of **HS-PS3-1.** Parts of the core ideas of **PS3.A: Definitions of Energy** and **PS3.B: Conservation of Energy and Energy Transfer**, part of the practice of **Using Mathematics and Computation Thinking**, and part of the crosscutting concept of **Systems and System Models** are fully addressed and integrated when students define the energy transformation and transfers into, out of, and within the solar box system and use that understanding to (a) define the limits on temperature (thermal energy) that can be produced within a box (via the computational spreadsheet model) given the design constraints and/or given the solar flux and (b) consider the usefulness of the different parameters for predicting the change in temperature of a solar oven, including for use in the redesign of an actual solar oven.

Together, through performance on **Task Components A, B, C, E, F, & H,** students can demonstrate their understanding of the NGSS performance expectation of **HS-PS3-3** as applied in this context**.** Parts of the core ideas of **PS3.A: Definitions of Energy, PS3.D: Energy in Chemical Processes**, **ETS1.A: Defining and Delimiting Engineering Problems**; part of the practice of **Developing and Using Models**; and part of the crosscutting concept of **Energy and Matter** are fully assessed and integrated when students define the energy transformation and transfers within the solar box system and test the effect of variations in different design components (via the computational spreadsheet model and following specific constraints) on the predicted temperature inside the oven, and then use that information and understanding to design, build, test, evaluate, redesign, rebuild, retest, and reevaluate their solar oven design. As students design, build, test, evaluate, redesign, rebuild, retest, and reevaluate, they will be engaging in making sense of and persevering while solving problems, and therefore students address **MP.1**.

By incorporating data and information from Task Components A, B, C, D, E, F, and G, **Task Component H** fully assesses **W.9-10.2.f** and **WHST.9-10.2.f**, providing a concluding statement that follows from and supports the information or explanation presented, as well as **W.9-10.2.e** and **WHST.9-10.2.e**, establishing and maintaining a formal style. Taken together, **Task Components A, B, C, D, E, F, G**, and **H** fully assess **W.9-10.7** and **WHST.9-10.7**, conducting research projects.

Evidence Statements

Task Component A

- Students construct a model depicting the wall of the solar oven at the molecular level to show the transformation of energy from solar to thermal energy:
  - Students develop a model with the following components, and identify and describe the components:
    - molecules within the wall of the oven in direct contact with one another
    - air molecules—more widely spaced than are wall molecules, and interacting with the wall of the oven
    - Incoming solar energy, in the form of radiation
    - Thermal energy/radiant heat, in the form of molecular movement
  - Students identify the following relationships among components in the model:
    - The transfer of molecular motion (heat) from the wall to the air.
    - The relationship between the addition of solar radiation and the production of thermal energy.
  - Students use the model to describe that the addition of solar energy leads to the production of thermal energy through the excitation of the molecules of the dark wall of the oven.
  - Students identify the color of the wall as a factor in the amount of solar energy converted into thermal energy.
- Students construct a model depicting the macroscopic-scale of the solar oven system to illustrate the movement of energy in the system:
  - Students develop a model with the following components, and identify and describe the components:
    - Solar energy
    - Thermal energy
    - The walls of the solar oven box
    - The window of the solar oven
    - The air inside the solar oven
  - Students identify and describe the following relationships among components of the model:
    - Solar energy as an energy flow into the system (input)
    - Thermal energy as an energy flow into the system (input), where it is formed at the walls of the solar oven through the transformation from solar energy
    - Movement of thermal energy through convection of air in the oven (energy flow within the system)
    - The output of thermal energy through the walls of the oven by conduction
  - Students use the model(s) to make the following connections:
    - Energy enters the oven as solar energy and is transformed at the walls of the oven to heat energy through the vibration of the molecules, connecting to the molecular scale model.
    - Thermal energy is distributed through the oven by convection and by conduction.
    - Thermal energy is lost through the oven walls by conduction.
    - If the system is defined as a closed system consisting of the oven walls, the air within the oven, and the air outside of the oven, no energy is lost within the system- just transformed- so that the total energy of the system remains the same.

Task Components B, F, & H

- In their original design plan, students:
  - Draw a scale representation of the oven showing the components and dimensions of the solar oven.
  - Justify the components and dimensions based on scientific reasoning related to how those components and dimensions maximize the desired function, including the capture of solar energy, the transformation of solar energy to heat energy, or the maintenance of heat energy within the oven.
- Students generate plan(s) for redesigning their solar oven. In their plans, students:
  - Draw a scale representation of the oven showing the components/dimensions of the solar oven, highlighting the places where the design has been changed.
  - Justify the components/dimensions based on scientific reasoning, observations from previous test(s), results of the computational simulations, and human and societal constraints.
- Students test the solar oven design by collecting peak internal temperatures at intervals that they determine.
- Students calculate the difference in temperature between the outside of the box and the inside of the box for each test of the solar oven design.
- In their comparisons of the designs:
  - Students identify and describe a connection between a change in the measured temperatures and a change in a design element.
  - Students describe scientific knowledge and/or results of the computational model as evidence to support the connection between the temperature difference and the design difference.
  - Students determine and describe how useful the equation is for predicting the change in temperature of an actual design, citing the effects of factors such as efficiency and solar flux that cannot be directly measured within the constraints of the task as written.
- In their final evaluation of the designs, students:
  - Make a claim identifying a design element that played the most important role in maximizing the change in temperature within the oven.
  - Cite as evidence the calculations, plots, or charts created in other task components.
  - Students evaluate the evidence to determine its sufficiency to support the claim as well as to counter any possible alternative explanations.
  - Make a connection between the design element and an increase in the amount of energy converted, the amount of solar energy entering the box, and/or the amount of energy that is kept in the box.

Task Component C & G

- Students reorder the equation for k, such that R is isolated on one side of the equation. Students add the resulting equation (L/k) to the ΔT equation in place of R.
- Students create and run a mathematical simulation that correctly associates the variables in the ΔT equation such that a change in any one variable produces a change in ΔT.
- Students create and run each simulation to produce a range in ΔT values for the range in design parameters.
- Students plot data for each simulation on a scatterplot with appropriate scales, axis labels, unit labels (where applicable), and title.
- Students describe the initial conditions of their system, including a justification of the unchanging numbers they chose as well as what the changes in parameters would mean for a physical construction.
- Students identify which specific function family best models the data from each simulation.

Task Component D

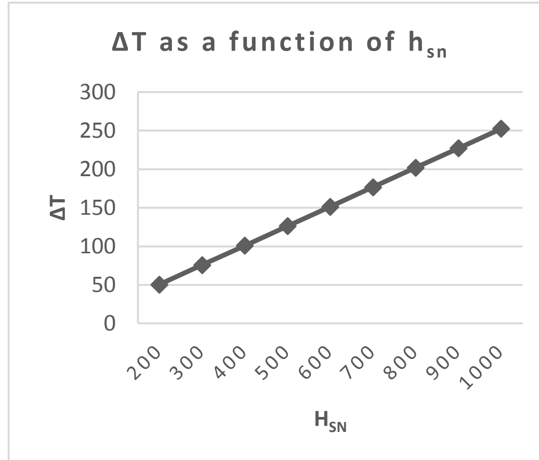
- Students construct an explanation that describes the relationship between
    - The type of function and how the ΔT changes relative to the variable.
    - The type of function and the type of variable.
- Students identify and describe the following observations from the data:
    - Linear relationships indicate that the changes in the variable are proportional to the ΔT.
    - Non-linear relationships indicate that one variable may have a greater change when there is a change in the other variable (different data ranges produce different ΔT values).
- Students show their reasoning that links the evidence to an explanation

Task Component E

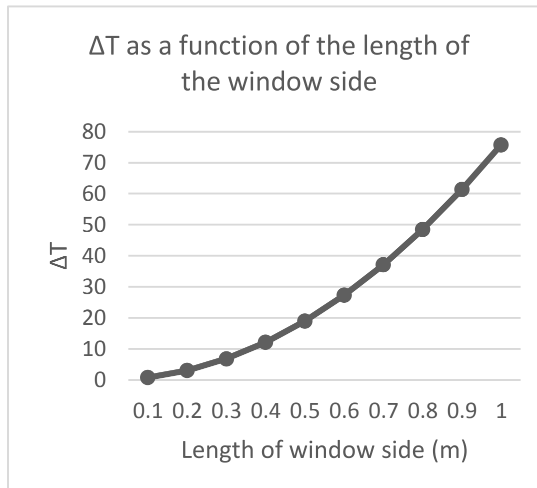
- Students report which variables are associated with the largest simulated temperature change that meets the listed criteria.
- Students make a statement that compares the numbers reported with student-produced criteria for environmental and societal considerations. Students include a statement about whether or not the numbers meet these new criteria/constraints.
- Students identify trade-off(s) between two variables or between a variable and a criterion or constraint, and describe the effect on the ΔT of the oven.
- Students describe the trade-off(s), including sound reasoning that ranks the order of importance of design variables relative to other design variables or criteria/constraints (e.g., the change in the size of the oven must be changed to accommodate the size of the cooking pots that will be going into the oven)

Sample Answers for the Computational Simulation

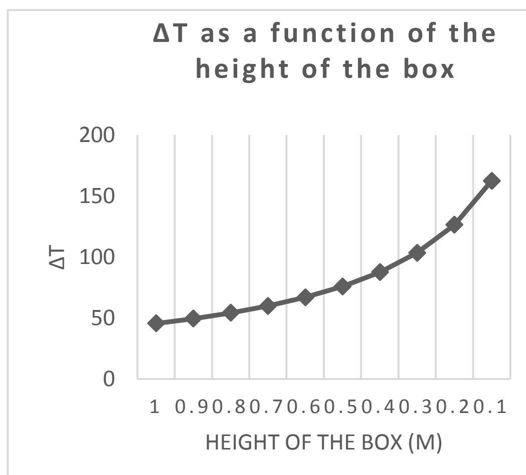
ΔT	L/k	η_o	H_{sn}	A_W	AB (walls & bottom)	AW / AB	height of box (m)	Width/ Length of Box (m)	Lenth of window side (m)	Width of Walls L (mm)	Width of Walls L (m)	k
Change in Solar Flux												
51	1.5152	0.5	200	1	3	0.33	0.5	1	1	50	0.05	0.033
76	1.5152	0.5	300	1	3	0.33	0.5	1	1	50	0.05	0.033
101	1.5152	0.5	400	1	3	0.33	0.5	1	1	50	0.05	0.033
126	1.5152	0.5	500	1	3	0.33	0.5	1	1	50	0.05	0.033
152	1.5152	0.5	600	1	3	0.33	0.5	1	1	50	0.05	0.033
177	1.5152	0.5	700	1	3	0.33	0.5	1	1	50	0.05	0.033
202	1.5152	0.5	800	1	3	0.33	0.5	1	1	50	0.05	0.033
227	1.5152	0.5	900	1	3	0.33	0.5	1	1	50	0.05	0.033
253	1.5152	0.5	1000	1	3	0.33	0.5	1	1	50	0.05	0.033



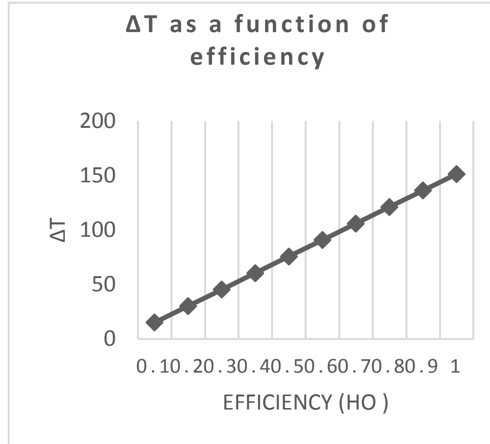
ΔT	L/k	η_o	H_{sn}	A_W	AB (walls & bottom)	AW / AB	height of box (m)	Width/ Length of Box (m)	Lenth of window side (m)	Width of Walls L (mm)	Width of Walls L (m)	k (conductivity)
Change in Size of Window												
1	1.5152	0.5	300	0.01	3	0	0.5	1	0.1	50	0.05	0.033
3	1.5152	0.5	300	0.04	3	0.01	0.5	1	0.2	50	0.05	0.033
7	1.5152	0.5	300	0.09	3	0.03	0.5	1	0.3	50	0.05	0.033
12	1.5152	0.5	300	0.16	3	0.05	0.5	1	0.4	50	0.05	0.033
19	1.5152	0.5	300	0.25	3	0.08	0.5	1	0.5	50	0.05	0.033
27	1.5152	0.5	300	0.36	3	0.12	0.5	1	0.6	50	0.05	0.033
37	1.5152	0.5	300	0.49	3	0.16	0.5	1	0.7	50	0.05	0.033
48	1.5152	0.5	300	0.64	3	0.21	0.5	1	0.8	50	0.05	0.033
61	1.5152	0.5	300	0.81	3	0.27	0.5	1	0.9	50	0.05	0.033
76	1.5152	0.5	300	1	3	0.33	0.5	1	1	50	0.05	0.033



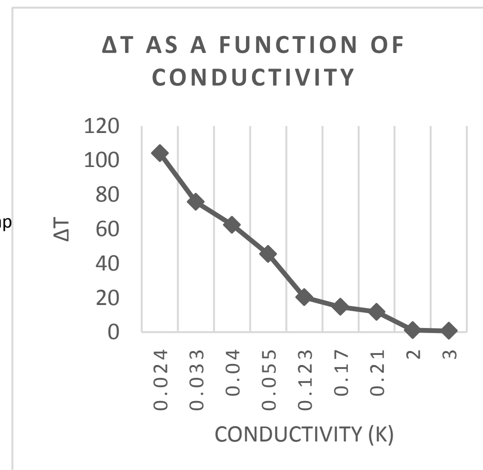
ΔT	L/k	η_o	H_{sn}	A_W	AB (walls & bottom)	AW / AB	height of box (m)	Width/ Length of Box (m)	Lenth of window side (m)	Width of Walls L (mm)	Width of Walls L (m)	k (conductivity)
Change in Size of Box (height)												
45	1.5152	0.5	300	1	5	0.2	1	1	1	50	0.05	0.033
49	1.5152	0.5	300	1	4.6	0.22	0.9	1	1	50	0.05	0.033
54	1.5152	0.5	300	1	4.2	0.24	0.8	1	1	50	0.05	0.033
60	1.5152	0.5	300	1	3.8	0.26	0.7	1	1	50	0.05	0.033
67	1.5152	0.5	300	1	3.4	0.29	0.6	1	1	50	0.05	0.033
76	1.5152	0.5	300	1	3	0.33	0.5	1	1	50	0.05	0.033
87	1.5152	0.5	300	1	2.6	0.38	0.4	1	1	50	0.05	0.033
103	1.5152	0.5	300	1	2.2	0.45	0.3	1	1	50	0.05	0.033
126	1.5152	0.5	300	1	1.8	0.56	0.2	1	1	50	0.05	0.033
162	1.5152	0.5	300	1	1.4	0.71	0.1	1	1	50	0.05	0.033



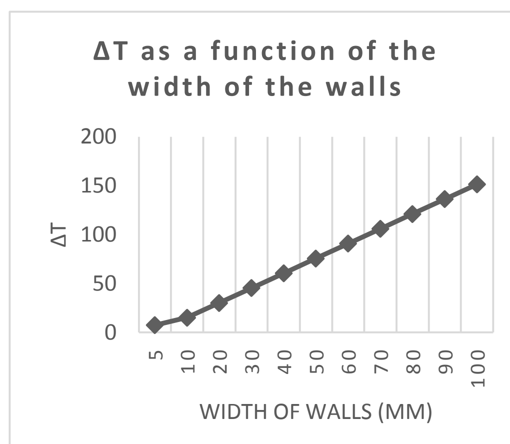
ΔT	L/k	η_o	H_{sn}	A_W	AB (walls & bottom)	AW / AB	height of box (m)	Width/ Length of Box (m)	Lenth of window side (m)	Width of Walls L (mm)	Width of Walls L (m)	k (conductivity)
Change in Efficiency of Box Design												
15	1.5152	0.1	300	1	3	0.33	0.5	1	1	50	0.05	0.033
30	1.5152	0.2	300	1	3	0.33	0.5	1	1	50	0.05	0.033
45	1.5152	0.3	300	1	3	0.33	0.5	1	1	50	0.05	0.033
61	1.5152	0.4	300	1	3	0.33	0.5	1	1	50	0.05	0.033
76	1.5152	0.5	300	1	3	0.33	0.5	1	1	50	0.05	0.033
91	1.5152	0.6	300	1	3	0.33	0.5	1	1	50	0.05	0.033
106	1.5152	0.7	300	1	3	0.33	0.5	1	1	50	0.05	0.033
121	1.5152	0.8	300	1	3	0.33	0.5	1	1	50	0.05	0.033
136	1.5152	0.9	300	1	3	0.33	0.5	1	1	50	0.05	0.033
152	1.5152	1	300	1	3	0.33	0.5	1	1	50	0.05	0.033



ΔT	L/k	η_o	H_{sn}	A_W	AB (walls & bottom)	AW / AB	height of box (m)	Width/ Length of Box (m)	Lenth of window side (m)	Width of Walls L (mm)	Width of Walls L (m)	k (conductivity)	Material Type
Change in Type of Box Material													
104	2.0833	0.5	300	1	3	0.33	0.5	1	1	50	0.05	0.024	air
76	1.5152	0.5	300	1	3	0.33	0.5	1	1	50	0.05	0.033	Styrofoam
63	1.25	0.5	300	1	3	0.33	0.5	1	1	50	0.05	0.04	Cottom
45	0.9091	0.5	300	1	3	0.33	0.5	1	1	50	0.05	0.055	Balsa wood
20	0.4065	0.5	300	1	3	0.33	0.5	1	1	50	0.05	0.123	Wadded Pap
15	0.2941	0.5	300	1	3	0.33	0.5	1	1	50	0.05	0.17	Drywall
12	0.2381	0.5	300	1	3	0.33	0.5	1	1	50	0.05	0.21	Card Board
1	0.025	0.5	300	1	3	0.33	0.5	1	1	50	0.05	2	?
1	0.0167	0.5	300	1	3	0.33	0.5	1	1	50	0.05	3	?



ΔT	L/k	η_o	H_{sn}	A_W	AB (walls & bottom)	AW /AB	height of box (m)	Width/ Length of Box (m)	Lenth of window side (m)	Width of Walls L (mm)	Width of Walls L (m)	k (conductivity)
Change in Width of Box Material												
8	0.1515	0.5	300	1	3	0.33	0.5	1	1	5	0.005	0.033
15	0.303	0.5	300	1	3	0.33	0.5	1	1	10	0.01	0.033
30	0.6061	0.5	300	1	3	0.33	0.5	1	1	20	0.02	0.033
45	0.9091	0.5	300	1	3	0.33	0.5	1	1	30	0.03	0.033
61	1.2121	0.5	300	1	3	0.33	0.5	1	1	40	0.04	0.033
76	1.5152	0.5	300	1	3	0.33	0.5	1	1	50	0.05	0.033
91	1.8182	0.5	300	1	3	0.33	0.5	1	1	60	0.06	0.033
106	2.1212	0.5	300	1	3	0.33	0.5	1	1	70	0.07	0.033
121	2.4242	0.5	300	1	3	0.33	0.5	1	1	80	0.08	0.033
136	2.7273	0.5	300	1	3	0.33	0.5	1	1	90	0.09	0.033
152	3.0303	0.5	300	1	3	0.33	0.5	1	1	100	0.1	0.033



ΔT	L/k	η_o	H_{sn}	A_W	AB (walls & bottom)	AW / AB	height of box (m)	Width/ Length of Box (m)	Lenth of window side (m)	Width of Walls L (mm)	Width of Walls L (m)	k (conductivity)
Change in the area of Solar Energy Converted >area of window (use of reflectors)												
83	1.5152	0.5	300	**1.1**	3	0.37	0.5	1	1	50	0.05	0.033
91	1.5152	0.5	300	**1.2**	3	0.4	0.5	1	1	50	0.05	0.033
98	1.5152	0.5	300	**1.3**	3	0.43	0.5	1	1	50	0.05	0.033
106	1.5152	0.5	300	**1.4**	3	0.47	0.5	1	1	50	0.05	0.033
114	1.5152	0.5	300	**1.5**	3	0.5	0.5	1	1	50	0.05	0.033
121	1.5152	0.5	300	**1.6**	3	0.53	0.5	1	1	50	0.05	0.033
129	1.5152	0.5	300	**1.7**	3	0.57	0.5	1	1	50	0.05	0.033
136	1.5152	0.5	300	**1.8**	3	0.6	0.5	1	1	50	0.05	0.033
144	1.5152	0.5	300	**1.9**	3	0.63	0.5	1	1	50	0.05	0.033
152	1.5152	0.5	300	**2**	3	0.67	0.5	1	1	50	0.05	0.033