TRANSFER OF **THERMAL ENERGY**

TEACHERS HANDOUT

Utah SEEd Standard PHYS.2.2
Next Generation Science Standard HS-PS3-4
Grade and Topic: High School Physics

THE UNIVERSITY OF UTAH
College of Education
UTAHFORGE

Transfer of Thermal Energy

Curriculum developed as a collaboration between the Utah FORGE project and the University of Utah College of Education, supported by the Department of Energy. This curriculum is aligned with national NGSS standards as well as the Utah SEEd standards. The curriculum provides support for diverse learners in diverse environments.

Contents

Overview

Thermal energy and the transfer of thermal energy plays a significant role in all of our lives. At a personal level, these processes are used in heating, cooling, and insulating our homes, in food preparation and safety, in our personal well-being and comfort. At the global scale, these processes are responsible for the Earth's climate and relevant to the current climate crisis. Most power plants, including geothermal plants, operate through the transfer of thermal energy. Enhanced geothermal energy systems are intended to make this transfer of geothermal energy more efficient than is possible through conduction and more widely available than existing geothermal energy systems.

In this lesson, students working in small groups of 3-5, will plan and conduct an investigation of how heat is transferred from one object to another. They will use this data to make inferences about the natural tendencies of heat distribution. To elaborate, students will conduct further investigations on other aspects of thermal energy transfer.

Grade and Topic:

High School Physics

Standards:

This lesson aligns with the following state and national standards

Utah SEEd Standard PHYS.2.2 -- Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system. Emphasize that uniform distribution of energy is a natural tendency. Examples could include the measurement of the reduction of temperature of a hot object or the increase in temperature of a cold object. (PS3.B)

Next Generation Science Standard: HS-PS3-4. -- Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). [Clarification Statement: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [*Assessment Boundary: Assessment is limited to investigations based on materials and tools provided to students.*]

Overall Objectives for Student Learning:

- Students will make observations about the 3 ways that heat is transferred and apply their observations to explain why objects come to thermal equilibrium.
- Students will plan and conduct an investigation of the transfer of thermal energy between objects with different temperatures.

- Students will use evidence to infer that the transfer of thermal energy results in a more uniform distribution of energy.
- Students will plan and conduct an investigation that furthers their knowledge of the transfer of thermal energy.

Prior Knowledge:

This lesson would fit into a unit on energy and energy transformations. Therefore, it is assumed that the students are familiar with the concepts of kinetic energy and energy transfer, including initial and final conditions. Likely the students are familiar with the kinetic theory of matter; matter is made of particles that are in constant motion, the phases of matter are a result of this motion.

Timeline:

This should take approximately four 90-min block class periods or eight 45-min class periods.

Materials:

See each section for the relevant material list

Support for Students with Disabilities

Students with Disabilities and at-risk learners benefit from specifically designed instruction that gives meaningful access to the general education curriculum (Individuals with Disabilities Education Act (IDEA), 2004). To ensure access to the core curriculum, evidence-based practices, including instructional scaffolding (Kim et al., 2018; Larkin, 2002) and explicit instruction (Archer & Hughes, 2010; Hughes et al., 2017), should be considered when developing lessons to meet individual student's learning needs. This document includes suggestions for teachers to individualize instruction when planning and implementing this lesson plan within each relevant section.

Activate Background Knowledge:

Review kinetic energy, energy, energy transfer, and initial and final conditions. Connect vocabulary to students' experiences with the content vocabulary.

Preparation:

Before Beginning

- Read the entire lesson sequence.
- Obtain materials for Explore and Elaborate sections.
- Decide what modifications to make, if any.

- Decide how to organize small class groups (students select their own groups, the teacher assigns groups, the teacher assigns groups with input from students, etc.).
- Decide how to share results for the Explain section.
- Decide the format of the presentations for the Elaborate section.

Day 1

- Prepare slides for the Engage presentation with the anchoring phenomenon and vocabulary words for class discussion. 6
- Prepare materials for the anchoring phenomenon.
- Prepare instructions and materials for heat transfer stations, set up stations.
- Prepare student handouts for the planning an experiment part of the Explore section.

Day 2

- Prepare materials for the Conducting an Experiment part of the Explore section.
- Prepare slides for discussing energy distribution in the Explain section.
- Prepare student handouts for energy distribution in the Explain section.

Day 3

- Prepare student handouts for the Planning an Experiment part of the Elaborate section.
- Prepare materials for the Conducting an Experiment part of the Elaborate section.
- Prepare materials for creating posters/presentations, whether as physical posters or as electronic presentations for the Elaborate section.

Day 4

- Upload student presentations.
- Prepare slides with students' expectations for being a good presenter and for being an active listener.
- Prepare slides with appropriate student responses.
- Prepare final assessment.

Engage: Stone Soup (60 min)

Student Objectives:

Students will make observations of a hot item added to water to warm the water and propose reasons that explain this phenomenon.

Students will make observations about the 3 ways that heat is transferred.

Students will apply these observations to their explanation of the warmed water.

Overview:

In this part of the lesson, the teacher describes the problem with ramen noodles and proposes a different way of cooking ramen: heating a rock and adding that to the ramen. The students test to see if their teacher's plan will work. First, they heat a metal cylinder in a water bath. Next, they transfer the heated cylinder to a beaker of cool water. Finally, they observe the results. Through small group and full class discussions, the students propose reasons to explain their observations. Next, the students will explore 3 stations that demonstrate how heat is transferred. Finally, the students will apply these forms of heat transfer to their explanations of why their teacher's proposed cooking method would or would not work.

Materials Needed:

Instant ramen, ie. Cup O'Noodles or Nissin (for demonstration)

A rock (for demonstration)

Each group of 4 students will need

1 metal cylinder, ie. specific heat or specific gravity cylinders

2 beakers filled with water

1 hot plate

1 pair of tongs or similar to safely remove the cylinder from the water bath.

1 thermometer

Station 1

1 beaker with ice water

1 beaker with hot water

1 beaker with water at body temperature

Station 2

1 hot plate

1 beaker filled with water

Glitter

Station 3

1 heat lamp

Student handouts – Stone Soup?, Station 1: Conduction, Station 2: Convection, and Station 3: Radiation

Safety:

Care should be taken around the hot plate and the heat lamp to avoid burns. Do not touch the hot elements, wait until they have cooled before handling. The hot water in Station 1 should be warmer than body temperature, but not hot enough to burn anyone. Prolonged contact with ice should be avoided.

Introduction (25 min)

To introduce the concept of heat transfer, the teacher will use the anchoring phenomena of heating soup. The teacher will tell a story about a "brilliant" idea they have to heat their instant ramen, then ask the students to test this idea by using a metal cylinder to heat a beaker of water. The teacher should set this station up in advance.

The physics is that the heat from the heated cylinder is being transferred to the water, which increases the motion of the particles of the water, increasing the temperature of the water. Heat will continue to move from the cylinder to the water until the temperatures are the same. This is a natural process that results in a more uniform distribution of energy in the system.

Suggested Teacher Script

[Teachers should modify the following story as relevant to their lives and classrooms.]

Okay, here is the deal. I am so busy with stuff right now [soccer practice, taking professional development classes, learning to kayak, etc.] that I almost never have time to prepare a lunch to bring to school! So, I went to the Chinese grocery and purchased a case of Nissin Instant Ramen. That should solve my problem, right?

But here is the problem, I can't microwave the water in the styrofoam cup! It doesn't work. And the hot water from the tap is not nearly hot enough. So, I was thinking, what if I put a rock on the heating vent to heat it up, and then added the rock to my instant noodles to heat the water. That should work, right? What do you think? No? Maybe? Possibly not?

[Accept answers from the students]

Alright, so you are going to help me test this idea. Now, it's going to take too much time to heat the rock on the heating vent. So instead, I'm going to have you heat a metal cylinder in a water bath, then transfer the cylinder to another beaker with water, and see if that will heat the water in the second beaker.

While you are doing this, I want you to think about what is happening to allow the hot cylinder to warm up the cool water. Think about what is happening in and around the cylinder and in and around the water. I want you to draw a model of what you think is happening. Then we will decide whether or not I should try using a hot rock to cook my ramen.

[Provide instruction on forming groups and safety (care in handling hot objects). Check to verify that the students understand the instructions, then allow students to begin working in their small groups.]

As the students work in their groups, the teacher will move through the class, checking on the different groups, asking questions, and highlighting observations.

Once the students have completed their observations and drawings of what is happening, the teacher will lead a full class discussion on heat transfer. First, the teacher should ask the students if they think this is a good or a bad idea. (It's a bad idea.) Students might describe how the cylinder was not hot enough to raise the temperature of the beaker very much, and how a rock sitting on a heating vent would probably be even less hot, so would work less well. The teacher should question this, why can't the cylinder heat the beaker up to nearly boiling? It was at that temperature when they added it to the beaker? This should raise questions about how much heat can flow from one object to another. The teacher should highlight ideas that are productive, such as only some of the heat from the cylinder is transferred to the water.

The teacher should also ask the students about their drawings, and what they think is happening in and around the water as the cylinder heats the water. Students might use words like heat, temperature, hot, cold. They might discuss the states of matter and the differences in the behavior of the particles in the solids and liquids, things like in solids the pieces jiggle, and in liquids they move around more. They might talk about energy, energy transfer, movement, flow. During the discussion, the teacher should collect the vocabulary words the students mention and introduce other relevant vocabulary words as needed.

The teacher should highlight ideas that are productive. For example, one productive idea is that heat is being transferred from the cylinder to the water. Another productive idea is that there is a difference between the motion of the molecules in the cylinder vs. the motion of the molecules in the water.

Before moving on, the teacher should check in with the students to see if they agree that the water heats up because heat is being transferred or moved from the cylinder to the water, and if they agree that there is a limit on how much heat can be transferred from one object to another.

Key Terms:

Kinetic Energy -- energy of motion. Anything that is moving has kinetic energy. Kinetic energy depends on the mass of the object, and how fast it's moving.

Thermal Energy -- heat energy, total kinetic energy of all of the particles in an object. Basically, you take all the moving particles, add up their individual energy from their motion, and that gives you the amount of heat.

Temperature -- the average kinetic energy of the particles in an object. This is what we measure with thermometers, and is how we determine if something is hot or cold. This is related to but fundamentally different than heat. Heat is all of the kinetic energy, temperature is the average kinetic energy. It is possible to have high temperature and low heat if the density is low (ex. the air in a hot oven).

Energy transfer -- energy, including heat energy, can be transferred from one object to another

Conduction -- the method of transferring heat from one object to another through direct contact, ie. The objects touch and heat flows between them

Convection -- the method of transferring heat from one object to another through fluid flow, ie. the fluid (liquid, gas, plasma) carries the heat from one place to another.

Electromagnetic Radiation -- energy in the form of electromagnetic waves. Light is a type of electromagnetic radiation. The electromagnetic spectrum includes radio waves, microwaves, infrared waves, visible light, ultraviolet radiation, x-rays, and gamma rays.

Infrared Radiation -- the part of the electromagnetic spectrum with longer wavelengths than visible light. Infrared radiation can be used to transfer heat. This is how we are able to hold our hand next to a fire or hot object and tell it is warm without touching it. This is how heat lamps work.

Additional Terms:

Fahrenheit temperature scale -- temperature scale commonly used in the United States, there are 180 degrees between the temperature at which water freezes, 32 degrees F, and temperature at which water boils, 212 degrees F

Celsius temperature scale -- temperature scale commonly used in most of the world, there are 100 degrees between the temperature at which water freezes, 0 degrees C, and temperature at which water boils, 100 degrees C

Kelvin temperature scale -- temperature scale commonly used in science, has the same increments as the Celsius scale, however, the scale is shifted such that 0 K is absolute zero, and indicates that there is no kinetic energy in the particles, absolute zero cannot be achieved.

Explanation (20-30 min)

Next, the students will explore 3 stations that demonstrate the ways that heat can be transferred. Heat can be transferred through conduction, convection, and radiation. The teacher should set these stations up in advance.

Conduction is when heat is transferred through direct contact. The students will touch each of the three beakers, one with ice water, one with hot water, and one with warm (body temperature) water. Heat is transferred from the hot beaker to the students' hands, from the students' hands to the cold beaker, and there is not a net transfer of heat for the beaker at body temperature (since there is a variation in body temperatures, it is unlikely that any student will not observe the temperature, however, if the beaker is at the same temperature as the student's hand, it will feel neither warm nor cool).

Convection is when heat is transferred through the motion of fluids. To demonstrate this, the students will place a beaker on a hot plate, turn the hot plate on, and add some glitter to the water. As the water heats from the bottom, the heated water will rise, displacing the water above it, pushing it to the side. This cooler water will move to the bottom of the beaker, establishing a convection cell. The motion of the fluid can be observed through the behavior of the glitter.

Heat is transferred through radiation in the form of infrared radiation. Students will hold their hands near the heat lamp to feel the heat coming off of this object.

Suggested Teacher Script

Okay, so we talked about how the heat is being transferred from the cylinder to the water, causing the temperature of the water to increase. [Just not enough to cook my ramen :( ] The next thing I want to discuss is the ways that heat can be transferred from one object to another.

You will be exploring 3 stations that demonstrate the various ways that heat is transferred.

[Provide instruction on forming groups, safety (care in handling hot objects), and rotating through stations. Check to verify that the students understand the instructions, then allow students to move to the three stations.]

As the students explore the stations, the teacher will move through the class, checking on the different groups, asking questions, and highlighting observations. The teacher will notify students when it is time to change stations.

Integration (5-10 min)

Finally, the teacher will ask the students to add three types of heat transfer to the drawings that they created earlier. The teacher will instruct the students to look again at their explanations and add to their drawing the places where the water is being heated (or cooled) by each process. The teacher should give the students a few minutes to finish this.

Suggestions for Specifically Designed Instruction in Engaging Students in the Lesson

A. Post expectations and directions in a form that is visual, explicit, and easy to access throughout the lesson.
B. Explicitly Teach Content Vocabulary (Kennedy et al., 2017).
    a. Teach and practice vocabulary included in the lesson plan that are included in key terms.
    b. Teach no more that 3-5 per lesson.
    c. Key terms and definitions that have been previously taught in previous lessons should be visibly accessible for students.
C. Integration
    a. Use explicit instruction to connect the Stone Soup? activity to the Stations activity.
        i. Model and guide instruction before independent practice.

Explore: Plan and Conduct an Investigation of the Transfer of Thermal Energy (75-100 min)

Student Objectives:

Students will plan and conduct an investigation of the transfer of thermal energy between objects with different temperatures.

Students will collect data on the temperature of the objects in the experiment.

Overview:

In this part of the lesson, the students will design and conduct an experiment to measure how heat is transferred from one object to another. While conducting the experiment the students will collect data on the temperature of the objects. The students will observe that as the energy is transferred, the objects will come to the same temperature. From this observation, the students can infer that the objects have come to a more uniform energy distribution.

Materials Needed:

Planning the experiment:

computers with internet access

projector

PhET Energy Changes Simulator applet
https://phet.colorado.edu/sims/html/energy-forms-and-changes/latest/energy-forms-and-changes_en.html

Student handouts -- Plan and Conduct an Investigation of the Transfer of Thermal Energy, part 1 and Transfer of Thermal Energy

Conducting the experiment:

Each group of 4 students will need

Hot plate

2 500 mL beakers

Water

2 thermometers

2 100 gram cylinders (various metals) from a specific heat cylinder kit or similar

Calorimeter (styrofoam cups can be used)

Additional optional items

Scale

Thermal blanket

Saltwater ice bath

Other materials to test (bricks, rocks, denatured alcohol, paraffin wax, etc)

Safety:

Use care when working with hot and cold objects. Use thermal protective gear to handle hot objects. Do not come into direct contact with the hotplate or objects placed on the hotplate. Avoid prolonged contact with ice. Use appropriate safety measures when working with thermometers. Care should be taken when working with glassware to avoid breakage. Use care when handling sharp objects. Use eye protection.

Introduction (20 min)

To begin, the teacher will ask the students to plan and conduct an investigation in which heat is transferred from one object to another. Two options for conducting this activity are provided. The teacher should select the option that is best for their classroom. In all situations, the students will be required to plan the experiment, conduct the experiment, and collect data from the experiment. The various options provide different scaffolds to enable the students to be successful in planning and conducting an investigation and collecting measurements to support their conclusions.

The teacher will introduce the idea that the students will be planning and conducting their own experiments. The primary question is from the demonstration of heat transfer: when does heat flow stop. In other words, heat will flow from the object with higher temperature to the object with lower temperature until ___________________? The answer is that heat is transferred until the temperatures are the same; this is a significant part of the zeroth law of thermodynamics, which defines temperature.

It is worth noting that because heat is the total kinetic energy of a system and heat is carried by the motion of the atoms and molecules that make up the system, heat is always being transferred in both directions. It is the net heat transfer that goes from hot objects to cold objects, and when the temperatures are equal, there is no longer a net transfer of heat. This is similar in both method and behavior to diffusion and dynamic equilibrium.

A significant part of this standard is the concept of systems, which is one of the NGSS Cross-Cutting Concepts, Systems and Systems Models. The standard describes how heat is transferred in a closed system. Therefore the students will need to conduct their experiment in a closed system. This means that in addition to needing to find ways of isolating their system from the environment, the students need to understand what is and is not in their system and figure out how to isolate their system from the environment. The teacher will need to provide scaffolding for this. A system is a group of things that are interacting. In an open system, energy and objects can come in and out, in a closed system nothing comes in and out. The boundaries of the system need to be delineated. While introducing this part of the lesson, the teacher will need to lead a discussion on systems. The teacher may wish to write key concepts on the board as the students bring them up and add additional terms as needed.

To help the students think about how to design the experiment, allow the students time to explore the "Intro" part of the "Energy Forms and Changes" PhET applet https://phet.colorado.edu/sims/html/energy-forms-and-changes/latest/energy-forms-and-changes_en.html

By exploring the PhET applet, the students can plan for how they will perform the experiment, figure out what they need to know, what they can measure, make errors, forget to make the needed measurements, etc. before conducting the actual experiment.

The teacher might want to demonstrate how to use the app but should allow the students the opportunity to explore things and think about things on their own. While they are exploring the app, provide the students with the outline for planning their experiment.

Suggested Teacher Script

Okay, do you remember when we were observing conduction, we noted that heat is flowing from the hot object to the cold object. That is the next question we are going to explore: How long will the heat flow from one object to the other?

To answer this question, working in small groups, you are going to plan and conduct your own experiment. You will be taking two objects at different temperatures, putting them in contact, so that heat can transfer between them, and then collecting data on how the temperature changes. You will be graphing this data, and drawing some conclusions about what is happening.

However, before we can start working on designing our experiment, we need to outline the boundaries of our system. So to start, can anyone tell me what a system is?

[Lead a discussion on systems. Ask students about examples of systems. Ask about open and closed systems. Ask about system components and boundaries. Bring the conversation back to the experiment, by asking about the components and boundaries of the experiment that they will be designing.]

So, in the experiment we will be designing, we want to take two objects at different temperatures, place them together so that heat can flow from one to the other, and collect data on the way the temperature changes. So what objects should be in our system?

[Students might answer, the hot and cold object, they might include other objects, the thermometers might need to be included.]

And what are the boundaries of the system? Here let's look at our cold drinks again. I can define my system to include whatever I want, right? So I could say that my system is the cup, the ice, and the water? If I define my system this way, does this have an open boundary or a closed boundary? Hold up 1 finger if you think this is an open boundary [demonstrate holding up one finger]. Hold up 2 fingers if you think this is a closed boundary [demonstrate holding up 2 fingers] and hold up 3 fingers if you have a question about this system [demonstrate holding up 3 fingers].

[Wait for students to respond. Call on students with 3 fingers. Answer questions or ask other students in the class to answer the questions. Next, ask students holding up 2 fingers to explain why they think this is a closed boundary. Finally ask students holding up 1 finger to explain why they think this is an open boundary. This is an open boundary for energy flow and is mostly closed with respect to matter flow, although there is some evaporation and condensation, so not completely closed.]

Okay, now that we have decided that this is an open system, what could I do to isolate it so that I don't have energy flowing in and out from the environment, and matter coming in and out through evaporation and condensation?

[Accept suggestions from the class.]

Great! I like the way you are thinking.

The next step is to explore an applet that allows you to conduct similar experiments. This should give you a chance to think about how you want to set up the experiment, what procedure you want to follow, what data you want to collect, etc. before you actually do the experiment.

In addition, we will be sharing the results of our experiments with the class in order to look for patterns so that we can have a better understanding of how the heat is being transferred. So, there is some specific data you will need to collect. In particular, you'll need to record which materials you decide to use and the initial and final temperatures of these materials, so that you can calculate the change in temperature. You may make additional measurements, but these are the ones you'll be sharing with the class.

[If selecting the quantitative variation, the students will also need to measure the masses of the materials, and look up the specific heat for these so that they can calculate the change in energy.]

[Pause to answer relevant questions. Show the app on the projector]

Okay, you can see in this app I have a brick, a piece of iron, a beaker of water, and a beaker of olive oil. I have 4 thermometers, which I can use to measure the temperature of these materials. I have a heater that can heat these objects, or use ice to pull heat from the objects. I can put the brick on the iron, the iron on the brick, either of the solids into the liquids, I can set the beaker of water on top of the brick, etc.

You can also turn on the energy symbols, which show you how much energy each object has and how that energy is moving. You can also see from the energy symbols that this is an open system because energy is being transferred to the environment.

Right now, you are going to get onto the computers and explore this applet. As you do so, think about what you want to actually do when you conduct the experiment in class. I will be giving you the outline that you can begin filling out. The materials we have available to work with are similar to the ones on the app.

[Give instructions on forming groups. Check to make sure that the students understand the assignment.]

Once students have formed their groups and understand the expectations, they can move to the computers to work on the applet. As the students are working on the applet, the teacher will hand out the outlines for planning the experiment. The teacher will also check on the students as they explore the app, asking them what they think they might want to do in their actual experiment, what data they should collect, how will they collect it, etc.

The teacher should add the new key terms to the previously created list of key terms.

Key Terms:

System -- A group of interacting things. In this case, the system includes the objects we are studying and the heat moving between them.

Open System -- A system in which things can move into and out of the system. The Earth is an open system for energy (energy comes from the Sun, sticks around for a bit, and is radiated back out into space). A river is an open system for water (water flows into the river from rainfall or snow/glacier melt, and flows out of the river into the ocean or lake).

Closed System -- A system in which things cannot move into and out of the system. The Earth is mostly a closed system for water (water evaporates, condenses, rains, flows to the ocean, and repeats this cycle; some water comes to the earth from comet strikes and some is lost through interactions with the solar wind, but mostly it is closed).

System Components -- The things that are included in a system. This can be objects as well as the energy of these objects.

System Boundaries -- The things that denote the edge of the system. The boundaries of the river are the headwaters at the top, the lake or ocean at the bottom, and the river banks at the sides. The boundary of the Earth is usually the atmosphere. We could also extend the boundary to the magnetosphere or reduce it to the ground and water.

Initial Conditions -- The state of the system at the beginning of making observations or measurements. In our case, we want to know the initial temperature of each object.

Final Conditions -- The state of the system at the end of making observations or measurements. In our case, we want to know the final temperature of each object.

Transitioning (5 min)

After allowing the students time to explore the applet, the teacher will transition to focus solely on planning the experiment. The teacher should provide the students with a list of possible supplies that the students can use. The teacher should review safety measures for working with hot and cold objects (use of thermal protective gear, do not come into direct contact with the hotplate or objects placed on the hotplate, use caution when handling ice) and safety regarding the use of thermometers (varies, but may include caution about potential breakages, and care in handling sharp objects), as well as general lab safety (eye protection, care in handling sharp objects). Depending on the class, the teacher may wish to provide some direct instruction on how to plan the experiment.

Planning the Experiment (20-30 min)

In this part of the lesson, the students will decide how to conduct the experiment, what data they need to collect, and how to collect the data. The teacher will provide support for the students as they make their plans, helping them think about their methods and techniques for collecting the data. Before the students begin working on their experiment, the teacher will check to make sure that the design is acceptable, and will provide additional scaffolding as needed to help students create a design that will allow them to make the necessary observations.

Use the student handouts to help the students organize their ideas and write up their procedure before beginning to collect data.

Measuring Heat Transfer:

In accordance with the standards, this experiment asks the students to observe heat transferring from one object to another through conduction by measuring the change in temperature of the objects once they are in contact. Within that constraint, the students have a fair range of control over what they do. Students will take materials at different temperatures, put them in contact so that the heat flows from one to the other, and will measure the temperature until the heat transfer is complete. However, the objects that the students select, the ways of heating/cooling the objects, the ways of putting the objects into thermal contact so that heat can be transferred, how and how often the students measure the temperature,

The student handouts provide scaffolding for designing the experiment. The students will need to complete the design process before they are allowed to obtain the materials they need. In this experiment, while the students will be measuring temperature, they will not be calculating the heat transferred, so this is only a semi-quantitative experiment. However, the teacher may wish to require the students to repeat the experiment to minimize error.

The teacher should encourage the students to think about how to isolate their experiment from the environment so that they are primarily observing heat being transferred from one object to the other, rather than heat being transferred to and from the environment.

The teacher should also encourage the students to think about how they will measure the temperature of different objects, and how many/how often they will want to take these measurements.

The teacher should also remind the students that heat and temperature are not the same thing, and ask them to think about what additional information they might need to be able to determine the heat of the objects.

Scaffolding Experimental Design:

Because heat will be transferred via radiation and convection to/from the environment, and because in order to measure the temperature, the thermometer needs to be in thermal equilibrium with the material it is measuring, there are more effective and less effective ways of heating objects and allowing the objects to transfer heat.

Adding a solid to a liquid, or combining two miscible liquids at different temperatures is going to maximize the surface area in direct contact, and increase the percentage of heat that is transferred between the two objects rather than lost to/gained from the environment. This will also allow for better measurement of the final temperature.

Performing the heat transfer in a calorimeter is also going to minimize the heat lost to/gained from the environment.

Starting with the cooler object at room temperature will also minimize the loss of heat to/gained from the environment prior to placing the objects in contact.

Heating the solid in a water bath will both prevent overheating the object (reduce the risk of burns) and allow a more accurate measurement of the initial temperature of the hot object. Using hot water as the hot object will also accomplish this.

For safety reasons, do not allow the students to use hot oil in this experiment.

Be particularly cautious about allowing students to heat the solid above the temperature of boiling water (directly on the hot plate). The students will need to use extra caution in handling these objects. In addition, it will be more difficult to measure the initial temperature of these objects. There are thermometers that are able to measure the temperature of solids, for example, IR thermometers and grill thermometers. If using regular classroom thermometers, consider wrapping the thermometer bulb and solid inside a piece of a thermal blanket.

If the students wish to use objects that are cooler than room temperature, water can be refrigerated in advance, solids can be cooled using a salty ice water bath. This technique will allow a more accurate measurement of the initial temperature.

Students who desire to place two solids in contact with one another should be encouraged to do so, but ask them to think about how they will make sure that the heat is being transferred between the objects, and not to/from the environment. Provide a thermal blanket to wrap the solids in.

Quantitative Variation:

If desired, the teacher can ask the students to calculate the heat transferred from one object to another. To do this, the students will need to measure the initial and final temperature of both objects, the mass of each object, and look up the specific heat of each object. They can then use the equation

Delta Q = mc DeltaT

Where Delta Q is the change in the thermal energy, m is the mass, c is the specific heat, and Delta T is the change in temperature.

The magnitude of Delta Q for the two objects in an isolated system will be the same. However, even using a calorimeter, it is difficult to isolate the system from the environment, and the results may actually be very different.

Before asking the students to calculate the heat transferred, ask them to research the topic online or to read the relevant section in their textbook.

Conducting the Experiment (20-30 min)

After the students have written their experimental procedure, the teacher will review it and if it is acceptable will approve the design. Once the teacher has approved the experimental design, the students will be allowed to obtain their equipment and safety gear and will conduct the experiment. As students conduct the experiment, the teacher will provide support as needed, verify that the students are following relevant safety procedures, and ask questions and highlight productive ideas. Verify that the students are collecting the necessary data.

Analysis and Conclusions (10-15 min)

After the students have conducted the experiment, provide time for them to graph their data, analyze their data, make inferences, and write their conclusions. The student handouts provide some questions to help scaffold the data analysis. The teacher may need to provide additional scaffolding in graphing data and performing calculations. The students can graph this on the student handout, on graph paper, or using graphing software. The teacher may wish to instruct the students on graphing the data using a spreadsheet or other graphing program.

Suggestions for Specifically Designed Instruction in Experiment Process

Introducing the Experiment:

A. Provide graphic or advanced organizers to scaffold student learning and classifying the three options of heat transfer.
B. Highlight main ideas and important directions for the experiment
C. List steps to complete and reach proficiency in PhET activity. Set expectations for students to move from one step to the next.
D. Provide task analysis of steps needed to complete the experiment.
E. Consider strategic grouping that allows students to be active participants with the needed supports.
F. Follow all accommodations and modifications listed on the IEP.

Planning the Experiment:

A. Provide a list of directions with clarification for steps that may be broad or have multiple interpretations to complete.
B. Provide an advanced organizer with scaffolded support to measure heat transfer (e.g., close procedure).
C. When students are working in a small group, explicitly explain and post role of each person in the group. Clarify expectations for each group member as the tasks switch focus.
D. Have students read aloud their procedures, clarifying each step in the process and setting up the students for success.
E. Review previously taught vocabulary, and assist students in understanding the transitioning meaning of vocabulary from explicit instruction to use in contextual meaning.
F. Clarify the meaning of commonly confused terms. For example, heat and temperature.
G. Provide models of measurement tools and data collection sheets.
H. Follow all accommodations and modifications listed on the IEP.

Conducting the Experiment:

A. Support students to be full participants in group work.

B. Follow all accommodations and modifications listed on the IEP.

Analysis and Conclusions:

A. Provide model of acceptable graphs for the experiment.

B. Define expectations for student to provide data analysis, make inferences, and write conclusions.

C. Consider response opportunities to report their results (e.g., written, verbal, technology, performance). 20

D. Follow all accommodations and modifications listed on the IEP.

Explain: Energy Distribution (40-50 min)

Student Objectives:

Students will use evidence to infer that the transfer of thermal energy results in a more uniform distribution of energy.

Overview:

Now that the students have planned and performed their experiment, and collected and graphed their data, the students need to make inferences regarding the behavior of the energy. In particular, the students have observed that the energy flow stopped once the objects reached the same temperature. From this observation, the students can infer that the objects have come to a more uniform energy distribution. The students will arrive at this inference through scaffolded small group conversations, and through collecting evidence from the PhET energy applet used to plan their experiments.

Materials Needed:

Computers with internet access

Whiteboard with dry-erase markers or shared google sheets or similar to share data

Projector

PhET Energy Changes Simulator applet
https://phet.colorado.edu/sims/html/energy-forms-and-changes/latest/energy-forms-and-changes_en.html

Student handouts -- Energy Distribution

Introduction (20 min)

The teacher will introduce this next section by asking students to share the results of their experiments with the class. The goal is to create a table of the aggregate data. The teacher can ask the students to write their answers on the board, or ask students to enter their results in a shared google sheet or similar. This data table provides a starting point for a class discussion on changes in temperature and changes in energy. The collected data table might look something like this:

Group Members	Object 1 (hot)	Object 2 (cold)	Initial Temp Object 1	Initial Temp Object 2
Sebastian, Sofia, Derek, Andrea	Brass	Water	97 degrees C	36 degrees C

Final Temp Object 1	Final Temp Object 2	Change in Temp Object 1	Change in Temp Object 2	(Optional) Change in Energy Object 1	(Optional) Change in Energy Object 2

The teacher will begin the class discussion by asking the students to make observations. The teacher should instruct all students that they will be asked to contribute, and then lead the discussion in such a way that all students do contribute. The teacher can ask students questions such as: What patterns do you see? What do you see that is the same? What do you see that is different? Can you explain (the pattern, the similarity, the difference)?

At the end of the discussion, the teacher should point out that the final temperature of object 1 is the same as the final temperature of object 2. Therefore, we can conclude that energy flows from object 1(the hot object) to object 2 (the cold object) until the temperatures are the same. Heat does not keep flowing from object 1 to object 2 after the temperatures are the same, even though that would not violate the law of conservation of energy.

This is a significant piece of physics. The observation that energy flows from a hot object to a cold object until the temperature of both objects is the same led to the zeroth law of thermodynamics (the definition of temperature) and the second law of thermal dynamics (which describes the direction of energy transfer within a system).

For classes that also calculated the change in energy, these numbers should be close, if not the same. The teacher can discuss with the class why these numbers might be different, i.e. the heat lost/gained from the environment, and the very real difficulties of actually thermally isolating objects.

Explanation (20-30 min)

Next, the teacher will ask the students to think about the energy distribution in the system.

Using the PhET energy applet, ask the students to repeat an experiment similar to the one they just completed in class. This time, in addition to measuring the temperature, turn on the energy symbols, and count the energy for each object before and after the objects exchange heat. Ask the students to make observations and predictions based on their observations and answer the questions on the student handout.

While the students are following the instructions, the teacher will walk around the class, dropping into the various discussions, highlighting productive ideas, asking probing questions.

Suggestions for Specifically Designed Instruction in Explaining Energy Distribution

Introduction:

A. Provide model of expectations to be reported.
B. Graphic organizer for students to complete.
C. Define contribution of student participation.
    a. Provide students a list of questions that will be asked during discussion prior to lecture.
    b. Assign students or groups a specific question that they will be asked to respond to prior to the discussion.
D. Provide a copy of conclusions to students.
E. Follow all accommodations and modifications listed on the IEP.

Explanation:

A. Pose questions that clarify the differences in the PhET experiment and actual student experiment.
B. State and list student expectations.

Elaborate: Further Experiments (90-135 min)

Student Objectives:

Students will plan and conduct an investigation that furthers their knowledge of the transfer of thermal energy.

Students will share their knowledge with their classmates.

Overview:

In this part of the lesson, the students will design and conduct an experiment that answers another question that the student has regarding the transfer of thermal energy. They will then present that information to the rest of the class.

Materials Needed:

Student Handouts -- Plan and Conduct an Investigation of the Transfer of Thermal Energy, part 2 and Further Experiments on Thermal Energy

Additional Materials will vary depending on what equipment is available in the classroom and what questions the students wish to investigate.

Suggested materials include

Hot plates

Beakers

Water

Thermometers

Cylinders from a specific heat test kit

Calorimeters

Scales

Thermal blankets

Saltwater ice bath

Heat conductivity kits

Assorted insulators (paper, cardboard, fiberboard, styrofoam, etc.)

Convection kits

Thermal expansion kits

Balloons or syringes

Heat lamps

Various surfaces (foil, colored paper, etc.)

Safety:

Use care when working with hot and cold objects. Use thermal protective gear to handle hot objects. Do not come into direct contact with the hotplate or objects placed on the hotplate. Avoid prolonged contact with ice. Use appropriate safety measures when working with thermometers. Care should be taken when working with glassware to avoid breakage. Use care when handling sharp objects. Use eye protection. Additional safety measures may be relevant depending on the equipment used.

Introduction (10-15 min)

The Explore section of this lesson asks the students to observe heat transferring from one object to another through conduction. This is consistent with state and national standards. However, there are many more questions that could be explored that involve heat transfer. In this part of the lesson, students will elaborate on their knowledge of heat transfer by planning and conducting an experiment that answers a question of their choosing.

To begin, the teacher will ask students to brainstorm other questions that they might have about thermal energy transfer. In their groups, ask students to write down 3-5 things they know about thermal energy and thermal energy transfer, and then 3-5 questions they still have about thermal energy and thermal energy transfer. Allow students 5-10 minutes to work on this. Next, ask each group to share 1-2 questions with the class.

As the students share their questions write them on the board. Ask students to propose experiments that could answer these questions. Not all questions can be answered, and sometimes the answers are not obtainable, as the classroom does not have the necessary equipment. Highlight questions that are answerable with available materials.

Here are some suggestions for other experiments that the students could design and carry out.

Students might want to ask additional questions about how thermal energy is transferred through conduction. Scientific supply companies have kits that can be used to measure the heat conductivity of different metals. Alternately, the students might be interested in insulators, which prevent heat from being conducted, the students could use household materials to test which are most effective at preventing heat from being transferred.

Students might be interested in the relationship between heat and temperature for various objects. The specific heat cylinders that are recommended in the Explore section are designed to demonstrate how different materials can have the same temperature but contain different amounts of heat.

Students might be interested in heat transfer via convection. Scientific supply companies have kits for measuring heat transfer via convection.

As convection works through the expansion and contraction of fluids as they heat and cool, the students may be interested in exploring the behavior of materials as heat is added. Scientific supply companies have kits that demonstrate the expansion of metals. The expansion of gases can be done using balloons, syringes or similar.

Students might be interested in heat transfer via radiation. This could be done through use of a heat lamp or hot plate or even sunlight. Students could measure temperature changes for different types or colors of objects, for objects at different distances, for objects at different angles.

Students might be interested in the rate of change of temperature in an object that is cooling to room temperature or heating up to room temperature. This can easily be measured and has an interesting behavior that might be fun for students to explore.

Planning and Conducting the Experiment (40-60 min)

Once the students have a better understanding of which questions can be answered using the available equipment, the teacher will instruct each group of students to select one question to answer, and design and conduct an experiment to answer this question. The teacher should allow time for students to conduct background research on their topic, using the internet or by reading the relevant section of their textbook.

The students will follow the same process as in the Explore section. The teacher will allow time for the students to develop their plan to collect data. Students can use the same scaffolding. Once the teacher has approved the data collection plan, students can collect the equipment needed and begin their experiment. Allow time for analysis and conclusions.

Communicating the Results (40-60 min)

When the students have finished their experiments, ask each group to present their findings to the class. Depending on classroom needs, this can be a formal presentation of their results, in which the students create a poster or PowerPoint to share with the class. Alternately, it could be less formal where each group gives a brief summary of their experiment to the class. As part of the presentations, the teacher will lead a class discussion.

The teacher will provide time for the students to prepare for their presentations. If the teacher decides the students should create PowerPoint or poster presentations, additional time needs to be allotted. Each presentation should include:

- The question being asked
- Description of the experimental procedure
- A graph or similar visualization of the data collected (qualitative data can be expressed via drawing or illustrations)
- The results of the experiment, ie. the answer to the question.

The teacher may wish to organize the presenting groups such that there is a flow to the discussion of thermal energy. For example: begin the presentations with groups that performed further experiments on conduction, then move to groups that performed experiments on convection, etc. After each presentation the students in the class will be required to participate in the class discussion either by 1) agreeing with and providing evidence to support the conclusions, 2) disagreeing with and providing evidence to refute the conclusions, 3) asking a question about the experiment. The teacher can choose which students to call on, or instruct the presenting group to choose someone. Students should be selected such that all students have an opportunity to participate.

Suggested Teacher Script

Okay, before we begin the presentations I want to give you some instructions and explanations, so you know what to expect. Each group will be presenting their experiment. In your presentation, you need to let us know your question, describe your experiment, tell us about the results, and then let us know the answer to the question. Once you have finished this part of the presentation, your classmates will have the chance to ask questions or respond to your claims. Each student not in the presenting group needs to be prepared to participate. To participate in the discussion, you can either 1) agree with the presenters and provide evidence to support this [demonstrate holding up 1 finger], 2) disagree with the presenters and provide evidence that contradicts the presenters [demonstrate holding up 2 fingers], or 3) ask a question [demonstrate holding up 3 fingers].

Does everyone understand what they will be doing?

[Answer relevant questions. Tell students the order of the presentations. Give the first group time to set up, then cue them to begin their presentation. When they have finished, remind the students of the discussion options.]

[To the presenting group] Great job, thank you for your presentation. [To the class] One finger if you agree with the presenters and can provide evidence to support this [demonstrate holding up 1 finger], two fingers if you disagree with the presenters and can provide evidence that contradicts them [demonstrate holding up 2 fingers], or three fingers if you have a question for the presenters [demonstrate holding up 3 fingers].

[Wait for all the students to hold up fingers indicating their response. Repeat the instructions as needed. Begin calling on students. Depending on class size and time constraints, between 2-5 students should have the opportunity to respond to each presentation. The teacher should select students such that every student has a chance to participate in the discussion. Presenters should be allowed to respond to student comments and questions. After the desired number of students have been called on, the next group can begin their presentation. Continue this process until all groups have presented.]

Suggestions for Specifically Designed Instruction in Elaborate

Introduction:

A. Clarify the expectations of brainstorming.
B. Give a model question that students may ask during brainstorming activity.
C. Consider response opportunities.

Planning and Conducting the Experiment:

A. Consider strategic grouping where all students may fully and meaningfully participate.

Suggestions for Specifically Designed Instruction for Online Research

A. Post and provide the directions and expectations for the students.
   a. Provide links, critical search words, and advanced organizer for note
   b. Assign student specific information to explore.
   c. Clear expectations for time and post and display a classroom timer.
   d. Consider allowing students to work in pairs or with a peer.
   e. Consider response types (e.g., verbal, written, paired).
   f. Demonstrate model of expectation.
   g. Extended guided practice with teacher, paraprofessional, or peer.
   h. Read aloud the information found on the website.
   i. Follow all accommodations and modifications listed on the IEP.

Communicating Results:

Suggestions for Specifically Designed Instruction for Presentation Preparation

A. State and post expectations for preparing a power point presentation
   a. Expected time
   b. Tools that may be accessed (e.g., computer, completed notes, team member).
   c. Independent vs. Group notes

B. Prepare advanced organizer of presentation with fillable document and/or slides that include:
   a. The question being asked
   b. Description of the experimental procedure
   c. A graph or similar visualization of the data collected (qualitative data can be expressed via drawing or illustrations)
   d. The results of the experiment, ie. the answer to the question.

C. Post or create representation of talk moves students may use when working in a group.

D. Assign students with disabilities the section of the presentation they will be responsible to prepare.

E. Narrow the options for presentation (e.g., PowerPoint, Prezi, written document, oral presentation without visual representation).

F. Match the researched information with the pertinent section of the PowerPoint.

G. Limit content to the information to include in the presentation to the information that has previously been researched and discussed.

H. Provide models and guided practice with a gradual release of learning to the student.

I. Provide a checklist to be completed of each task in the preparation process.

J. Follow all accommodations and modifications listed on the IEP.

Suggestions for Specifically Designed Instruction for Proposal Presentation

A. Create an advanced organizer with script that includes:
B. Allow student to practice the presentation prior to presenting in class.
C. Consider alternate forms of presentation (e.g., just to teacher, record in private and submit, oral presentation only, visual demonstration only).
D. Provide clear grading requirements prior to preparation and presentation of proposal.
E. Explicitly teach and model expectations when being an audience member during peer presentations.
F. Follow all accommodations and modifications listed on the IEP.

Evaluate (30 min)

Student Objectives:

Students will demonstrate their knowledge of heat transfer and heat distribution through an individual assessment.

Materials Needed:

Individual Assessment

Overview:

The final step of the lesson is to administer an individual assessment to evaluate the students' knowledge of heat transfer and energy distribution in a system. The teacher can administer this assessment in whichever way they normally administer exams.

Suggestions for Specifically Designed Instruction for evaluation

A. Follow grading expectations and give feedback for grading procedures.

B. Evaluate only learning objectives of the lesson (e.g. reading, spelling, and quality of presentation skills are not a learning target in this lesson).

C. Consider holistic scoring.

D. Follow all guidelines in the student's IEP.

References

Archer, A. L., & Hughes, C. A. (2010). *Explicit instruction: Effective and efficient teaching.* Guilford Publications.

Hughes, C. A., Morris, J. R., Therrien, W. J., & Benson, S. K. (2017). Explicit instruction: Historical and contemporary contexts. *Learning Disabilities Research & Practice*, 32(3), 140-148.

Individuals with Disabilities Education Act, 20 U.S.C. § 1400 (2004)

Kennedy, M. J., Rodgers, W. J., Romig, J. E., Lloyd, J. W., & Brownell, M. T. (2017). Effects of a multimedia professional development package on inclusive science teachers' vocabulary instruction. *Journal of Teacher Education*, 68(2), 213-230.

Kim, N. J., Belland, B. R., & Axelrod, D. (2018). Scaffolding for optimal challenge in K–12 problem-based learning. *The Interdisciplinary Journal of Problem-based Learning*.

Larkin, M. (2002). *Using scaffolded instruction to optimize learning*. http://www.vtaide.com/png/ERIC/Scaffolding.htm

Michaels, S. & O'Connor, C. (2012). *Talk science primer*. Cambridge, MA: TERC. Available at: https://inquiryproject.terc.edu/shared/pd/TalkScience_Primer.pdf

NGSS Lead States. 2013. *Next Generation Science Standards: For States, By State*s. Washington, DC: The National Academies Press.

https://www.schools.utah.gov/file/e5d886e2-19c3-45a5-8364-5bcb48a63097

https://www.nextgenscience.org/trademark-and-copyright