TEACHER GUIDE

Why does sand at the beach feel hot, even when the water feels cool?

Overview

In this hands-on activity, students first investigate what happens when water samples of different temperatures and masses are combined. Students analyze and interpret their experimental data to draw conclusions about the effects of these variables on thermal equilibrium temperature when heat transfer occurs. Students then investigate what happens when samples of different materials with the same mass and initial temperature are added to room temperature water. Students analyze and interpret their experimental data to draw conclusions about the relationship between the specific heat capacity of a substance and the degree to which its temperature changes when a given amount of heat is transferred per unit mass. Lastly, students use their data to calculate the experimental specific heat capacity of one of the materials tested. At the end of the investigation, students will be able to explain why the sand at a beach feels so much hotter than the water, even though both are experiencing the same solar radiation on a summer day.

Standards

NGSS Performance Expectations

- **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).

NGSS SEPs/DCIs/CCCs

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
• Planning and carrying out investigations • Analyzing and interpreting data • Constructing explanations and designing solutions	**PS3.A: Definitions of Energy** • Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that	• Patterns • Cause and effect • Energy and Matter • Systems and

• Developing and using models • Engaging in argument from evidence	a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. **PS3.B: Conservation of Energy and Energy Transfer** • Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. • Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.	System Models

Prerequisites

Before doing this activity, students should be familiar with the following ideas:

- A system is a group of components that interests us in a particular scenario. Everything outside the system is considered the surroundings.
- Energy cannot be created or destroyed, but it can move from one component to another within a system or be transferred between a system and its surroundings. This means that energy lost/gained by a system must be equal to the energy gained/lost by its surroundings.
- Temperature is a measure of the average kinetic energy of the particles in a system. It increases as the particles move faster and decreases as the particles move more slowly.
- Thermal energy is the sum of the kinetic energy of all the particles in a system in units of joules. The thermal energy in a system depends not only on the average kinetic energy of the particles (temperature), but also on the number of particles present.
- Heat is the amount of thermal energy transferred when two systems of different temperatures come in contact with each other. A system cannot *have* heat. Systems *transfer*

heat when they come into contact with other systems and there is a temperature difference.

- Heat transfers from a component with higher average kinetic energy/higher temperature to a component with lower average kinetic energy/lower temperature until the components reach thermal equilibrium. At this point, temperature remains constant, as kinetic energy, on average, is evenly distributed among the particles. Thus, there is no longer any net transfer of thermal energy.
- Specific heat capacity is a characteristic property of a substance that represents the amount of thermal energy required to change the temperature of one gram of the substance by one degree Celsius.
- The amount of heat transferred when components of different temperatures come in contact can be calculated using the equation $q = mc\Delta T$, where q is the amount of heat transferred (in joules), m is the mass of the component (in grams), c is the specific heat capacity of the component (in J/g °C), and ΔT is the final temperature minus the initial temperature of the component (in °C).
- A negative value of q indicates thermal energy leaving the component. A positive value of q indicates thermal energy entering the component.

See this activity's article on Khan Academy for links to related videos, articles, and practice exercises.

Essential questions

- How does heat transfer occur when two components of different temperatures are combined within a closed system?
- What is the relationship between the specific heat capacity of a substance and the degree to which its temperature changes when a given amount of heat is transferred per unit mass?

Materials

- For each student:
  - Student activity guide (provide paper copies or assign digitally)
  - Lab notebook or other paper for recording experimental data and responses to *Follow-up questions* (optional, not necessary if completing digitally)

- For each group:

  Parts 1 & 2:
  - water
  - ice
  - 1 Styrofoam cup (Styrofoam is a registered trademark, but any polystyrene foam cup will work)
  - 2 beakers-250 mL (or other similar sized heat-resistant containers)
  - 1 beaker-500 mL (or other similar sized heat-resistant container)
  - 1 balance (or kitchen scale)
  - 2 thermometers
  - 1 hotplate
  - 1 heat-resistant mitt
  - 1 insulated pad

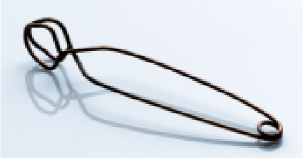
  Part 2 (additional materials):
  - 25 g copper (wire, nails, or shot)
  - 25 g lead (wire, fishing weights, or shot)
  - 25 g glass (beads or marbles)
  - 3 extra-large test tubes
  - tape/marker for labeling test tubes
  - 1 test tube holder
  - 1 weighboat (or small container for measuring mass on the balance)

Implementation suggestions

- Approximate time to allot for each section:
  - *Setting the stage* and pre-lab discussion (20 minutes)
  - *Part 1: Heat transfer between water samples*
    - Investigation (45 minutes)
    - Follow-up questions and discussion (20 minutes, could be assigned or homework)
  - *Part 2: Heat transfer between water and other materials*
    - Investigation (45 minutes)
    - Follow-up questions 1-5 and discussion (20 minutes, could be assigned for homework)
    - Follow-up questions 6-11 and discussion (25 minutes, could be assigned for homework)
  - *Let's get creative!* (45 minutes, could be assigned for homework)

- The time allotments above are suggestions and may vary depending on the needs of your class. The sections of the activity may be split up in different ways to fit your schedule and the pace of your students. For example, *Setting the stage* could be assigned as pre-lab homework, and any of the *Follow-up questions* could be completed as post-lab homework. Data collection for *Parts 1 and 2* can be completed during different class periods. For *Part 2*, you might consider assigning *Follow-up questions* 1-5 for homework and using time in the following class to discuss student answers and to have students work with their lab teams on *Follow-up questions* 6-11.

- Notes on set-up and safety:
    - Depending on the set-up of your classroom, it may make sense to place containers of water at each lab station, so that students are not going back and forth to the sink. Having squirt bottles of water available may also help students to mass water in the Styrofoam cup or beaker more effectively.
    - Students will be using a hotplate. Before starting the activity, remind students that hot glassware looks the same as cool glassware. They should always use a heat-resistant mitt when handling glassware that is being heated or has been heated on the hotplate. Since hot glassware may crack if placed directly on a cool surface, remind students to place beakers on an insulated pad when removing them from the hotplate. The type of silicone hot pad used in kitchens or a folded dish towel will work well if you do not have specific lab equipment for this purpose.
    - In Part 2, students will be heating the materials in test tubes in a boiling water bath. When students remove the heated test tubes from the bath, they should use a test tube holder, like the one pictured below. It is a good idea to demonstrate to students ahead of time how to use this tool properly.

      If you do not have test tube holders available, a heat-resistant mitt with silicone grip pads may be used. It is important that students be able to grasp the test tube securely, so that they are able to remove it from the water bath and pour the contents into the Styrofoam cup safely.
    - If safety goggles are available, these should be worn. Remind students not to look directly down into a beaker that is being heated. Steam can cause burns, and gas bubbles bursting off the surface may spatter liquid upward.
    - For the materials in Part 2 (copper, lead, and glass), it is best if they are in small

pieces, such as metal shot and glass beads. This will provide more surface area for thermal energy transfer. If you use lead fishing weights as an alternative, smaller ones will be better, and if you use metal wire, consider cutting it into smaller segments. Marbles are a good alternative to glass beads.

- Invite students to read the *Setting the stage* section and answer the questions independently or with a partner. Then, discuss the *Setting the stage* section as a class and address any misconceptions still present.
- Divide students into pairs or small groups, and direct them to read carefully through the instructions for *Investigation (Part 1)*.
- Before distributing materials for *Part 1*, instruct students on safety considerations and answer any questions about the procedure. Then, distribute the materials for Part 1 only.
- Instruct groups to work together to complete *Investigation (Part 1)*. Circulate while students are working to make sure they are following safe practices and to provide support.
- After groups have completed *Investigation (Part 1)*, instruct students to pour out any remaining water in the sink, dry their materials, and wipe down their work areas. Remind students to use caution if moving a hotplate, as it may still be hot.
- Invite students to work with their lab teams to complete *Follow-up questions (Part 1)*. You may wish to discuss student responses as a class before moving on to Part 2. (This is a good stopping point if you will be doing the activity over multiple class periods.) If you do not have time in class, *Follow-up questions (Part 1)* can be assigned for homework, and you can begin the following class period with a discussion of student responses.
- Once students have completed *Follow-up questions (Part 1)*, distribute the additional materials for Part 2.
- Direct students to read carefully through the instructions and work together to complete *Investigation (Part 2)*. Circulate while students are working to make sure they are following safe practices and to provide support.
- After groups have completed *Investigation (Part 2)*, instruct students to pour out any remaining water in the sink, dry their materials, and wipe down their work areas. Remind students to use caution if moving a hotplate, as it may still be hot.
- Invite students to work with their lab teams to complete *Follow-up questions (Part 2)*. If you do not have time in class, *Follow-up questions (Part 2)* can be assigned for homework, and

you can begin the following class period with a discussion of student responses. You can also assign *Follow-up questions (Part 2)* 1-5 for homework and give students time in the next class period to work with their lab teams on *Follow-up questions (Part 2)* 6-11.

Possible misconceptions

- **Incorrect:** Thermal energy and heat are synonymous.
    - **Correct:** Thermal energy is the sum of the kinetic energy of all the particles in a system. The amount of thermal energy in a system depends on the average kinetic energy of the particles (temperature) and the number of particles in the system. Heat is the amount of thermal energy *transferred* when systems of different temperatures come into contact with each other. A system will have a certain amount of thermal energy. A system cannot *have* heat. A system can only *transfer* heat when it comes into contact with another system at a lower temperature.

- **Incorrect:** No more energy changes occur once two systems reach thermal equilibrium.
    - **Correct:** When thermal equilibrium is reached, kinetic energy, on average, is evenly distributed among the particles in the two systems. The particles, however, continue to move around and collide with each other. Kinetic energy is transferred between particles during these collisions, but because the average kinetic energy of all particles in the two systems is the same, no *net* change in thermal energy will occur.

- **Incorrect:** When two systems at different temperatures come in contact, the thermal equilibrium temperature will always be halfway in between their initial temperatures.
    - **Correct:** The thermal equilibrium temperature will depend not only on the initial temperatures of the two systems, but also on the mass of each system and on the specific heat capacities of the materials in each system.

Support for multilingual learners

- Solicit students’ prior knowledge and experiences related to this topic.
- Use visuals (photos, diagrams, videos) to build background knowledge, illustrate the goals of the activity, and show how students will set up the investigation and collect data.
- Use targeted language support. Introduce cognates and diagrams to scaffold understanding.
- Use home language resources such as digital translation tools to translate written instructions into students’ home languages.

- Be strategic in grouping students, so that students who are new English language learners are teamed with students who have greater fluency in English.
- Provide alternative ways for students to demonstrate their learning. For example, students could share their responses to the creativity follow-ups in a variety of ways.
- Provide a graphic organizer for the creativity follow-ups to support students in organizing their ideas.

Support for students with disabilities

- Provide multiple modalities for accessing the text and information in the activity. These could include diagrams, text readers, read-aloud activities or chunking text into smaller pieces.
- Provide additional visual scaffolds, including diagrams and videos.
- Break the investigation into discrete chunks so that students can tackle smaller subsets of the investigation procedure.
- Provide a graphic organizer for the creativity follow-ups to support students in organizing their ideas.

Answer key

Setting the stage

We often say that something in our environment “feels hot” or “feels cold.” These sensations are due to thermal energy transfer between our bodies and our surroundings. In order to understand this process and others related to it, we need to keep in mind some key concepts.

First of all, we should remember that a **system** is a group of components that interests us in a particular scenario. Everything outside the system is designated as the **surroundings**. When considering thermal energy transfer, it is important to define clearly what the system is, so that we can notice if energy is moving into or out of the system.

The **Law of Conservation of Energy** tells us that energy cannot be created or destroyed, but it can move from one component to another within a system or be transferred between a system and its surroundings. This means that energy lost/gained by a system must be ________ *equal to* ________ the energy gained/lost by its surroundings.

When we think about quantifying something in terms of how “hot” or “cold” it is, we often think about its temperature. **Temperature** is a measure of the average (circle one) **[✓ kinetic]/potential** energy of the particles in a system. This kind of energy is related to the __________ *motion* ______________ of the particles.

- As particles move faster, their kinetic energy (circle one) **[✓ increases]/decreases**, and temperature (circle one) **[✓ increases]/decreases**.
- As particles move more slowly, their kinetic energy (circle one) **increases/[✓ decreases]**, and temperature (circle one) **increases/[✓ decreases]**.

Temperature can be measured using a _______ *thermometer* _____________ with a scale in units of degrees Celsius.

Thermal energy is the *sum* of the kinetic energy of *all* the particles in a system in units of joules. The thermal energy in a system depends not only on the average kinetic energy of the particles (temperature), but also on the number of particles present. Therefore, a bucket of water at 25 °C will have (circle one) **more/[✓ less]/the same** thermal energy compared to a swimming pool of water at 25 °C.

Heat is the amount of thermal energy transferred when two systems of *different temperatures* come in contact with each other. A system cannot *have* heat. Systems *transfer* heat when they come into contact with other systems and there is a temperature difference. Components within a system can also transfer heat if they are initially at different ___________ *temperatures* _______ when they come into contact.

The direction of heat transfer is always from a component with (circle one) **lower/[✓ higher]** temperature to a component with (circle one) **[✓ lower]/higher** temperature. Heat transfer continues until the components reach the same temperature, meaning that the average kinetic energy of the particles is the same in both components. When a system reaches this point where temperature remains constant, we say it is at **thermal equilibrium**. Particles continue to move around and collide, but kinetic energy, on average, is now evenly distributed among the particles, so no net transfer of thermal energy will occur.

Consider a scenario where two components at different temperatures come into contact within a system. Component A has a temperature of 25 °C when it comes into contact with component B, which has a temperature of 150 °C. What do you expect will happen?

Heat will transfer (circle one) **[✓ to]/from** component A (circle one) **to/[✓ from]** component B.

As heat transfer occurs:

- the temperature of component A will ________ *increase* _______________ and
- the temperature of component B will ________ *decrease* _______________ until

- the temperature of component A is _______ *equal to* _______ the temperature of component B.

The amount of heat transferred when components of different temperatures come in contact depends on several factors, which you will investigate in this activity. The heat transferred to or from a particular component can be calculated using the equation:

$$q = mc\Delta T$$

In this equation, q is the amount of heat transferred (in joules), m is the mass of the component (in grams), c is the specific heat capacity of the component (in J/g °C), and ΔT is the final temperature minus the initial temperature of the component (in °C).

Specific heat capacity is a characteristic property of a substance that represents the amount of thermal energy required to change the temperature of the substance per unit mass.

The sign of q tells us the direction in which heat transfer occurs with respect to our system or a specific component within the system. A negative value of q indicates thermal energy (circle one) **entering/[✓ leaving]** the component. A positive value of q indicates thermal energy (circle one) **[✓ entering]/leaving** the component.

Now that you've reviewed some key concepts, let's investigate thermal energy transfer and develop an explanation for why sand on a beach feels so hot, even when the water feels cool.

Investigation (Part 1): Heat transfer between water samples

Let's make a prediction!

For trial #4, you will heat ~50 g of water to ~100 °C and add it to ~25 g of room temperature water in a Styrofoam cup. How do you predict the thermal equilibrium temperature will compare to trial #1, where you used ~25 g of water at ~100°C? Explain your reasoning.

Students should predict that increasing the mass of the heated water will cause the thermal equilibrium temperature to be higher, because 50 g of water at 100 °C has twice as much thermal energy as 25 g of water at the same temperature. Therefore, when it comes in contact with the room temperature water, more thermal energy will transfer before the system reaches thermal equilibrium.

Students' data will vary. The values for the mass of the water in the cup and the initial temperature of the water in the cup should be consistent to the ones place for all four trials, but variation in the tenths place is to be expected. All mass and temperature data should be recorded to at least the tenths place.

Follow-up questions (Part 1)

1. If we consider the system to be the water originally in the Styrofoam cup and the water added to the Styrofoam cup, sketch two different models to show how heat transfers between the components in the system when:
    a. water from the hotplate is added
    b. water from the ice bath is added

   Use arrows to show the direction of heat transfer in each scenario.

   Students should draw pictures that represent heat moving from an area of higher temperature to an area of lower temperature in each case.

2. Use your experimental data as evidence to support the models you sketched above.

   When water from the hotplate (~100 °C or 50 °C) was added to room temperature water (~20 °C), we saw the temperature on the thermometer rise from 20 °C to a temperature in between the initial temperatures of the two water samples (specific values will vary). This showed that thermal energy was transferring from the higher temperature water (so, its temperature decreased) to the lower temperature water (so, its temperature increased).

3. What effect did increasing the mass of the heated water have on the amount of heat transferred within the system? Use your experimental data as evidence to support your claim.

   Increasing the mass of the heated water increased the amount of heat transferred within the system. We observed that the final thermal equilibrium temperature of the system was higher when 50 g of water at 100 °C was added to 25 g water at room temperature compared to when only 25 g of water at 100 °C was added to 25 g water at room temperature. The temperature of the original water in the cup rose more, meaning it absorbed more thermal energy, when more of the heated water was added.

4. In addition to mass, what other variable affected the amount of heat transferred within the system? Use your experimental data as evidence to support your claim.

   The difference between the initial temperatures of the water samples also affected the amount of heat transferred. We observed that as the difference in initial temperature of the water samples decreased, the temperature of the water originally in the cup changed less, indicating that less heat was transferred. For example, the final thermal equilibrium temperature of the system was higher *when 25 g of water at 100 °C was added to 25 g water at room temperature compared to when 25 g of water at only 50 °C was added to 25 g water at room temperature.*

5. You measured the thermal equilibrium temperature of the system when the temperature stopped going up (hot water added) or when it stopped going down (cold water added). What would you expect to happen to the temperature of the system, in either case, if you left the cup of water sitting out on the table for an hour after you finished the experiment? Explain your reasoning with words and diagrams.

If the thermal equilibrium temperature of the system was higher or lower than room temperature, then the system would undergo heat transfer with the surroundings. Thermal energy from the water would transfer to lower temperature air at the surface of the liquid (or thermal energy from the air would transfer to the lower temperature water). This would occur until the system and surroundings reached thermal equilibrium.

Diagrams should show the direction of energy transfer between the water in the cup and the surrounding air based on temperature differences.

Investigation (Part 2): Heat transfer between water and other materials

Students' data will vary. The values for the mass of the material, the initial temperature of the material, the mass of the water in the cup, and the initial temperature of the water in the cup should be consistent to the ones place for all three trials, but variation in the tenths place is to be expected. All mass and temperature data should be recorded to at least the tenths place.

Follow-up questions (Part 2)

1. If we consider the system to be the water originally in the Styrofoam cup and the material added to the water in the cup, sketch a model to show how heat transfers between the components in the system.

Students should draw pictures that represent heat moving from an area of higher temperature to an area of lower temperature in each case.

2. What variables were kept constant for all three trials in Part 2?

The mass of the material, the initial temperature of the material, the mass of the water in the cup, and the initial temperature of the water in the cup were kept (relatively) constant in all three trials.

3. Fill in the table below by calculating the change in temperature of each material and the change in temperature of the water in the Styrofoam cup for each trial. List the 4 substances (the three materials and water) in order from the largest change in temperature to the smallest change in temperature.

Trial #	**Material**	**(T_{final} - $T_{initial}$) for material**	**(T_{final} - $T_{initial}$) for water in cup**
1	*copper*	*Students' answers will vary; values should be negative.*	*Students' answers will vary; values should be positive.*
2	*lead*	*Students' answers will vary; values should be negative.*	*Students' answers will vary; values should be positive.*
3	*glass*	*Students' answers will vary; values should be negative.*	*Students' answers will vary; values should be positive.*

Order from ***largest to smallest*** change in temperature:

lead (largest), copper, glass (smallest)

4. Each substance has a characteristic specific heat capacity. Based on your temperature data and the table of accepted specific heat capacity values below, what is the relationship between the specific heat capacity of a substance and the degree to which its temperature changes when a given amount of heat is transferred per unit mass? Use evidence from your experiment to support your claim.

Substance	**Specific heat capacity (J/g °C)**
water (H_2O)	4.184
copper (Cu)	0.384
lead (Pb)	0.127
iron (Fe)	0.449
aluminum (Al)	0.897

glass	0.840
PET plastic	1.030

The higher the specific heat capacity of a substance, the less its temperature will change when a given amount of thermal energy is transferred per unit mass. Since we kept mass and initial temperature relatively constant in our experiment, the amount of thermal energy available to transfer from the material to the water was relatively constant. Lead, which has the lowest specific heat (0.127 J/g °C) of the three materials in our experiment, had the greatest change in temperature (values will vary). Glass, which has the highest specific heat capacity of the three materials (0.840 J/g °C), had the smallest change in temperature (values will vary). Copper, which has a specific heat capacity in between (0.384 J/g °C) lead and glass, experienced a temperature change in between (values will vary).

5. The accepted specific heat capacity values for iron and aluminum are listed in the table above. Imagine that you carried out the same experiment as in Part 2 using these two metals. Refer to your response for question #3—where would you place iron and aluminum in the order from largest to smallest change in temperature? Explain your reasoning.

*Order: lead (largest), copper, **iron**, glass, **aluminum** (smallest)*

Since iron's specific heat capacity falls between the specific heat capacities of copper and glass, we would expect its change in temperature to fall in between those two. Since aluminum has a specific heat capacity greater than all the other materials, we would expect its temperature change to be the smallest.

6. Use your experimental data, the specific heat capacity of water (4.184 J/g °C), and the equation $q = mc\Delta T$ to calculate the amount of heat transferred to the water in the Styrofoam cup when the heated copper was added in trial #1.

Students' answers will vary. All answers should be given in joules and should be positive.

q = (25 g)(4.184 J/g °C)(ΔT value from the table in question #3 above)

7. Does the heat transferred to water (q) have a positive or negative sign? Explain what the sign tells you.

The heat transferred to water (q) has a positive sign, showing that thermal energy is being transferred to the water from the higher temperature copper metal.

8. Based on your answers above, how much heat was transferred from the copper to the water? Will this q value for copper have a positive or negative sign? Explain your reasoning.

The heat transferred from the copper must have the same magnitude as the heat transferred to the water, because energy is conserved. The q value for the copper will have a negative sign, because thermal energy is transferring out of the copper to the water.

+q (water) = —q (copper)

9. Use your experimental data, the q value from question #8, and the equation $q = mc\Delta T$ to calculate the specific heat capacity of copper.

Students' answers will vary. All answers should be given in J/g °C and should be positive.

$$c = \frac{q\ value\ from\ question\ \#8\ above}{(25\ g)(\Delta T\ value\ from\ the\ table\ in\ question\ \#3)}$$

10. Compare the experimental value you calculated for the specific heat capacity of copper to the accepted value given in the table above. Is your value close to the accepted value? What are some sources of error in the design of the experiment that might cause your value to be different from the accepted value?

Students' responses will vary. Their experimental values may or may not be close to the accepted value for the specific heat capacity of copper. In either case, encourage students to consider sources of error in the experimental design.

Some examples might include:

- *thermal energy transferred to the surroundings when the test tube is removed from the water bath, before the metal is added to the system*
- *thermal energy transferred to the surroundings at the surface of the water, where it is in contact with the air*

- *not allowing time for the thermometer to reach thermal equilibrium with the system when reading initial temperatures*

11. Taking into account the sources of error that you identified above and what you know about effective experimental design, what are some changes you would make to the procedure and setup in Part 2? What would you do to improve the accuracy of your experimental value for the specific heat capacity of copper?

Students' responses will vary. They should consider adding multiple trials, come up with ways to minimize thermal energy transfer to the surroundings, and address any other sources of error identified above.

Keep creating!

Student pamphlets should explain how the lower specific heat capacity of sand, compared to water, causes the sand to increase in temperature more than the water, even though both are experiencing the same solar radiation on a sunny summer day. Students should use diagrams and descriptions based on their model of heat transfer to explain that thermal energy transfers from the sand to the soles of their feet because the temperature of the sand is higher. This raises the temperature of the soles of their feet, so the sand "feels hot." Conversely, thermal energy transfers from their feet to the water when they come in contact, because the temperature of the water is lower.

Student examples of natural phenomena or engineering challenges related to specific heat capacity will vary, but they should explain how specific heat capacity plays an important role in whatever examples they choose.