ASPECt
Assessing Students' Progress on the Energy Concept

Candle & Fan:
AP17-6 (MC) & AP56-4 (CR)

High School – Energy Transfer by Forces

TASK OVERVIEW

Students observe a demonstration of a fan that spins while over a lit candle. They create a model representing what they think causes the fan to spin. They also describe the parts of the model and what causes the fan to spin. Finally, the students write an argument that explains the role that thermal energy and forces play in causing the fan to spin.

TARGETED DCIs, SEPs, AND CCCs

Disciplinary core ideas

- PS3.A-H.2: At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.
- PS3.A-H.4: These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.

- PS3.A-M.3: The term "heat" as used in everyday language refers both to thermal energy (the motion of atoms or molecules within a substance) and the transfer of that thermal energy from one object to another. In science, heat is used only for this second meaning; it refers to the energy transferred due to the temperature difference between two objects.
- PS3.C-M.1: When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object.
- PS1.B-M.3: Some chemical reactions release energy, others store energy.
- PS4.B-H.2: When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells.

Science & engineering practices

- SEP2-H.3: Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.
- SEP7-H.5: Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.

Crosscutting concepts

- CC5-M.4: The transfer of energy can be tracked as energy flows through a designed or natural system.
- CC2-H.2: Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.

Related Performance Expectations

- HS-PS3-2: Develop and use models to illustrate that energy at the macroscopic scale can be accounted for as a combination of energy associated with the motion of particles (objects) and energy associated with the relative positions of particles (objects). [*Clarification Statement*: Examples of phenomena at the macroscopic scale could include the conversion of kinetic energy to thermal energy, the energy stored due to position of an object above Earth, and the energy stored between two electrically charged plates. Examples of models could include diagrams, drawings, descriptions, and computer simulations.]

TASK PERFORMANCE EXPECTATION

Develop a model to illustrate what causes a fan to spin when a candle is lit underneath it and *defend a claim* about cause-and-effect relationships that reflects knowledge about the atomic/molecular scale and ideas about energy transfer.

NOTES

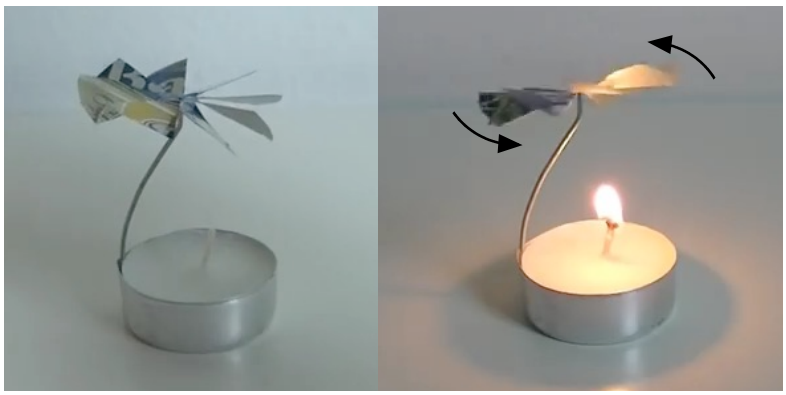
The context of this item involves the mechanism of convection currents, that is, that warm air is less dense than cool air, so it is pushed upwards by the cool air. NGSS does not explicitly reference air convection, but it does include discussion of convection in the oceans and mantle.

LINK TO ONLINE VERSION

http://assess.bscs.org/i/test/606

Task

A teacher shows her class a demonstration of a fan that spins over a lit candle.



Watch the video to see the demonstration.

http://test.p2061.org/items/media/uploads/image/ASPECt_3D/spinning_fan-mute.mp4

The students notice that the fan only spins after the candle is lit. They also notice that air around the fan and candle is warmer when the candle is burning than when the candle is not burning.

The teacher asks the students to use ideas about energy to describe what is happening when the fan is moving and when it is not moving. One student says that the increase in thermal energy of the air is causing the fan to spin. Another student disagrees and thinks that the increase in thermal energy is not enough to cause the fan to spin. She thinks that there must be a force involved.

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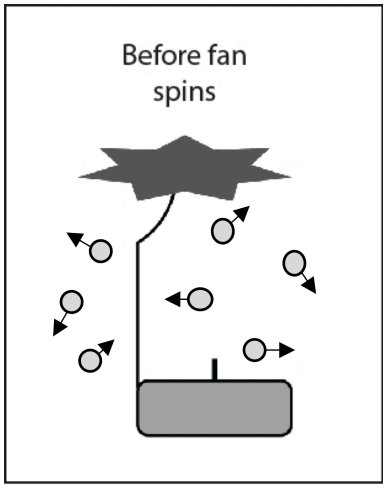
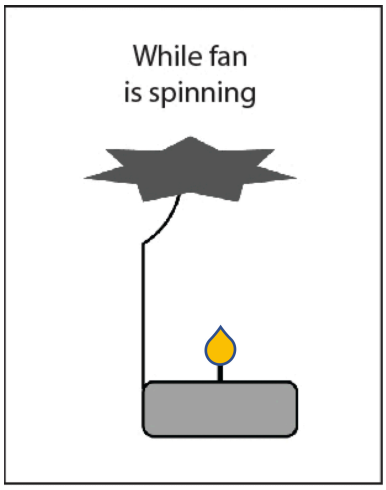
1. The students decide to make a model to better communicate their ideas. The model below shows the candle/fan system before the candle is lit. The gray circles represent the molecules of air, and the black arrows show the direction the molecules are moving. The length of the arrows represents the relative speeds of the molecules with longer arrows representing faster molecules. The model shows that before the candle is lit, the molecules of air are moving randomly around the candle and fan.



Create a model that represents the motion of the molecules of air and the energy transferred between the candle, air, and fan while the candle is lit and the fan is spinning. Your model should include:

- Gray circles to represent the molecules of air
- Black arrows to represent the speed and direction the molecules are moving
- Red arrows to represent the transfer of energy



2. Describe how the motion of the molecules of air changed from before the fan spins to while the fan is spinning.

3. Describe how energy is being transferred while the candle is lit and the fan is spinning.

----------Multiple-choice Version of #4----------

4. Which of the following explains the roles that both the thermal energy of the air and forces play in causing the fan to spin?

   A. Energy from the burning candle is transferred to the air around the candle, increasing the thermal energy of the air. The thermal energy moves upward and causes the fan to spin. Energy is a force and forces cause objects to move.

   B. Energy from the burning candle is transferred to the air around the candle, increasing the thermal energy of the air. This means the air now contains more heat molecules. The heat molecules move upward to the fan and collide with the fan blades. The interaction between the heat molecules and the fan is a force that transfers energy to the fan causing it to spin.

   C. Energy from the burning candle is transferred to the air around the candle, increasing the thermal energy of the air. This causes the molecules of the air above the flame to move faster. These faster moving molecules move upward and collide with the fan. This interaction between the air molecules and the fan is a force that transfers energy to the fan causing it to spin.

----------Constructed-response Version of #4----------

4. Using your models and what you know about energy, write an argument that would convince the students that both the thermal energy of the air and forces play a role in causing the fan to spin. Be sure to use ideas about molecular motion, energy, and forces.

Alignment to Targeted DCIs, SEPs, and CCCs and Scoring Rubrics

QUESTION 1

Create a model that represents the motion of the molecules of air and the energy transferred between the candle, air, and fan while the candle is lit, and the fan is spinning. Your model should include:

- Gray circles to represent the molecules of air
- Black arrows to represent the speed and direction the molecules are moving
- Red arrows to represent the transfer of energy

LEARNING GOAL

Learning Performance

- Draw a model representing the candle, fan, and air system after the candle is lit and the fan starts to spin.

Targeted DCIs, SEP, and CCC

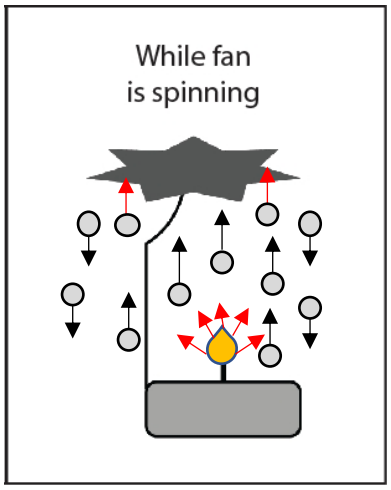
- PS3.A-H.2: At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.
- PS3.A-H.4: These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which

mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.

- PS3.C-M.1: When two objects interact, each one exerts a force on the other that can cause energy to be transferred to or from the object.
- SEP2-H.3: Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.
- CC5-M.4: The transfer of energy can be tracked as energy flows through a designed or natural system.
- CC2-H.2: Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.

SCORING RUBRIC

Ideal Response

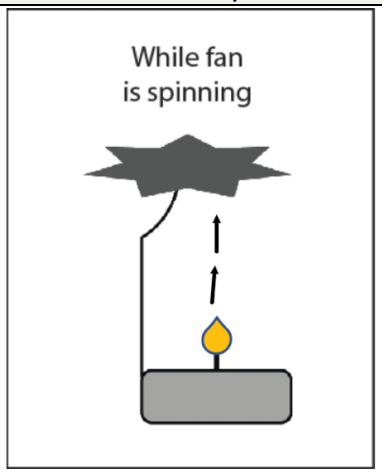
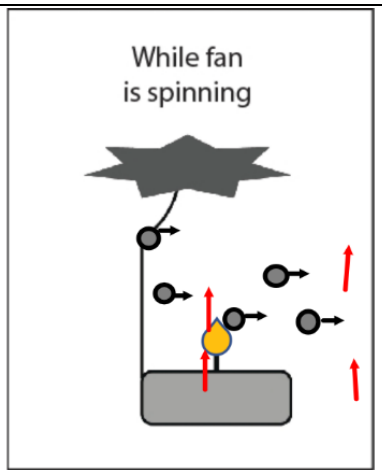


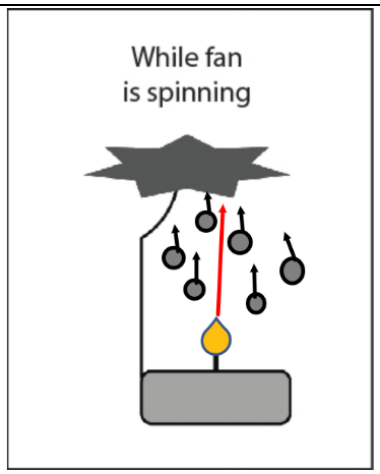
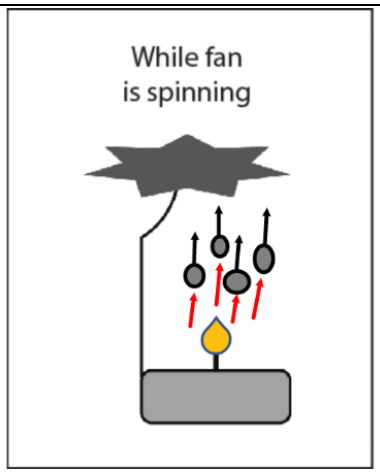
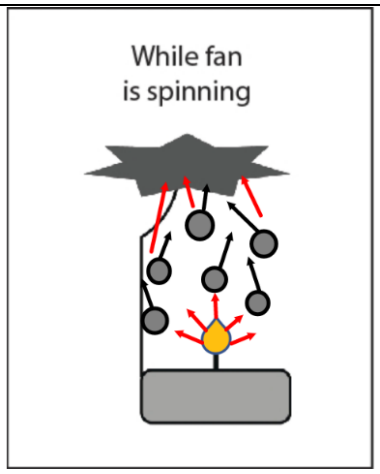
Elements of a Correct Response

Categories	Elements
Student includes the essential components of the system	• Gray circles to represent the molecules of air [Note that the candle, fan, and flame are provided.]

Student draws black arrows to represent the speed and direction the molecules are moving	• Black arrows pointed upward to represent the molecules of air moving upward. • Black arrows pointed downward to represent the molecules of cooler air moving downward at the edges. (Optional)
Student draws red arrows to represent the transfer of energy	• Red arrows to represent energy being transferred from the burning candle to the molecules of air. • Red arrows to represent energy being transferred from the molecules of air to the fan.

Sample Student Responses

Student response	Scoring description
	Score = 0 The model does not include particles of air, their motion, or energy transfer.
	Score = 1 The model includes particles of air, but the motion arrows are indicating the incorrect direction of motion, and the energy arrow are not pointing from the flame to the particles.

	Score = 2 The model includes particles of air and arrows indicating the upward motion of the particles, but the energy transfer arrow is not showing energy transfer from the flame to the particles and from the particles to the fan.
	Score = 3 The model includes particles of air, arrows indicating the upward motion of the particles and arrows illustrating the transfer of energy from the flame to the particles of air. It does not include energy transfer arrows from the particles to the fan.
	Score = 4 The model includes all the elements in the rubric.

QUESTION 2

Describe how the motion of the molecules of air changed from before the fan spins to while the fan is spinning.

LEARNING GOAL

Learning Performance

- Describe how the motion of the molecules of air changed from before the fan spun to while the fan is spinning.

Targeted DCIs, SEP, and CCC

- PS1.B-H.1: Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.
- PS4.B-H.2: When light or longer wavelength electromagnetic radiation is absorbed in matter, it is generally converted into thermal energy (heat). Shorter wavelength electromagnetic radiation (ultraviolet, X-rays, gamma rays) can ionize atoms and cause damage to living cells.
- PS3.A-M.3: The term "heat" as used in everyday language refers both to thermal energy (the motion of atoms or molecules within a substance) and the transfer of that thermal energy from one object to another. In science, heat is used only for this second meaning; it refers to the energy transferred due to the temperature difference between two objects.
- ESS2.C-M.4: Variations in density due to variations in temperature and salinity drive a global pattern of interconnected ocean currents.
- CC2-H.2: Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.

SCORING RUBRIC

Ideal Response

Before the candle is lit, the molecules of air are moving randomly around the candle and fan. After the candle is lit, the molecules of air move faster and start moving upward toward the fan.

Elements of a Correct Response

Categories	Elements
Student describes the motion of molecules before and after the candle is lit	• Before the candle is lit, the molecules are moving randomly. (Note: Students do not have to mention randomly explicitly. They can imply it by writing something like "the molecules are going in every direction.") • After the candle is lit, the molecules are moving faster. • After the candle is lit, the molecules start moving upward toward the fan. • After the candle is lit, the molecules of cooler air move downward at the edges. (Optional)

Sample Student Responses

Student response	Scoring description
"The motion of the molecules air changed when the fan started spinning by spinning around the blades."	Score = 0 The response does not include a correct description of how the motion of the molecules of air changes, from the initial random motion of the molecules of air to the upward and more rapid motion of the molecules after the candle is lit.
"While you light the candle the air from the candle rises up and pushes the fan."	Score = 1 The response includes the element that the molecules of air start moving upward, but not the initial random state of the molecules.

"Before all the molecules were spinning everywhere and in all directions when the candle was not on but when the candle is lit the molecules are all in one direction to the fan causing it to spin."	Score = 2 The response describes the change in the direction of motion from moving randomly to moving in an upward direction, but it does not include the change in speed.
"Before the molecules moved randomly in the air, but after the candle is lit the molecules go faster with the increase in and energy and move up with the increase in heat."	Score = 3 The response includes all the elements in the rubric.

QUESTION 3

Describe how energy is being transferred while the candle is lit and the fan is spinning.

LEARNING GOAL

Learning Performance

- Describe how energy is being transferred while the fan is spinning.

Targeted DCIs, SEP, and CCC

- CC5-M.4: The transfer of energy can be tracked as energy flows through a designed or natural system.

SCORING RUBRIC

Ideal Response

Energy is being transferred from the burning candle to the molecules of air and energy is being transferred from the molecules of air to the fan.

Elements of a Correct Response

Categories	Elements

Student uses a crosscutting concept	• The transfer of energy can be tracked as energy flows through a system (i.e., energy is transferred from the candle to the air and from the air to the fan). [energy flow]
	  ○ Energy is transferred from the lit candle to the air/molecules of air.
	  ○ Energy is transferred from the air/molecules of air to the fan.

Sample Student Responses

Student response	Scoring description
"The energy is being transferred by the fan spinning, causing the molecules and energy to move up."	Score = 0 The response does not include a correct description of how energy is transferred from the candle to the air to the fan, only the effect that the fan has on the air around it after it is set in motion.
"The lit candle transfers thermal energy into the surrounding air molecules."	Score = 1 The response includes the element that the energy is transferred from the lit candle to the air molecules.
"Energy from the flame gets transferred to the air molecules and then to other molecules and then to the fan."	Score = 2 The response includes both elements in the rubric.

QUESTION 4

Using your models and what you know about energy, write an argument that would convince the students that both the thermal energy of the air and forces play a role in

causing the fan to spin. Be sure to use ideas about molecular motion, energy, and forces.

LEARNING GOAL

Learning Performance

- Construct (or select) an argument to support the claim that thermal energy of the air and forces played a role in causing the fan to spin.

Targeted DCIs, SEP, and CCC

- PS3.A-H.2: At the macroscopic scale, energy manifests itself in multiple ways, such as in motion, sound, light, and thermal energy.
- PS3.A-H.4: These relationships are better understood at the microscopic scale, at which all of the different manifestations of energy can be modeled as a combination of energy associated with the motion of particles and energy associated with the configuration (relative position of the particles). In some cases the relative position energy can be thought of as stored in fields (which mediate interactions between particles). This last concept includes radiation, a phenomenon in which energy stored in fields moves across space.
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- PS1.B-M.3: Some chemical reactions release energy, others store energy.
- SEP7-H.5: Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.

- CC2-H.2: Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system.

SCORING RUBRIC

Ideal Response

Energy from the burning candle is transferred to the air around the candle, increasing the thermal energy of the air and the speed of the molecules of the air. This causes the molecules of the air to move upwards toward the fan. When the molecules reach the fan, they collide with the fan blades. The interaction between the molecules and the fan is a force that transfers energy from the molecules to the fan causing the fan to spin.

Elements of a Correct Response

Categories	Elements

Student either states or uses a general science idea	• The lit candle or flame transfers energy to the air around it. (Students may be using the following ideas.) [*links burning candle & energy transfer*]
	  ○ Some chemical reactions release energy. (i.e., the chemical reaction that occurs as the candle wax reacts with oxygen releases energy that is transferred to the air.)
	  ○ The absorption of light results in an increase of thermal energy (i.e., as the burning candle transfers energy to the air by light, the thermal energy of the air increases).
	  ○ Light transfers energy from place to place (i.e., the light from the lit candle transfers energy to the air).
	• Thermal energy is associated with the motion (or kinetic energy) of the molecules that make up the objects (i.e., as the thermal energy of the air increases, the molecules of air move faster). [*links thermal energy & motion of molecules*]
	• Hotter air moves upward [as gravity pulls cooler air downward] (i.e., the faster moving molecules of the heated air move upward the fan). [*hotter air rises*]

	• A force/push can transfer energy from one object to another resulting in a change in motion (i.e., energy is transferred from the molecules of air to the fan when the molecules of air hit the fan and causes the fan to spin). [*links force & energy transfer*]
Student uses reasoning that explicitly address the role of thermal energy and force in the phenomenon	• Energy from the burning candle is transferred to the air around the candle, increasing the thermal energy of the air, which resulted in the movement of air upward toward the fan. • The molecules of the heated air exert a force/push on the fan that causes it to spin.
OR	
Student selects the correct response to the multiple-choice version	C. Energy from the burning candle is transferred to the air around the candle, increasing the thermal energy of the air. This causes the molecules of the air above the flame to move faster. These faster moving molecules move upward and collide with the fan. This interaction between the air molecules and the fan is a force that transfers energy to the fan causing it to spin.

Sample Student Responses

Student response	Scoring description
"Just like a hot air balloon heat rises and moves the fan and when the heat rises to the hot air balloon the balloon will fly."	Score = 0 The response does not use ideas about molecules in motion or energy and forces to explain the phenomenon.
"Thermal energy takes play into the movement of molecules, as the increased heat increases the speed of the molecules surrounding the faster moving molecules by heat."	Score = 1 The response only includes the science idea that increasing the temperature increases the speed of the molecules, not the idea that the molecules exert a force on the fan.

"If the candle is lit, then the heat energy from the candle, along with the thermal energy from the air would cause the molecules to move, forcing the molecules in the same direction."	Score = 2 The response includes the idea that the candle transfers energy to the molecules of air and causes them to move upward, but it does not include the idea that the air molecules exert a force on the fan.
"the thermal energy coming from the candle is transferred into the molecules which gives them the energy to move upwards towards and the molecules then enact force on the fan to push it"	Score = 3 The response includes all the elements of the rubric.

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