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Driving Question: To stop or not to stop?

Sub-driving question	Lesson	Lesson question	Brief description	Phenomena	What kids learn	Learning Performances
Lesson Set 1: What makes things start going?	1	To stop or not to stop?	Students watch a video of a professional Rube Goldberg machine to start thinking about systems and interactions between objects. As anchoring activities for the following lessons, students observe a set of phenomena that behave in unexpected ways. These include a radiometer, a Jupiter pendulum with/without a battery, a rollback coffee can, a "top secret" spinning top, and a set of blocks that melt ice at different rates.	• Various functioning apparatuses, some that stop and others that keep going in unexpected ways. • Professional Rube Goldberg machine video	• Some things stop quickly and others keep going for a long time • Every phenomenon that we observed includes at least two things interacting in some way	• Students observe, describe, compare and contrast processes in systems. • Ask questions (about the function of devices that they observe) that will help them to investigate why some devices stop while others keep going.
	2	What makes a radiometer spin?	Students watch a second "Rube Goldberg" machine, but one that works on light, in order to identify systems and processes involved. Then, students return to the radiometer (which they saw in the last lesson) and consider how to construct a model to represent which systems are involved in its operation, what processes they go through, and how these systems interact. This is the basis of the "Energy Transfer Model" (ETM) that develops throughout the unit.	• Video of light-powered professional Rube Goldberg Machine • Radiometer	• When a phenomenon occurs, some objects are involved and others are not. • The energy of a system increases if it, or any part of it, increases in speed. • Light can affect systems by transferring energy to them. • Scientific models are useful for representing how phenomena occur.	• Develop an initial model of how a process in one system (the glowing of a flashlight) initiates a process in another system (the spinning of a radiometer) when these systems interact via light.
	3	What makes a Hero's engine spin?	Teacher demonstrates a "Hero's engine" as a device that is similar to the radiometer (e.g., it can be made to turn by something else), but moves because of heat rather than light. Students build their own Hero's engine to try to make it spin for as fast or long as possible, but recognize that their engine does not spin as fast as the teacher demo, which uses a stronger flame. Students construct an Energy Transfer Model to describe the Hero's engine and recognize that the same form can be used to represent the radiometer.	• Students construct a Hero's engine to try to meet a design goal (e.g. spinning as fast as possible). • Students observe a Hero's engine as see through a thermal camera to observe heating prior to spinning.	• The larger the flame powering a Hero's Engine, the faster it will turn. • A Hero's engine and a radiometer function differently but can both be represented with the same Energy Transfer Model (ETM) • When a Hero's engine operates, it does not start spinning right away, which indicates that some other process must be happening that we have not yet identified.	• Design and construct a Hero's engine to meet a particular design goal (e.g., spinning as fast as possible). • Construct a model to describe the energy transfer to the can in a Hero's Engine.
Lesson set 2: How can energy be transferred from one system to another?	4	Why do hot things make other things hot?	The teacher points out that in a Hero's Engine, which they just investigated, the flame doesn't touch the water - only the can does. Students explore how a hot object transfers energy to a colder object when they are in contact.	• Heat conduction through a pop can, with and without insulating tape • Two knifes in a towel	• Materials with different temperatures in contact with each other transfer energy to each other. • The temperature of a hot object (or a hot area of an object) decreases and the temperature of a cold object (or a cold area of an object) increases	• Students use the principle of energy transfer from hot to cold objects to explain temperature changes in two objects in contact with each other. • Students draw an energy diagram that depicts changes in particle motion in each object and transfers via

					when the two objects are put in contact with each other. ● Different materials have different thermal conductivities. ● The warmer an object, the faster the particles of which it is made move.	conduction.
	5	How do collisions transfer energy?	Students bridge from the microscopic to the macroscopic view of energy transfer by looking at collisions between macroscopic and microscopic objects. After “zooming out”, students zoom back in to see that energy transfer happens back and forth in two objects in contact, but on average goes from hotter to colder object.	● Billiard balls colliding ● Collisions between particles in objects ● objects of different sizes ● Collisions between a cart of varying speed and mass and a block of Styrofoam ● A simulation of the relation between molecular motion and temperature	● When two objects collide, energy is transferred from the faster object to the slower one. ● Energy is transferred between objects of different temperatures in contact with each other because of collisions between their particles. ● The temperatures of objects in contact changes until they reach the same temperature. ● When energy is transferred to an object such that its speed increases, we call this an increase in kinetic energy. ● When energy is transferred to an object such that the random motion of its atoms/molecules increases (i.e., temperature increases), we call this an increase in thermal energy.	● Students investigate collision between coins to gather evidence to support the claim that in a collision between coins, energy is always transferred from the faster moving coin to the slower moving coin. ● Students construct a scientific explanation of why collisions between particles are responsible for the transfer of energy between objects in contact with different temperatures. ● Students investigate the qualitative relationship between the speed and mass of an object and the energy transferred from it when it is stopped by a collision.
<u>Lesson set 3:</u> How can energy be transferred even when objects don’t touch?	6	How can objects push or pull each other even if they don’t touch?	Students investigate interactions without contact by exploring magnetic cart collisions and “explosions”. Students explore magnetic phenomena to explore how fields convey pushes/pulls even when objects are not in contact. Teacher presents fields as a new type of system (or subsystem) that can transfer energy to or from objects.	● Magnetic carts that push on each other (collide) without touching ● Magnetic carts that are held together then released ● Kids explore how magnets affect the iron filings around them	● Two repelling magnets that are held close to each other can start moving when they are released ● Magnets affect the region of space around them ● Fields between magnets explain how they can push/pull on each other even when they are not in contact. ● Energy is transferred to/from a field when the distance between objects that interact via the field changes.	● Students use the idea of fields to explain why magnets push on each other even when they are not in contact. ● Students draw an energy transfer model representing a system of two repelling magnets held together then released.

	7	Why do things speed up as they fall?	Students build on their experiences with magnetic fields to consider gravity as a field. Students gather evidence to connect changes in height to the energy transferred from a gravitational field, and they relate changes in fields between interacting objects to changes in their motion.	• Videos that obfuscate gravity and magnetic attraction to help students draw parallels between magnetic and gravitational fields • Videos of magnetic carts repelling and attracting with different masses • "Joule apparatus" in which a falling water bottle forces a cork to turn around a thermometer, heating it. • Video of a ball being thrown upward and falling again	• Like magnets, gravity acts via a field. • As the arrangement of objects interacting at a distance (via fields) changes, the amount of energy stored in the field (potential energy of the system) changes. • As an object moves farther from the Earth, energy is transferred to the gravitational field between the Earth and the object.	• Students gather and analyze data to relate the height an object falls to the energy transferred from the gravitational field to the object. • Students draw an energy transfer model representing energy changes as a ball is thrown upward and falls back down. • Students use an energy transfer model of a ball thrown upward to construct a scientific explanation relating the speed of the object when it is thrown upward to its speed with it lands.
	8	What makes bouncy balls go back up?	In the last lesson, students explored how energy transfer to/from gravitational fields can explain why objects slow down, stop, and turn around again when they are thrown upward. In this lesson, they "flip" this perspective to explore why a bouncing ball can reverse direction and come back up again, just as they have seen in gravitational and magnetic phenomena. Using a simulation of elastic materials, students recognize that atomic spacing changes as atoms stretch or compress and that atoms interact at a distance. This is the basis for speculating that there is a field between the atoms and that energy can be transferred to or from this field when elastic materials are deformed. (While this field is the electric field, it is not named in this lesson.) Students use the idea of energy transfer to/from the field between atoms to explain bouncing balls and the rollback can. The lesson concludes by discussing that phenomena such as bouncing balls, pendulums, and the rollback can all eventually stop.	• Simulation of change in distance between atoms when an elastic material is stretched/compressed. • Bouncing balls with different elasticity • Basketball/tennis ball demonstration • Inverted racquetball • Rollback coffee can	• Like magnets and gravity, atoms interact with each other via fields • As materials are stretched or compressed, energy is transferred to/from the electric field between atoms as their configuration changes. • Swinging pendulums, bouncing balls, and rollback cans eventually stop.	• Students use a particle model of matter to support the claim that energy is transferred to a field between atoms when elastic materials are stretched or compressed.
Lesson Set #4: Why do things eventually slow down and stop?	9	Where does energy go as things slow down and eventually stop?	In the previous lesson, students noticed that bouncing balls eventually stop, as do rollback cans and pendulums. Now, students explore the connection between random particle motion, energy transfer to the environment system, and slowing/stopping over time. Students also explore how random particle motion tends to transfer to the	• Use a thermal camera to compare an object rolling vs. sliding down an incline • Use a thermal camera to see thermal "prints" left by balls bouncing on felt. • Revisit pendulum swinging	• Systems slow down and stop as they transfer their motion to random motion of particles both in the system and the surroundings. • Energy tends to spread out because of random molecular motion • Energy transferred to the surroundings	• Students present evidence to support the claim that when a sliding object slows down, energy was transferred to its surroundings. • Students construct an energy transfer model that represents the energy changes that occur when a ball

			environment system and spread out and why sometimes it is difficult to detect a temperature change in a large enough system even when energy is transferred to it.	and link its stopping to molecular motion. • Use a thermal camera to look at dissipation of hot water in different sized containers.	can be difficult to detect if the surroundings are big enough. • Some materials are better than others at preventing heat transfer between systems.	bounces but does not return to its original height.
<u>Lesson Set #5:</u> How can we keep things going?	10	How does burning keep things going?	In the last lesson set, students explored why devices eventually slow down and stop. In this lesson, students revisit Hero's engine and explore why a cup with vent fans cut into it will spin when hung above a burning candle. After this, students consider how chemical reactions can transfer energy from fields between atoms to the motion of atoms and molecules, and ultimately objects, to keep things going.	• Chemical reaction between cupric chloride and aluminum • Spinning cup above a candle • Chemical reaction between cupric chloride and steel wool	• Substances seeming to appear/disappear is evidence of a chemical reaction • In burning, substances seem to appear and disappear, and there is a transfer of energy from the burning system to the surroundings via atomic collisions. • In chemical reactions, atoms form new configurations to produce new substances. This reconfiguration transfers energy either to or from the field between the atoms.	• Construct an energy transfer model to show how a chemical reaction can warm substances and the surroundings.
	11	How does electricity keep things going?	Students revisit the Jupiter pendulum with/without a battery and investigate how electricity can keep things going in simple electric circuits and phenomena.	• Revisit Jupiter pendulum and Secret Top with and without a battery • Explore electric circuits • Model energy transfers as a light bulb operates a radiometer • Aluminum-Air battery • Use a hand-cranked generator to power electric circuits.	• Electricity transfers energy between systems that interact via electric fields. • Electricity can transfer energy into moving devices that exactly compensates for the amount of energy transferred from the device to the surroundings. • Most electricity is generated by burning fuel with oxygen to heat water to turn turbines • In a battery, chemical reactions release energy that can be transferred to devices via electricity.	• Students construct an energy transfer model that represents how a device can keep going when it is connected to a source of electricity.
	12	Concluding the unit	Students revisit key findings from each learning set and look for evidence of energy transfers between systems in everyday life.			