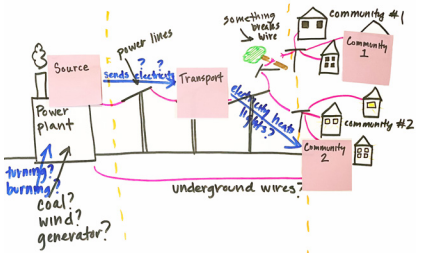
Unit Storyline

Lesson Set 1: How does electricity transfer through systems to power communities, and what causes instability in these systems?

LESSON 1

What can we learn from a blackout in Texas about producing reliable energy for our communities?

Anchoring Phenomenon **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
A winter storm in Texas in February 2021 led to devastating widespread blackouts throughout the state.  Hartmut Schmidt, Heidelberg	We explore a new phenomenon by reading a series of articles about widespread blackouts in Texas and by drawing on the experiences of our friends and family. We make an initial consensus model of what happens to our electricity production system when it is stable and during a blackout. We develop questions for our DQB and brainstorm initial ideas about ways we could design more reliable systems to meet our communities' energy needs. We figure out: • There are several subsystems that we agree are important for understanding how energy transfers to power our communities when the system is stable and during a blackout.	

Navigation to Next Lesson: We decide to document the electricity infrastructure in our homes and communities to look for patterns that could help us understand how the system works and identify important design constraints.

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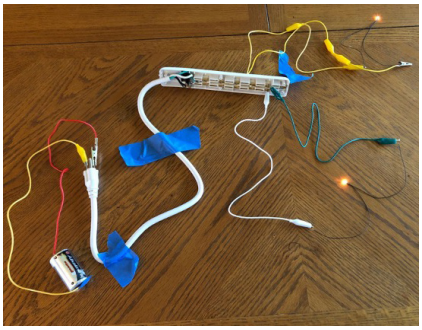
LESSON 2

What structures in the system enable energy transfer from one source to multiple devices, buildings, and neighborhoods?

Investigation 2 days

Phenomenon or design problem

In a power strip, there are three pieces of metal that are each connected to three wires within the plug. Similar structures are found within a house, and even within electrical grid substations.

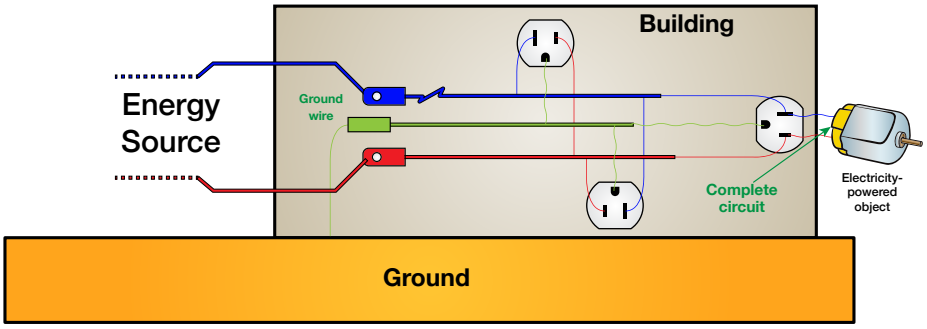


What we do and figure out

We compare photos and drawings of structures that provide electricity in our buildings and neighborhoods. We dissect a power strip and connect it to a battery to power multiple devices. We read about the function of ground wires and circuit breakers. We develop a model of how structures of the power strip system enable it to transfer energy from one source to multiple devices. We use this model to draw parallels to larger-scale systems (buildings, neighborhoods) and test the effects of short circuits and broken circuits. We figure out:

- Energy will transfer from a source to a device when a complete circuit is formed, but will not transfer when there is a break in any of those paths.
- When energy transfers through a circuit system without powering any devices, we call this a short circuit. A short circuit occurs when there is a direct conducting path from one side of the energy source to the ground or to the other side of the source. A single short circuit in a system can cause blackouts in the entire system.

How we represent it



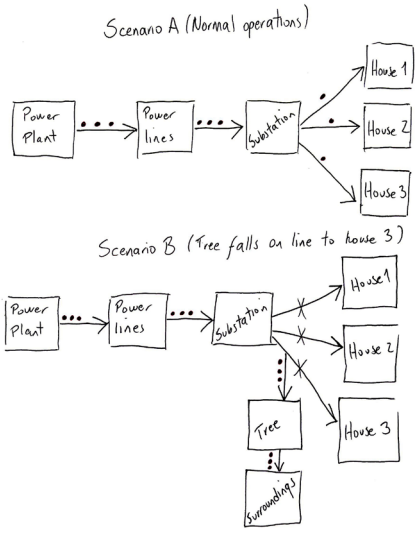
Navigation to Next Lesson: We are thinking that short circuits or broken circuits could have been a cause for the patterns of blackouts we saw in Texas, so we want to investigate this possibility.

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LESSON 3

Could the blackouts in Texas have been caused by a broken or short-circuited circuit?

Investigation **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Electricity demand forecast data did not match electricity production in Texas during February 2021.  FEMA, M. Raphael	We read about an energy crisis that began in Ohio and a strategy engineers have used to prevent short and broken circuits in power lines. We use the Engineering Design Tracker to keep track of our ideas. We develop a new representation to model energy transferred in various parts of the system. We analyze electricity demand and supply data in Texas and use this to brainstorm ideas of where to go next. We figure out: • Engineering constraints can affect the implementation of a possible solution. • The production of electrical energy must match the demand for electrical energy. • The cold temperatures during the Texas blackout caused a spike in energy demand, which was accompanied by a drop in the supply of electrical energy.	 Data Source: US Energy Information Administration

Navigation to Next Lesson: We saw a mismatch between the amount of energy generated and the amount of energy demanded by communities in Texas, which led us to wonder what could have caused the observed drop in the supply.

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LESSON 4

What makes an energy source reliable?

Investigation **2 days**

Phenomenon or design problem

Descriptive and graphic data on a variety of energy sources reveal puzzling inconsistencies in each energy source's reliability during the blackout.



US Marine Corps, Pfc. J. Handeland

What we do and figure out

We use informational cards and several data representations from the 2021 Texas energy crisis to seek additional information about specific sources of energy to help us figure out which source might be responsible for the drop in supply we discovered in Lesson 3. We use a new tool called a Decisions Matrix to keep track of how well each source meets criteria we think are important. We figure out:

- The energy used to create electricity in a power plant comes from Earth's systems.
- Making decisions about complex societal issues like energy production requires defining criteria for success that might not be straightforward or easy to quantify.

How we represent it

	Energy Sources Impact Criteria				
	Criterion #1	Criterion #2	Criterion #3	Criterion #4	Criteri
Energy Source	High Reliability	High Renewability	High Efficiency		
Wind	*	****	**		
Solar	*	****	*		
Biomass	***	***	**		
Coal	****	*	**		
Natural Gas	****	**	***		
Nuclear	****	***	***		
Hydroelectric	***	***	****		
Geothermal	***	****	**		

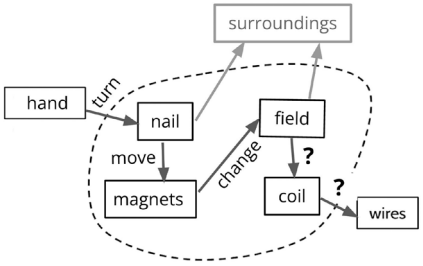
Navigation to Next Lesson: Since we are now wondering why some energy sources are more reliable than others (or efficient, powerful, dispatchable), we want to compare how the electricity from these different sources is produced.

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LESSON 5

Where does electrical energy come from?

Investigation **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
A light connected to a generator glows and nearby compass needles change direction when either the magnet or the wires in a generator move. 	We use diagrams of power plants to figure out how they transfer energy into wires. We dissect a generator and then reverse-engineer it. We use compasses to investigate energy transfer between the magnet and wire, and model the energy transfer through fields inside our generators. We figure out: • Many power plants have generators, which are loops of copper wire and powerful magnets. • Matter changes and/or motion can cause energy transfer through contact (and vice-versa). • The motion of a magnet can generate changing fields, which can cause energy transfer at a distance (and vice-versa). • When moving matter (e.g., pushing wind or steam) moves the magnets inside a generator, that can cause energy transfer into wires through changing fields.	

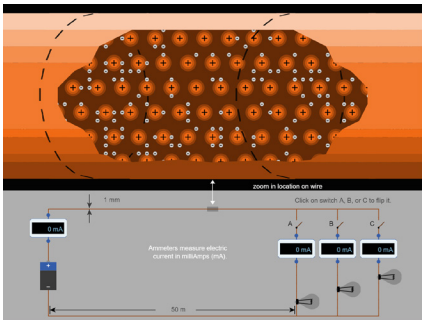
Navigation to Next Lesson: Though we have a model for how generators transfer energy to wires, we don't know what is happening inside the wires when they transfer energy (electricity) to our communities.

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LESSON 6

How does energy transfer in wires?

Investigation **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
A simulation of electrons in a wire shows their motion with various circuit configurations and power sources, and it provides a measure of energy and current in various parts of the system.  Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.	We read about electric and magnetic fields to help us model energy transfer involving fields more closely, focusing on transfers inside a wire. Using a simulation, we explore how various characteristics of an electrical system could influence the transfer of electrical energy, as well as their relation to energy loss, and check our results using classroom equipment. We figure out: • Electric and magnetic fields change when energy transfers into or out of them. • Electric fields can push electrons. "Electrical energy" is the energy of the movement of electrons transferring through pushes from fields. • A turbine transfers energy through electric and magnetic fields to the electrons in a wire, causing them to slosh back and forth continuously. • Electrons cause the atoms of the wire material to heat up, transferring energy from the system to the surroundings as "heat."	*Wire Sim Results* • *As ... increases, ... decreases.* • *As ... increases, ... increases.* • *As ... increases, ... doesn't change much.*

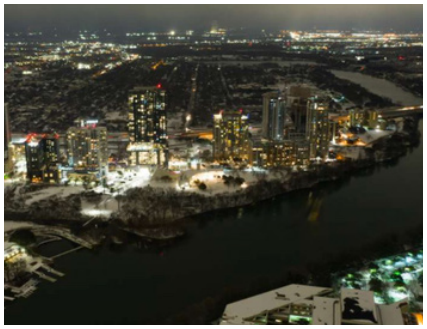
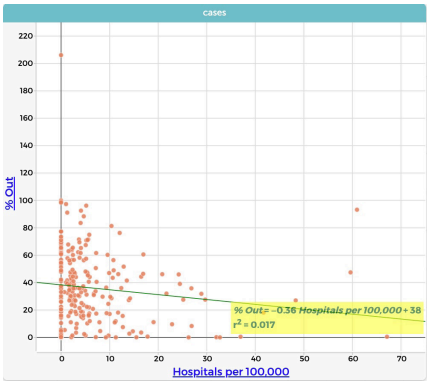
Navigation to Next Lesson: Since we figured out that cold weather does not affect energy loss from wires much, we think we can model in greater detail how insufficient supply can account for the effects on people in Texas.

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LESSON 7

What could have caused the disparities we saw in the blackouts in Texas?

Problematizing 2 days

Phenomenon or design problem	What we do and figure out	How we represent it
A data set shows disparities between counties impacted by the energy crisis in Texas that are not well explained by our model.  Jared Tennant	We develop a model based on evidence showing how insufficient supply entering the electrical system could lead to buildings losing power during a crisis. We test our models using Electric City, and we notice that to keep the lights on in one building, we need to cut power to others. We use data to test for correlations with county-level factors, and we consider limitations on this analysis. We figure out: • Power companies in Texas probably had to make decisions about who lost power in some places in order to keep the lights on in others. • There is no one factor that explains why some counties in Texas lost power and others did not.	 Images generated using CODAP (https://codap.concord.org/), developed at the Concord Consortium. Data Source: Mills & Gorman (1997)

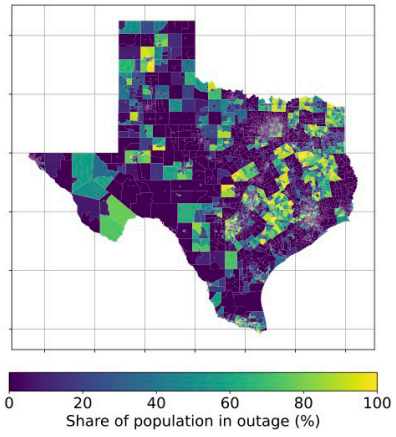
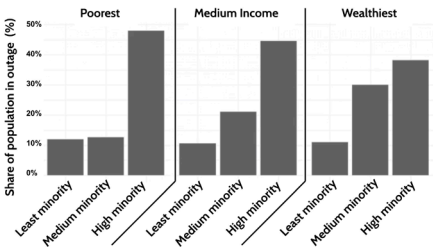
Navigation to Next Lesson: We figured out limitations associated with analyzing data grouped by counties because the scale of a single county is large. We wonder what those data look like at a smaller scale.

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LESSON 8

Why do design solutions affect some people differently than others?

Putting Pieces Together **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Scientists looking at satellite data uncovered patterns in the Texas power outages that we could not discern at a county-level scale.  Zeal Shah, Feng Chi Hsu, Jay Taneja, JP Carvallo	We listen to (and read the transcript of) a podcast featuring a scientist whose research group used satellite data to investigate patterns in who lost power in Texas. We read about two fictionalized families in Texas and consider how existing disparities can make the impact of a power outage inequitable across communities. We figure out: • An imbalance of energy supply and demand was the primary cause of the blackouts in Texas in February 2021. • There are design solutions for avoiding this in the future, but they come with trade-offs. • Across Texas, what neighborhood people lived in made an impact on whether they lost power. • Power outages have an inequitable impact on people in communities where there are existing disparities. • Throughout Texas, power companies made decisions to keep the power on in neighborhoods with "essential" buildings.	 Zeal Shah, Feng Chi Hsu, Jay Taneja, JP Carvallo

Navigation to Next Lesson: We figure out trade-offs, related to generating power, around which sources we use. We leave with a home learning about trade-offs associated with various energy sources.

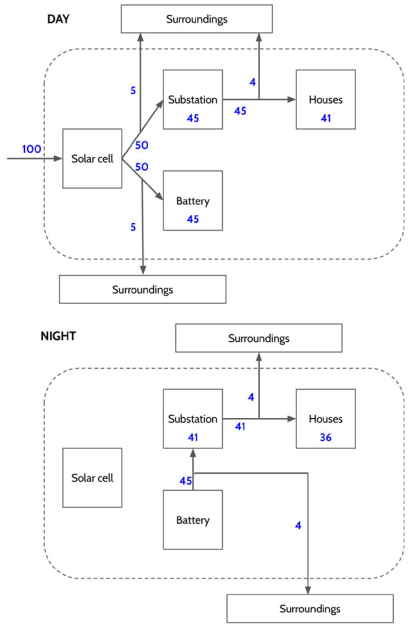
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Lesson Set 2: What design solutions could improve the electricity systems in our communities?

LESSON 9

How can energy storage make our systems more reliable during an energy crisis?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Batteries are not currently widely used in power grids.  Tennessee Valley Authority	We develop and revise energy transfer models to represent how batteries can make electric grid systems more reliable. We quantify how much energy was needed to prevent the energy crisis in Texas 2021. We use data from energy storage solutions to calculate the number of batteries needed and the costs associated with adding these batteries to the system. We wonder about the nonfinancial costs of design solutions. We figure out: • All forms of energy production and other resource extraction have economic, social, environmental, and geopolitical costs and risks as well as benefits that we will need to consider when making decisions about our own communities. • Design solutions that store excess energy can prevent an energy crisis by bridging the gap between energy demand and supply. • Energy storage systems can make an electric grid more reliable by providing power when the energy supply drops.	

Navigation to Next Lesson: We wonder what additional, non-financial costs might be associated with design solutions.

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LESSON 10

What decisions do we need to make to design more reliable systems to meet our community's energy needs?

Investigation **3 days**

Phenomenon or design problem

There are multiple criteria, constraints, and trade-offs to consider in making engineering decisions, and the interested parties in our communities don't always agree.



Finetooth, CC BY-SA 3.0

What we do and figure out

We read about trade-offs associated with various energy sources. We create a class Consensus Decisions Matrix that represents the criteria we agree are important when making decisions. We read quotes from interested parties, and develop and carry out an interview protocol to capture the values of people in our community. We begin developing a plan for improving electricity infrastructure in our community. We figure out:

- When developing design solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.
- Input from interested parties can be a great tool for determining the values that should guide how we address trade-offs.

How we represent it

Ranking	Criterion & Reason - Interested Party #1 (Mother)	Criterion & Reason - Interested Party #2 (Grandmother)
Highest Priority	Cost: I have three kids, and I belong to the middle income bracket, which means the cost of living is super high. If the electricity bill were to be cheaper, that would be a big help	Environmental Impact: I have seen the impact we are having in the environment. My biggest priority is to ensure we do not continue damaging our plant.
Second Highest	Safety: A power plant can affect our town and our environment, especially if it is going to be close to where I live. I don't want something polluting the air of the water that my family drinks.	Social Impact: Some communities living close to where the power plants are built might be more affected. I don't want energy generation to affect other communities.
Second Lowest	Environment: I want to have a planet for my kids and grandkids.	Cost: Electricity is expensive, but I can afford it
Lowest Priority	Aesthetics: I want my region to look nice, but it is not a big priority. If it is going to be close to my place and affect my property value, then I would care more.	Reliability: I know the fluctuation of energy in this region is not significant, so that is not my main concern.

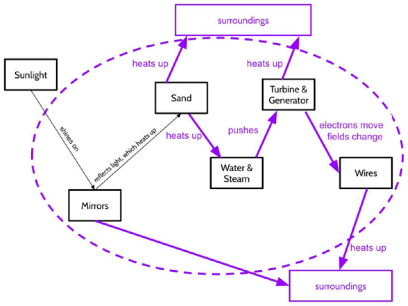
Navigation to Next Lesson: While we have identified trade-offs associated with various energy sources and criteria from various interested parties, we have not yet produced designs for improving the electricity infrastructure in our community that responds to interested parties' opinions that address these trade-offs.

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LESSON 11

What have we figured out, and what can we carry forward?

Putting Pieces Together **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Complex global challenges manifest in our communities. Developing solutions will require science practices and creative design thinking. 	We learn about the Energy Grid Calculator, a computational model that we use to measure the success of our solutions against a variety of criteria. We describe our design solution to our classmates, and we give each other feedback that we use to refine our designs. We return to the DQB and celebrate our progress in light of all the questions we can answer. We work through an assessment task in which we explain energy transfer in a solar sand power plant and use data to evaluate the feasibility of using this technology to provide reliable power to a community. We figure out: • Science learning is about asking questions, defining problems, and gathering evidence to answer those questions and address those problems.	

Navigation to Next Lesson: This is the last lesson of the unit.

Lessons 1–11 **28 Days Total**

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Unit Storyline

Lesson Set 1: How does land stretch and when/why does it break?

LESSON 1

What is happening in the Afar region?

Anchoring Phenomenon **2.5 days**

Phenomenon or design problem

A series of changes in Earth's crust over short and long timescales reveal puzzling patterns of earthquakes and cracks in Ethiopia, Africa, and similar patterns in North America.



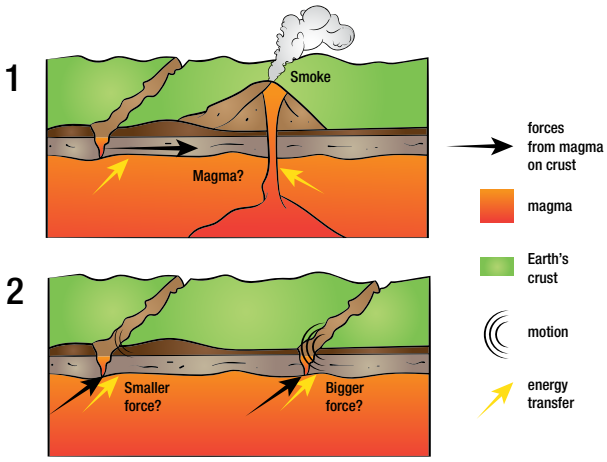
Akihito Ito CCBY 4.0

What we do and figure out

We explore a StoryMap about a series of events that left a giant crack in Earth's crust in the Afar region. We connect to prior earthquake experiences and to earthquakes near us. We read about selected North American earthquakes and compare them with the events in Afar. We develop an initial model for before, during, and after the events. We develop questions for the Driving Question Board and ideas for investigations. We figure out:

- A crack opened up in the Afar region in 2005. A volcanic eruption and an earthquake also occurred.
- Earthquakes seem connected to faults, and most, but not all, happen along plate boundaries.
- Earthquakes happen underground and can cause cracking/moving of Earth's surface.

How we represent it



Navigation to Next Lesson: We have explored multiple cases of earthquakes causing cracks in the ground. We wonder what could be causing the ground to shake and break.

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LESSON 2

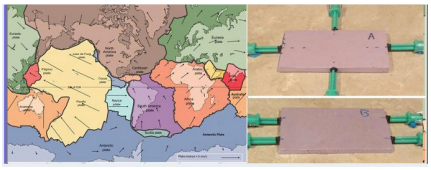
What allows a system to remain stable when forces are acting on it, and what causes it to suddenly change?



Investigation **3 days**

Phenomenon or design problem

Earth's plates show variation in their motion over the course of a year. Some combinations of contact forces on a piece of foam keep it stationary, and others do not.

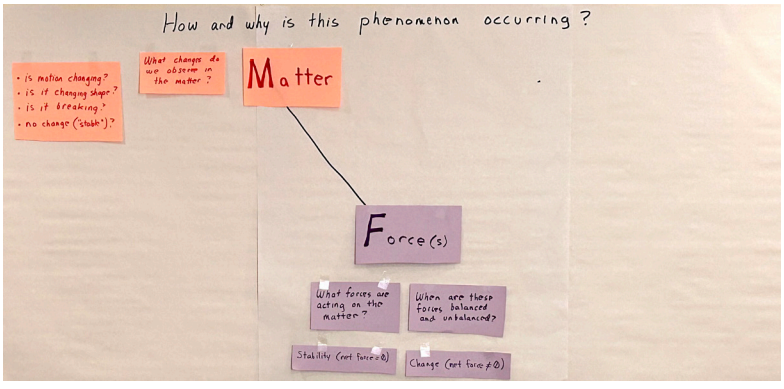


What we do and figure out

We analyze plate motion data. We develop a physical model to identify force interactions between plates. We investigate the conditions that result in stability and change in motion of an object when multiple forces act on it. We use free-body diagrams to explain and predict how the magnitude of the forces applied at different scales impact the stability and changes in the matter within the system. We figure out:

- Stability is dependent on scale.
- The net force is the sum of all the forces acting on an object; it is zero when the forces are balanced along every axis.
- Forces at different scales can help explain why matter remains in a stable state and why its motion changes.

How we represent it



Navigation to Next Lesson: We have identified the net force of contact forces as a contributing factor in explaining the stability and changes within both matter and Earth' systems. We wonder about the changes in matter when external forces on an object continue to increase.

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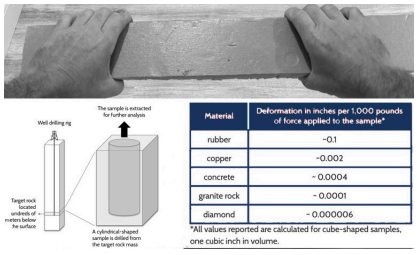
LESSON 3

What happens to the matter and energy in a system when the magnitude of balanced forces on it increases?

Investigation **3 days**

Phenomenon or design problem

Foam changes shape when we push or pull on it. Rock samples often change shape after they are extracted from the surrounding bedrock. Compression machines measure deformation as external forces are applied to a sample.



Material	Deformation in inches per 1,000 pounds of force applied to the sample*
rubber	~0.1
copper	~0.002
concrete	~ 0.0004
granite rock	~ 0.0001
diamond	~ 0.000006

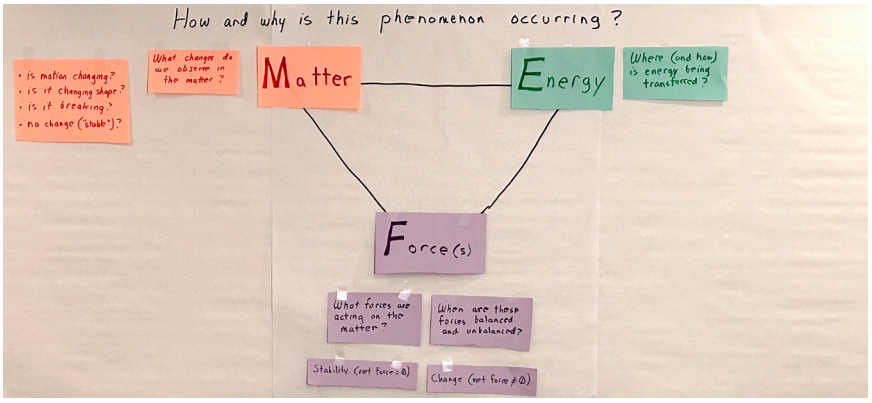
*All values reported are calculated for cube-shaped samples, one cubic inch in volume.

What we do and figure out

We explore changes in a piece of foam as higher-magnitude forces are applied to it. We develop a model relating how unbalanced forces cause the observed changes in matter and energy transfer. We predict whether rock would behave like the piece of foam. We gather information from a reading. We ask questions about the relationship of our new ideas to what is happening in Earth systems. We figure out:

- Changes in matter and energy transfers happen together.
- Unbalanced forces transfer energy.
- All solid materials deform elastically when force is applied to them, up to a point.
- When solids deform past their elastic limit, they permanently deform; this includes a permanent change in shape, cracks, and/or breaking into smaller pieces.

How we represent it



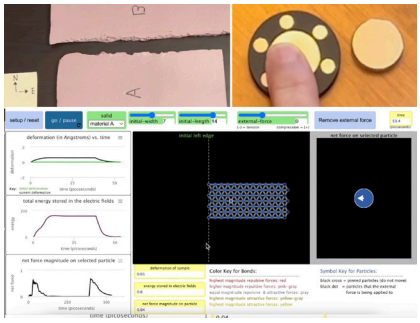
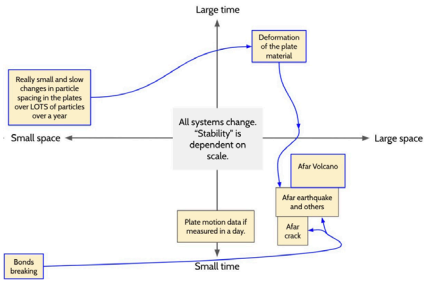
Navigation to Next Lesson: We raised new questions about the force interactions, elastic behavior and elastic limits, and energy transfers in solids that could help explain how earthquakes occur.

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LESSON 4

What is changing in the matter at a particle level before an earthquake, and when a solid elastically deforms or breaks?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
When two pieces of foam are pushed in perpendicular directions against each other, they suddenly slip, and sometimes smaller pieces break off the larger ones. 	We evaluate different models for understanding and explaining earthquakes, elastic deformation, and breaking of solid matter. We use a computer simulation to investigate how external forces on a solid affect matter changes and energy transfers at the particle level. We revise our M–E–F poster to account for the roles of fields on large-scale phenomena, and we use these ideas to explain volcanic eruptions in an Electronic Exit Ticket. We figure out: • All changes in matter (bending, breaking, state change) are changes in motion, either macroscopic or at the particle level. • If unbalanced forces deform a solid too much, some of the particles in it move far enough apart that their bonds break. • Matter produces various fields (electric, magnetic, gravitational); fields exert forces that act across a distance on other particles. • Energy can be transferred to, transferred from, and stored in fields.	

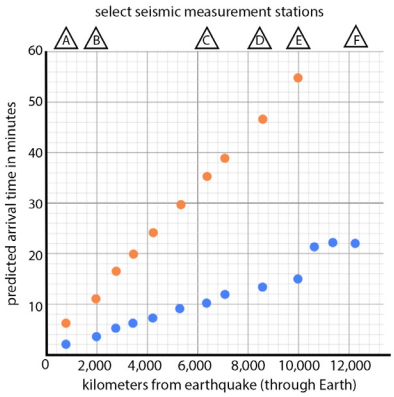
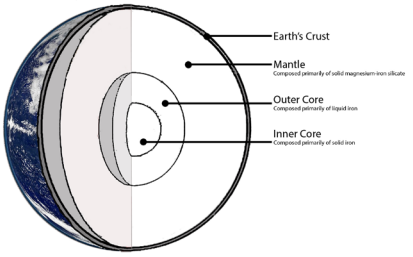
Navigation to Next Lesson: Though we can explain earthquakes and volcanoes at plate boundaries, Afar is not very near a plate boundary, so we need additional data to determine what is different about what is happening in the plates or below them at Afar.

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LESSON 5

How do we investigate the connection between matter in Earth's interior and surface features above?

Investigation, Putting Pieces Together **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Mathematical representations of earthquake data reveal anomalies in the speed at which seismic waves travel through Earth.  	We wonder what could be happening in Earth's interior that could cause unbalanced forces on the crust of the Afar region. We investigate how energy transfers differently through different types of matter. We use a scale model to predict how long it should take seismic waves to reach various distances around Earth if the planet is made of solid rock. We analyze seismic data to determine how long it actually takes the waves to reach these distances. We graph the data to explore how well our model fits reality. We figure out: • The speed of a wave through matter depends on the matter through which it is passing. • Seismic velocity data provide evidence that Earth is composed of layers. • Earth has a solid inner core, a liquid outer core, a mantle, and a crust. • Differences in matter in the mantle cause unbalanced forces in different locations, which is why some regions have different kinds of surface features than others.	

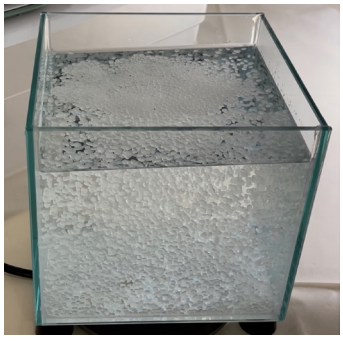
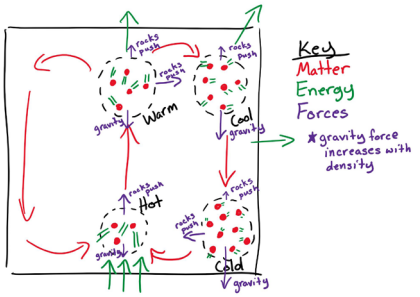
Navigation to Next Lesson: We wonder how temperature differences and motion in mantle matter could explain forces that cause change on Earth's surface.

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LESSON 6

How is temperature related to the behavior of the matter in the mantle?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
When liquid in a fish tank or a lava lamp is heated from below, the solid matter suspended in the liquid moves. 	We develop a model to explain the movement of material in the mantle. We analyze a video of a tank simulating the matter in the mantle to figure out what happens to the matter when heat is added. We observe convection in the tank and revise our model to represent it. We compare this model to tomography data and revisit our DQB. We figure out: • Increasing the temperature of matter in the mantle causes particles to move faster and farther apart, occupying a larger volume that results in a lower density. • The relationship between the gravitational force and the pushing forces from beneath that act on matter in different parts of the mantle explains the cycling of matter in Earth's interior through convection.	

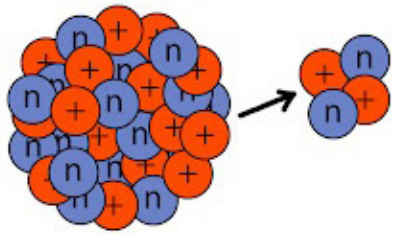
Navigation to Next Lesson: We saw that heat affected the density of parcels in the mantle tank, and we think this is also happening in the matter in the mantle. Now we wonder what might be causing this increase in energy that causes the differences in parcel density.

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LESSON 7

Where does the energy that drives convection come from?

Investigation, Putting Pieces Together **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Scientists have used models to predict that a large portion of the heat that drives mantle convection comes from nuclear-scale processes that are unimaginably tiny in comparison. 	We want to know where the heat comes from that drives mantle convection. We jigsaw a series of articles that answer this question from a forces perspective, a matter perspective, and an energy perspective. We develop a cause–effect model that integrates these three perspectives to explain how radioactive decay results in the release of enough heat to drive convection in the solid rock of Earth's mantle. We figure out: • Nuclear energy can be modeled as being stored in the mass of the atomic nucleus itself. • An imbalance of forces (strong and electric) in an atomic nucleus can cause particles to leave the atom, transferring kinetic energy into the surrounding material. This is a type of radioactive decay. • Radioactive decay at the subatomic scale continually generates new energy, providing the primary source of the energy that drives mantle convection at the macroscopic scale.	

1	*Larger atoms (or unstable nuclei)*	causes	*the forces to be unbalanced*	because	*the particles in the nucleus (protons and neutrons) will be further away from each other so the strong force will be weaker than the E-M force.*
2	Unbalanced forces	causes	*protons and neutrons to be released from the nucleus, or electrons*	because	*the forces holding them together won't be as strong as the forces pushing them apart/ repulsion.*
3	*Particles leaving the nucleus*	causes	*the atom to change into a new atom in a predictable way*	because	*every atom has a unique atomic number and that determines what element it is.*
4	*Particles leaving the nucleus , or energy transfer out of the nucleus , or the atom changing*	causes	*Particles with high kinetic energy to move into the space between between atoms*	because	*the energy that was in the mass of the nucleus is now in the kinetic energy of the escaping particles (optional and the rest of the nucleus itself)*
5	*The high KE particles leaving the nucleus*	causes	Collisions with surrounding atoms	because	*the neutrons and protons to move fast and collide with other atoms*
6	Particles colliding with the surrounding atoms	causes	*Heating of surrounding particles (vibrating particles, thermal energy, particles with high average kinetic energy)*	because	*Collisions transfer energy. The kinetic energy of the escaping particles will transfer into the vibration of the surrounding particles when they collide (thermal energy)*
7	Heat from radioactive decay	causes	material from the mantle to move upward into the crust, and material from the crust to move down into the mantle	because	*product of hot material will be less reactive per volume, so cooler material higher up will be pulled down, pushing the hot material up - this is called convection.*

Navigation to Next Lesson: Radioactive decay helped us understand what might be driving some of the processes we see in Earth's mantle. We wonder whether we will find radioactive material in the rock in the Afar region.

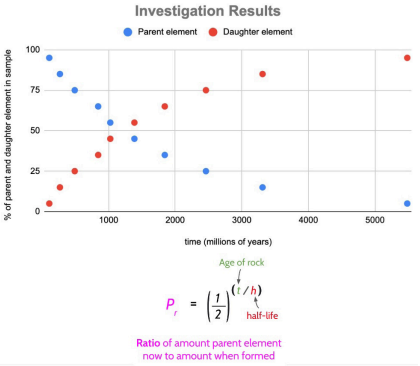
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Lesson Set 2: How do forces determine what will happen on Earth's surface?

LESSON 8

Is the rock at Afar radioactive, and what can that tell us?

Investigation **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Crystals from different rock samples around the Afar region contain different amounts of U-238 and K-40. The atoms in a simulation of radioactive elements within a crystal change over time from one type of atom to another.  Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.	We analyze the radioactive element composition of rocks from Afar. We use a simulation to collect data on how the amount of radioactive material in a rock crystal changes over time. We use mathematical thinking to compare patterns in our graphs to those in an equation of exponential decay, and we use that equation to determine the age of rocks from Afar. We figure out: • Radioactive decay of elements follows a characteristic exponential decay law, with a specific lifetime (timescale) for each; we can use this to determine the ages of rocks and other materials from the ratio of parent to daughter elements present. • Some of the rock on the western and eastern edges of Afar formed hundreds of million years ago. But most of the rock in the middle of the Afar region is very young, appearing over the last few million years.	

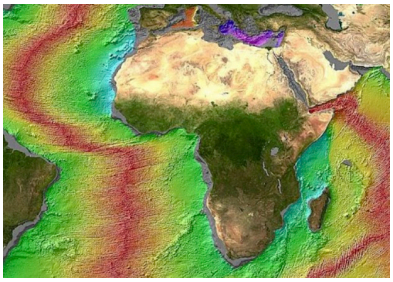
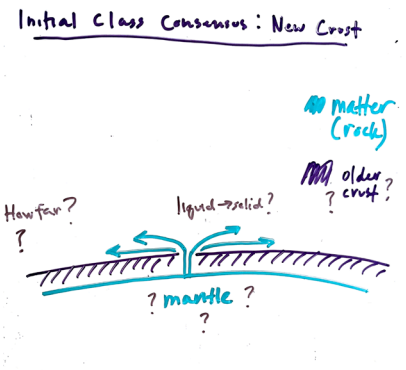
Navigation to Next Lesson: Now that we have a way to determine the age of any rock, we think that comparing the ages of rocks found in other parts of the world to those found at Afar may help us figure out how long the processes going on in Afar might continue, and how they might be similar to or different from changes that have happened elsewhere on Earth.

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LESSON 9

How does the rock in Afar compare to the rock around the world, and what does this tell us about the history and future of the region?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
A map of crustal ages on continents and in the ocean shows several puzzling patterns, including very young basalt in the Afar region.  Adapted from: NOAA, Elliot Lim	We look at data on the crustal ages of rocks around the world and notice that the farther the rock is from some plate boundaries in the ocean, the older it is. We model what might be going on at these boundaries. We determine the density of basalt (oceanic crust) and granite (continental crust) and wonder about how that affects forces and energy transfer. Finally, we add questions to the DQB about plate boundaries and types of crust. We figure out: • Continental crust is, on average, significantly older and less dense than oceanic crust. • As you move outward from some plate boundaries in the middle of the ocean, the basalt rocks get older, suggesting that the material originated at the boundary and was pushed outward over a large timescale. • The new rock in Afar is young basalt, suggesting that a similar process may be occurring there.	

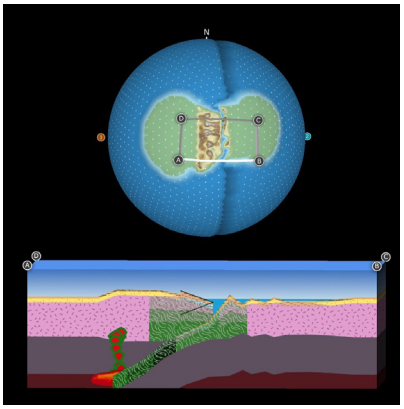
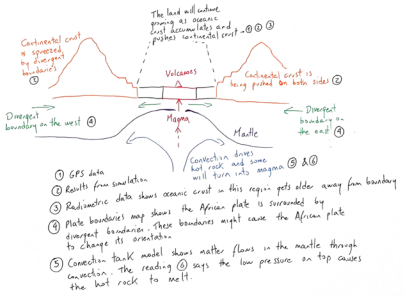
Navigation to Next Lesson: We want to know whether all places where plates are in contact look like these lines in the ocean where basalt is forming. We decide to look more closely at plate boundaries where continental crust meets oceanic crust.

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LESSON 10

What is happening at plate boundaries?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
The interactions of plates in a simulation show changes in matter in the mantle and on the surface near plate boundaries.  Images generated using Tectonic Explorer (https://tectonic-explorer.concord.org/), developed at the Concord Consortium.	We use a simulation to investigate how plates interact at divergent and convergent plate boundaries. We analyze data to compare the surface features on Earth to the surface features represented in the simulation. We develop a model that explains how the interactions of plates result in the surface features we identified. We wonder which forces are acting on plates that can help us explain the patterns we identified in their motion. We figure out: • The movement of plates and their interactions at plate boundaries shape the planet's surface features, such as mountains, islands, earthquakes, and volcanoes.	

Navigation to Next Lesson: We are wondering which forces are acting on plates that could help us explain their motion patterns on the surface and in the mantle.

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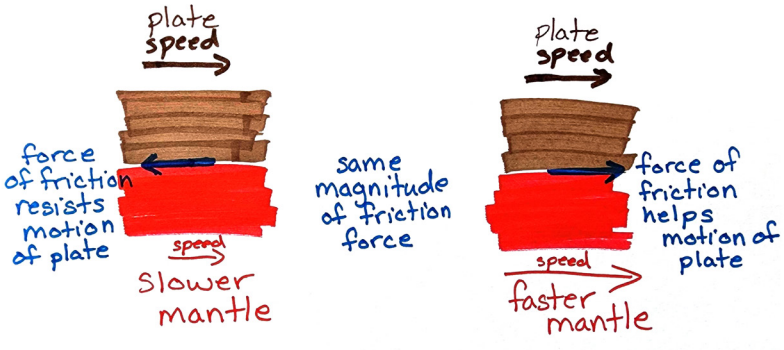
LESSON 11

How might forces between the mantle and plates affect plate motion?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out
Different objects require different amounts of force to drag them at a constant velocity. 	We investigate variables that we consider may affect friction forces between an object and the surface it slides over. We connect our conclusions from our investigations to properties of the plates and motion. We figure out: • The force of friction depends on the mass of the object and the material of the surfaces rubbing together, but not on the surface area between the object and the surface.

How we represent it



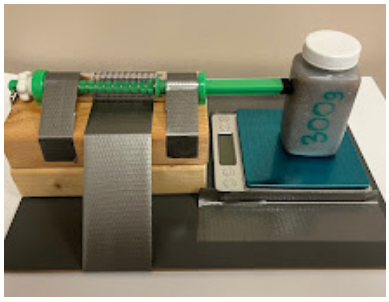
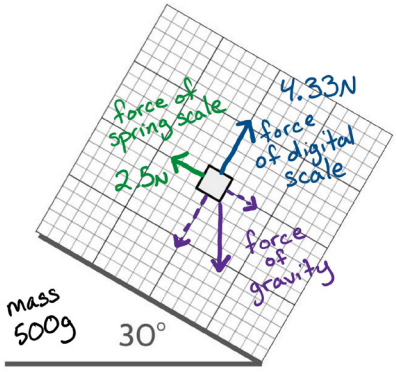
Navigation to Next Lesson: We are still wondering how other forces, like gravity, affect plate motion.

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LESSON 12

How do forces act on objects, such as the plates, when they are on inclines?

Investigation, Putting Pieces Together **2 days**

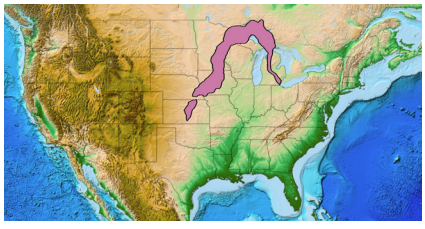
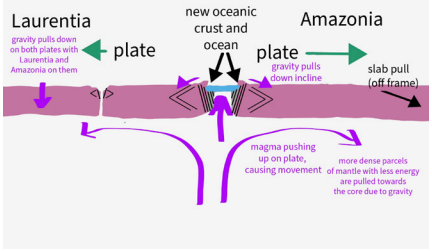
Phenomenon or design problem	What we do and figure out	How we represent it
Changing the incline of an object ramp changes the weight registered on a scale under the object and the magnitude of the force registered on a spring scale against the object. 	We model forces acting on plates and investigate forces on an object placed on an incline. We model how the force of gravity can be split into two vector components to make sense of how gravity pulls down inclines, and we connect this to plate motion to update our plate interactions model. We figure out: • The force of gravity can be broken into components that pull parallel and perpendicular to an incline, and as the incline gets steeper, the component of gravity parallel to the incline increases. • The force of gravity on an object is directly proportional to the mass of the object. • The force of gravity contributes to changes in plate motion through processes called slab pull and ridge push.	

Navigation to Next Lesson: We have revised our consensus model of plate interactions and are wondering how it might explain other Earth events.

LESSON 13

How can we use our science ideas to explain what happened at the Midcontinent Rift?

Putting Pieces Together **1 day**

Phenomenon or design problem	What we do and figure out	How we represent it
The Midcontinent Rift started to tear apart like the Afar rift, but failed.  Data Source: ArcGIS	We revisit our Scale Chart poster and Driving Question Board and complete a transfer task comparing the fate of the Midcontinent Rift to the growing Afar rift. • Many processes on the Scale Chart poster have effects on other processes at different scales. • Processes that occurred at the Midcontinent Rift 1.1 billion years ago are similar to what is occurring at Afar today. • Thermal convection and the interaction of forces with plates can be used to explain how the Midcontinent Rift failed.	

Navigation to Next Lesson: This is the last lesson of the unit.

Lessons 1–13 **27.5 Days Total**

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Unit Storyline

Lesson Set 1: What factors can make driving more risky?

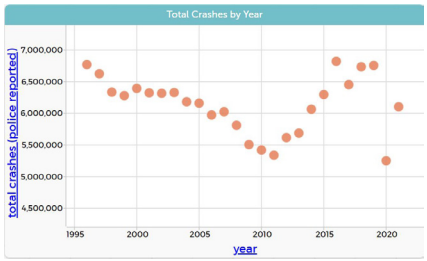
LESSON 1

Why is driving safer today than it was 10 years ago, even though the number of vehicle collisions has gone up?

Anchoring Phenomenon **4 days**

Phenomenon or design problem

Overall we have seen a gradual decrease in crashes over time, but in recent years something has caused the number of crashes and fatalities to increase.



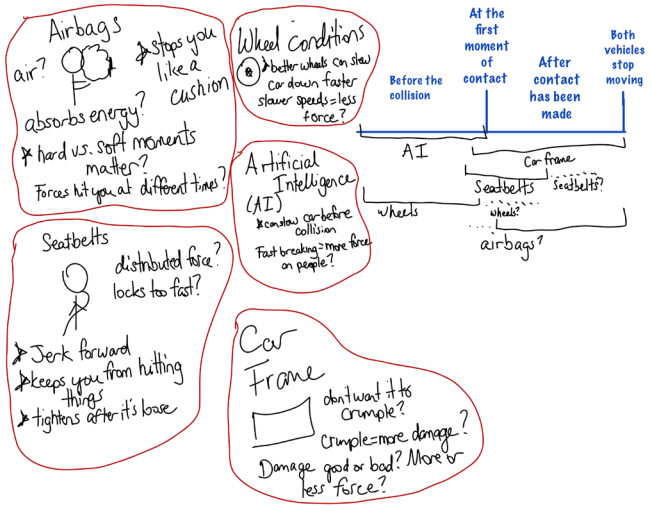
Images generated using CODAP (https://codap.concord.org/), developed at the Concord Consortium; Data Source: NHSTA

What we do and figure out

We develop models to show how distracted driving and changes in vehicle design might contribute to trends in vehicle safety over time. We ask questions about the causes of these trends and develop ideas for investigation to help figure out the answers to our questions. We figure out:

- While overall trends in deaths have decreased, in recent years the number of collisions and injuries has increased.
- There are many potential causes for these trends, including changes in driver behavior (such as distracted driving), changes to vehicle design (such as airbags), changes to road conditions (such as stop signs that are easier to see), and changes to policy (such as speed limits).

How we represent it



Navigation to Next Lesson: We think there are many factors that can contribute to the trends we see on our graphs. One of our ideas is that distracted driving may be a major cause of increased crashes and injuries. We want to figure out what impact distracted driving can have on a collision, among other things.

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LESSON 2

How does being distracted affect whether you will avoid a collision?

Investigation **2 days**

Phenomenon or design problem

Videos of an undistracted driver and a distracted driver encountering an obstacle provide speed and time data that are plotted on a graph.

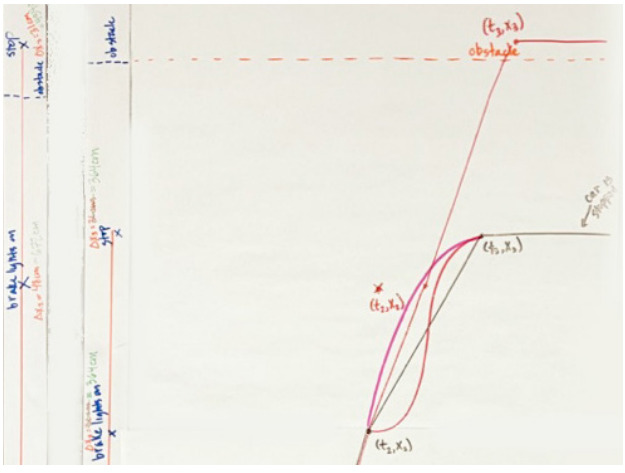


What we do and figure out

We analyze videos of two drivers encountering a sudden obstacle: one who is undistracted and one who is distracted. We plot each to show how being distracted affects the motion of the vehicle over time. We figure out:

- We can plot the distance that a vehicle travels over time to learn more about how it is moving, including its speed.
- Distracted driving lengthens reaction time, which means that the driver has less distance over which to stop before the obstacle.

How we represent it



Navigation to Next It seems like a shorter reaction time is key to preventing accidents. We want to investigate what else could increase a driver's reaction time other than whether the driver is distracted.

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LESSON 3

How does speed affect whether you will avoid a collision?

Investigation **2 days**

Phenomenon or design problem

A speed versus reaction distance graph is used to compare reaction times and distances traveled at higher speeds for both distracted and undistracted drivers.



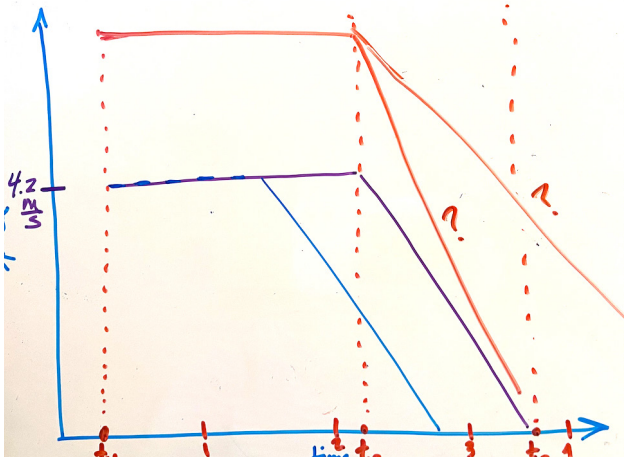
Photo courtesy of photos-public-domain.com

What we do and figure out

We use mathematical models to generate data about how speed affects reaction distance. We identify design features that can decrease reaction distances to prevent collisions in the event of a sudden obstacle. We figure out:

- We can plot the speed at which a vehicle travels over time to learn more about how it is moving, including how its speed is changing.
- If you are going faster before the collision, your reaction time will not change but your reaction distance will, because distance = speed * time.
- There are engineering solutions that can affect reaction distance, such as speed limits and phones that turn off notifications while driving.

How we represent it



Navigation to Next Lesson: We figured out that driving is more dangerous when the car is moving faster because the car will travel farther during the time it takes the driver to react, making it harder to avoid an accident. We are wondering whether speed will also affect the time it takes to stop once the driver begins braking.

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LESSON 4

What affects the amount of time it takes a vehicle to stop after the driver presses the brakes?

Investigation **3 days**





Phenomenon or design problem

A controlled environment of a cart going down a ramp and then braking when it reaches the bottom provides a context to investigate the relationship between the speed at the bottom of the ramp, mass, braking force acting on the cart, and the length of time it takes to stop.



What we do and figure out

We use a speed versus time graph to predict how the initial speed, braking force, and mass of a moving vehicle affect its stopping time. We collect data to test our predictions and graph it in CODAP. We use curve fits to identify patterns indicating a mathematical relationship. To further test this relationship, we use a simulation to gather additional data. We figure out:

- The more braking force that is applied to a moving cart, the less time it takes to stop.
- The more mass and/or initial speed of a moving cart, the more time it takes to come to a stop.
- Mathematical models can help make very good, but not perfect, predictions of the changes in motion of a real-world object.
- It is not possible to eliminate measurement errors, but steps can be taken to reduce them.

How we represent it



Images generated using CODAP (https://codap.concord.org/), developed at the Concord Consortium

Navigation to Next Lesson: We are ready to put the pieces together to see what progress we have made in answering our questions about vehicle collisions.

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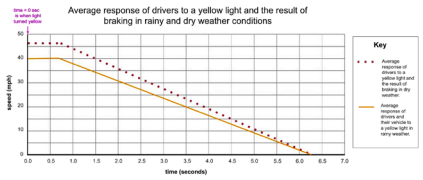
LESSON 5

Can we use mathematical models to explain differences in stopping in wet conditions?

Putting Pieces Together **1 day**

Phenomenon or design problem

Though drivers are using more braking force in wet and rainy conditions, they are stopping later or running red lights.



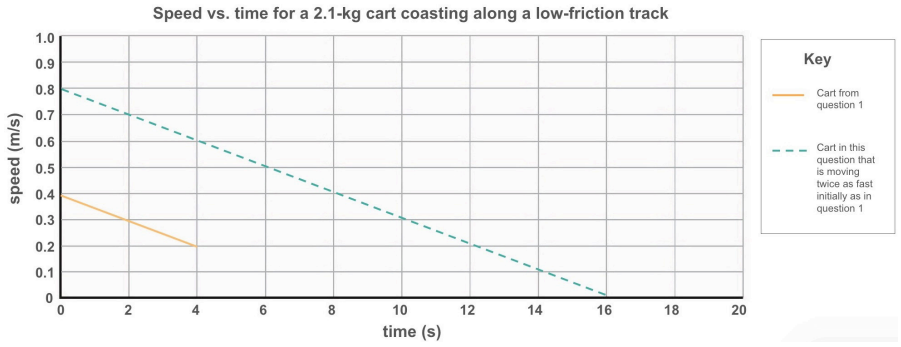
Data Source: Li, et al. (2012)

What we do and figure out

We rearrange our equations to show a = F/m and F = ma and add to our M–E–F triangle to show that unbalanced forces cause change in motion. We analyze vehicle stopping times in wet and rainy conditions. We complete an Electronic Exit Ticket to predict the stopping time for carts going various speeds with friction. We figure out:

- The slope in a speed over time graph shows how quickly an object changes speed over time and is the acceleration.
- Unbalanced forces cause change in motion.
- We can design solutions to increase stopping distance or time in wet and rainy conditions.

How we represent it



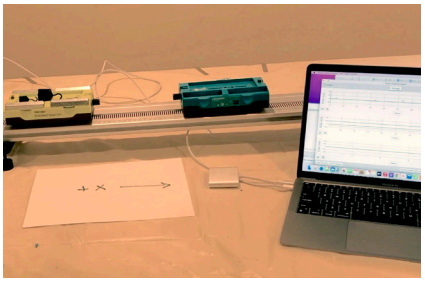
Navigation to Next Lesson: Though we have answered many questions about avoiding collisions, we identified the questions we had (and new questions) about objects that are unable to avoid collisions and are colliding.

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LESSON 6

Do our motion relationships help predict any of the interactions or outcomes in a collision?

Investigation **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Dynamic carts provide data about speed and contact forces in a collision. Data on fatalities show differences for different-mass vehicles. A simulation produces data on speed changes for different-mass vehicles for various collision conditions. 	We analyze sensor data from a collision of a cart with a barrier and another between two carts. We analyze fatality data from collisions between different-mass vehicles. We develop an equation for the outcomes of two-vehicle collisions and test it with data from a simulation. We develop and use alternate algebraic models to solve for the mass or velocity of an object before or after a collision. We figure out: • When two objects collide, the contact forces on each object are equal in magnitude and opposite in direction, acting over the same time period. • In a collision between different-mass vehicles, the occupants of the larger-mass vehicle are at less risk of death and/or injury. • The momentum of an object is the product of its mass and its velocity. • During a collision, the total momentum of the colliding objects is conserved when there is no unbalanced external net force on the system.	Conservation of momentum relationships $m_A \times \Delta v_A + m_B \times \Delta v_B = 0$ Change in momentum of object A; Change in momentum of object A $m_A \times v_{Af} + m_B \times v_{Bf} = m_A \times v_{Ai} + m_B \times v_{Bi}$ final momentum of object A; final momentum of object B; initial momentum of object A; Initial momentum of object B Total final momentum; Total initial momentum This the result of: • An unbalanced net force, acting on each object , causing a change in its motion. • The two forces are in the system equal in magnitude and opposite in direction to each other at every point in time there is an interaction.

Navigation to Next Lesson: Differences in the velocity change in a collision between vehicles of different masses are correlated to differences in passenger safety. We are wondering how and why a difference in velocity would affect the passengers inside the vehicle.

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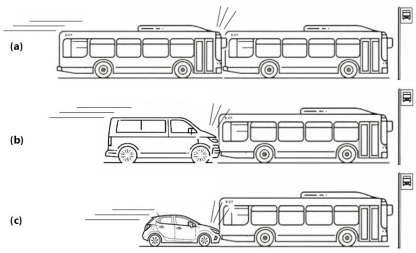
LESSON 7

Can our models be used to predict the motion of real-world vehicles in a collision?

Putting Pieces Together, Problematizing **2 days**

Phenomenon or design problem

Data sets for factors that could potentially lead to increased injuries in collisions provide information on how the trends have changed over time.

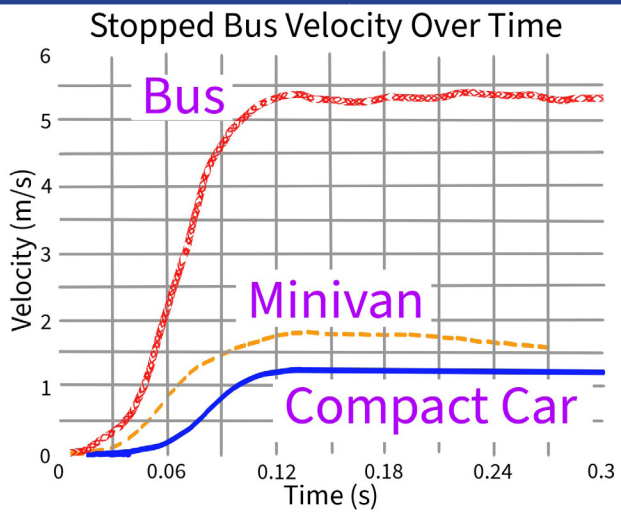


What we do and figure out

We apply our ideas about momentum to an assessment about vehicles colliding with a stopped bus. We look at new data on factors to explore possible correlations with the trends we identified in Lesson 1. We discuss correlation versus causality. We explore a simulation of a vehicle collision to look for additional variables we want to explore. We add new questions to the Driving Question Board about safety features. We figure out:

- Our mathematical model for momentum can be used to predict and explain changes in motion.
- Speed, mass, and new technology are probably all contributing to the trends we identified in Lesson 1.
- New safety features may be weakening the strength of certain trends that we identified in Lesson 1.

How we represent it



Navigation to Next Lesson: We have some ideas about how safety features might weaken some of the driving safety trends that we identified by improving collision outcomes over time. We want to investigate some of these features in more detail.

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Lesson Set 2: How are vehicles designed to keep people safe?

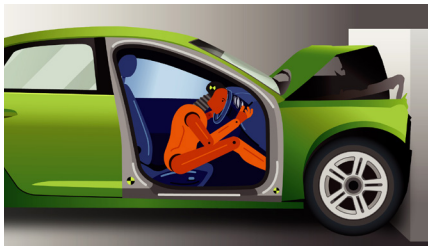
LESSON 8

What interactions happen during a vehicle collision, and when do they happen?

Problematizing, Investigation **1 day**

Phenomenon or design problem

A video of a vehicle collision is fast. An animation and simulation data show the timing of events for collisions with and without safety features.

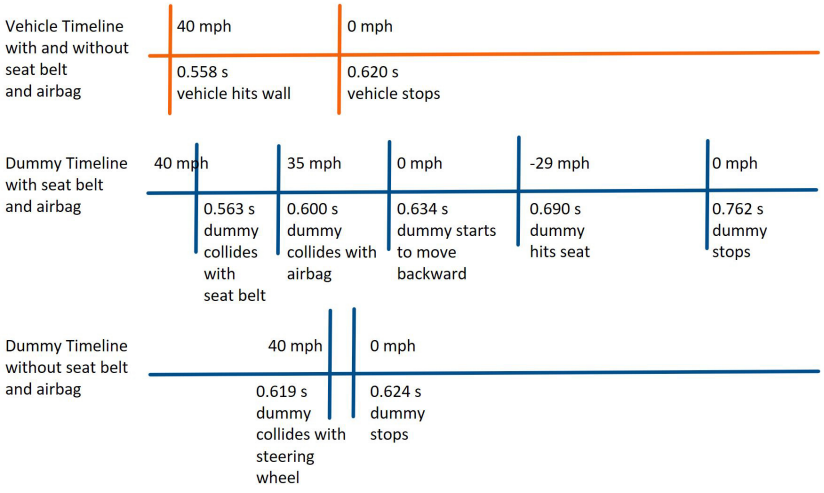


What we do and figure out

We watch a video of people in a collision and determine it is too fast to analyze. We create collision timelines using an animation based on simulation data for the vehicle and crash test dummy with and without seat belts and airbags. We use velocity data from the simulation to add velocity data to our timelines. We figure out:

- The total change in velocity of the vehicle and the crash test dummy is always the same, regardless of safety features.
- In a collision, no matter the presence of seat belt and airbag, the vehicle will take the same amount of time to reach a velocity of 0.
- In a collision with safety features, a crash test dummy changes velocity over a longer period of time than in a collision without safety features.

How we represent it



Navigation to Next Lesson: We know safety features increase the time it takes a person to change velocity in a collision. We use our mathematical models to identify that we should examine what safety features do to forces to see how much a difference in time can make in a collision.

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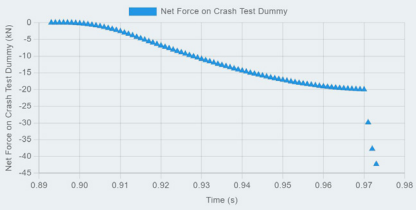
LESSON 9

How do safety features affect the forces over time on a person during a collision?

Investigation **2 days**

Phenomenon or design problem

The collision simulation provides force over time data for crash test dummies using various rigidities of seat belts and airbags in a collision.



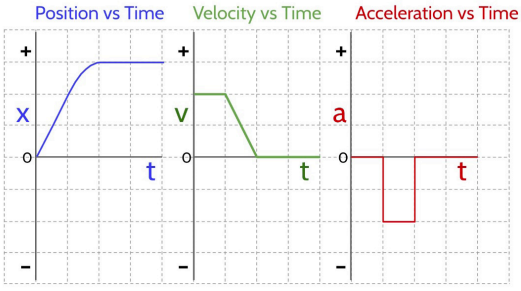
What we do and figure out

We read about force interactions on drivers during collisions. We make predictions and collect data from a simulation about how safety features affect force versus time. We try to optimize the characteristics of seat belts and airbags in a simulation. We explain why survivability changes in different vehicle collisions using simulation results. We figure out:

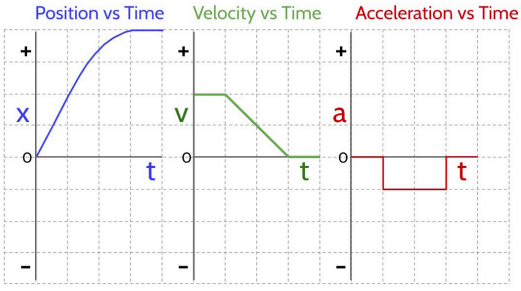
- Reducing the peak force on a body reduces injury.
- Safety features of the vehicle, such as seat belts and airbags, increase the length of time that forces are applied to the body and reduce the magnitude of the peak forces applied over that time.
- When Δv is higher, peak force on the person is higher and likelihood of survivability goes down.
- Newton's second law can be rearranged to show that $F\Delta t = m\Delta v$.

How we represent it

High Risk Collision



Low Risk Collision



Navigation to Next Lesson: Having explained how seat belts and airbags are designed to make driving safer, we start considering some ways that the body of the vehicle could be redesigned to further reduce risk.

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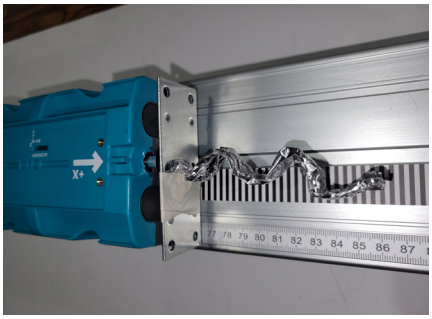
LESSON 10

How are the bodies of cars designed to make collisions safer?

Investigation **2 days**

Phenomenon or design problem

Many modern vehicles have crumple zones designed into the the front and back of the car, but many vehicles before the 1990s and all vehicles before 1952 did not.



What we do and figure out

We make observations of a collision between two cars designed and built 50 years apart. We propose and compare solutions for the design of a vehicle's crumple zone to determine which of these designs provides better protection for the driver. We figure out:

- The rigidity and length of the crumple zone determine the magnitude of the force acting on the vehicle when it hits the wall.
- The longer the crumple zone, the longer the time lower forces act on the vehicle.

How we represent it

		RIGIDITY		
		Low	Medium	High
LENGTH	Short	A: 79%	B: 79%	C: 79%
	Medium	D: 88%	E: 80%	F: 79%
	Long	G: 100%	H: 80%	I: 79%

Navigation to Next Lesson: Though we know that the length and rigidity of the crumple zone affect the forces acting on the car and affect the safety of vehicle occupants, we haven't yet explained whether this is due to changes in the forces acting on the person.

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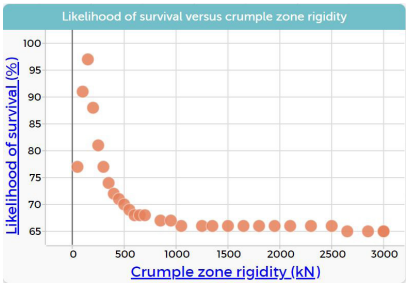
LESSON 11

How do the rigidity and length of the crumple zone influence the safety of the occupants during a collision?

Investigation **2 days**

Phenomenon or design problem

Simulated car collision data provide evidence on how the length and rigidity of the crumple zone affect the motion and forces on a vehicle and crash test dummy.



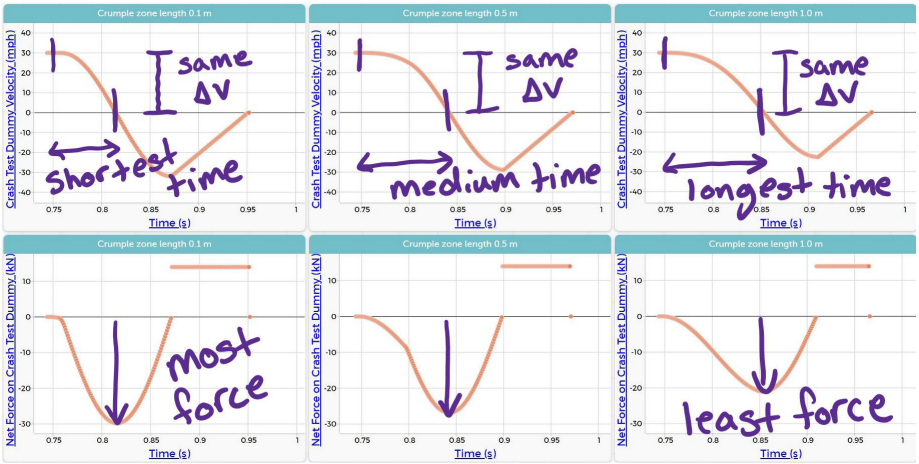
Images generated using CODAP (https://codap.concord.org/), developed at the Concord Consortium

What we do and figure out

We analyze crash test results from simulated collisions to identify how the rigidity and length of the crumple zone affect the forces acting on vehicle occupants. We apply the concepts about matter, energy, and forces to explain how the design of the crumple zone can enhance safety during a collision. We figure out:

- A less-rigid and longer crumple zone results in lower peak forces over longer periods of time acting on vehicle occupants during a collision.
- Energy transfers to the crumple zone as matter deforms.
- The amount of deformation is related to the amount of energy transferred.
- When the crumple zone is too short, the peak force is very high and the time to stop is very short.

How we represent it



Images generated using CODAP (https://codap.concord.org/), developed at the Concord Consortium

Navigation to Next Lesson: We have figured out that crumple zones can be designed to extend the time over which a crash test dummy comes to a stop in a collision. We are considering how velocity of vehicles affects safety.

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LESSON 12

How can we use our models from across the unit to explain how vehicle systems can be designed to increase safety?

Putting Pieces Together, Problematizing **3 days**

Phenomenon or design problem

There are opposing arguments about whether speed limits should be decreased or allowed to continue to increase.



bairli1, Pixabay

What we do and figure out

We compare arguments about speed limits, considering both science ideas and societal impacts. We construct a Gotta-Have-It Checklist and use the list to develop explanations of how criteria and design solutions can increase vehicle safety. We figure out:

- There are many criteria that can be individually designed to collectively affect vehicle safety.
- Different arguments can be made on issues related to vehicle safety, and trade-offs and societal impacts also need to be considered.

How we represent it

Science-Ideas Argument Comparison

What is the problem that these arguments are trying to solve?

Why is it important to compare arguments?

Use the following table to help compare and evaluate the competing arguments.

Identify the Key Science Ideas and Supporting Evidence

	Argument #1	Argument #2
Write the argument claims here.	**Maintaining speed limits** Speed limits should stay the same and not be lowered to a maximum of 55 miles per hour because lowering speed limits would not increase safety.	**Lowering speed limits**

Navigation to Next Lesson: Now that we have a better understanding of the physics, we see that societal values also impact design decisions, and we need to consider trade-offs. We are wondering how we can apply this to our community.

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Lesson Set 3: How can we make design decisions that will make driving safer for everyone?

LESSON 13

How can we use our science ideas and societal wants and needs to evaluate arguments around design solutions?

Investigation **1 day**

Phenomenon or design problem

There are many trade-offs when considering the balance among science ideas, societal constraints, and ethical issues of a design solution.



What we do and figure out

We determine that risk is always involved in driving, but the risks are outweighed by benefits. We consider other issues in our community. We use the Argument Comparison Tool to compare arguments about a design solution relevant to our community, and survey others to determine other issues related to transportation in our community. We figure out:

- Science ideas alone cannot capture the whole picture related to trade-offs, and societal impacts must be considered.
- Trade-offs are evaluated when making decisions about safety from a scientific perspective, and societal wants and needs are messy; there is not always one correct answer to design solution arguments.

How we represent it

Argument Comparison Tool

What is the problem that these design solutions are trying to solve?

Why are we evaluating these two different design solution arguments? Why are the pros and cons of each argument important to understand?

Use the following tables to help compare and evaluate the different design solution arguments.

Identify the Key Science Ideas and Supporting Evidence

	Argument #1	Argument #2
Write the argument claims here.		
What key science ideas have we developed that support or refute this argument?		
What, if any, data does the author use as evidence to support this particular argument?		

Navigation to Next Lesson: We have been talking about decision making related to transportation safety and are curious to see what our caregivers, friends, and family think.

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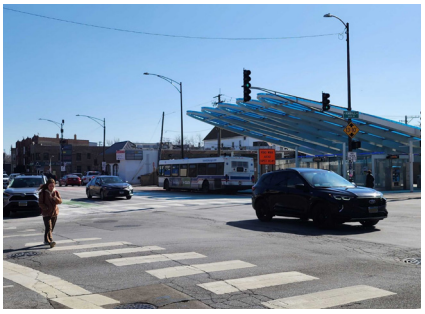
LESSON 14

What can we do to make driving safer for everyone in our community?

Putting Pieces Together **3 days**

Phenomenon or design problem

Students notice a variety of real-world problems related to vehicle safety.



What we do and figure out

We develop solutions to driving-related problems we care about, using physics models to present our proposal in a format we choose. We figure out:

- We can impact change by offering evidence-based solutions to specific, solvable problems.
- We can analyze problems by considering the scope of the effect they have on people or things we care about.
- Identifying cause–effect factors within a system can help us prioritize specific criteria to optimize these solutions.
- We can use approximated values and reasonable assumptions in our physics models to support a case for why a problem exists or how a solution can make it safer.

How we represent it

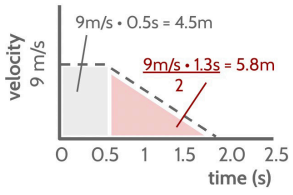
Solution 1: Install speed humps on Park Ave.

We can reduce vehicle speed on Park Ave, and therefore reduce the chance of collision with a cyclist on the bike path route.



20 mph = 9 m/s
reaction time = 0.5 s

9 m/s • 0.5 s x = 4.5 m = 15 ft
9 m/s / ***7 m/s/s*** = 1.3s brake time
½ • (9 m/s • 1.3s) = 5.8 m
= 19 ft → 34 ft



Navigation to Next Lesson: We have come a long way in this unit. Next class, we will have the opportunity to demonstrate how much we have learned in an assessment.

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LESSON 15

How can we use physics and engineering ideas to make decisions that will make driving safer for everyone?

Putting Pieces Together 1 day

Phenomenon or design problem

Design solutions from the 20th century intended to prevent pedestrian injury or death do not look like the design solutions we see on cars today.

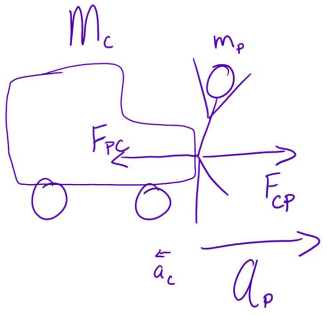


What we do and figure out

We take an end-of-unit transfer-task assessment. We revisit the DQB and determine what questions we can now answer. We reflect on and document the most important things learned in our unit. We figure out:

- We can use physics and engineering ideas to evaluate the merits of two design solutions and make recommendations for improvements.
- We can use our physics and engineering ideas to answer questions on our Driving Question Board.

How we represent it



$$m_c a_c = F_{PC} = -F_{CP} = -m_p a_p$$

$$m_c \Delta v_c = -m_p \Delta v_p$$

Navigation to Next Lesson: This is the last lesson of the unit.

Lessons 1–15 **32 days total**

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Unit Storyline

Lesson Set 1: What causes collisions between Earth and objects in space?

LESSON 1

Why is stuff falling from the sky?

Anchoring Phenomenon **3 days**

Phenomenon or design problem

A rock from space hit Siberia in 2013. It glowed brightly as it traveled through the air for a few seconds, and then it exploded and damaged windows in buildings for many miles.

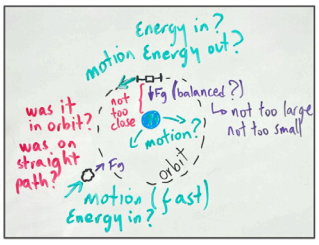


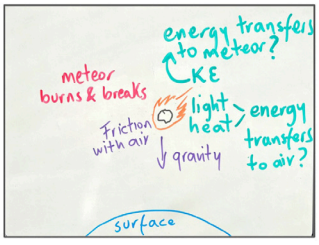
What we do and figure out

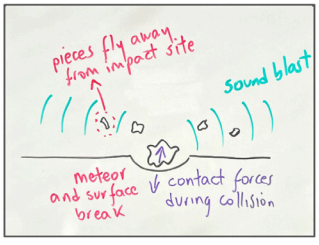
We explore video of the Chelyabinsk meteor. We categorize data on related phenomena. We develop two models, one to explain the observed changes during the Chelyabinsk event, and one to explain the motion of different space objects. We record questions and ideas for investigations and data we need to answer them for our Driving Question Board. We figure out:

- A rock from space broke up over Siberia in 2013, lit up the sky, and damaged buildings.
- Similar phenomena have been observed in other places around the world throughout history. Sometimes pieces of the stuff hit the ground, and sometimes they do not.
- Some space objects in the solar system remain in orbit, while others collide with different objects.

How we represent it







Navigation to Next Lesson: Since gravity pulls space objects toward each other, we wondered how it can cause some objects to move in orbit and others to hit Earth.

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LESSON 2

How far does Earth's gravity extend into space?

Investigation **3 days**

Phenomenon or design problem

Various tools in our lab allow us to measure the strength and direction of forces between two objects' fields when the distance between them is changed.



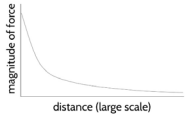
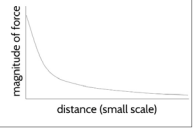
What we do and figure out

We make predictions about the gravitational force experienced by objects at different distances from Earth's surface and carry out an investigation of magnetic forces versus distance. We analyze data for various objects and distances. We use mathematical models to determine the strength of the force acting on different space objects and consider whether this helps explain why some objects collide with Earth while others remain in orbit. We figure out:

- When two objects interact at a distance through a field, the forces between them are equal in magnitude and opposite in direction.
- Newton's law of universal gravitation mathematically models how gravitational forces depend on the masses of and distance between two objects.
- The force of gravity experienced by space objects alone does not fully explain why some collide with Earth while others remain in orbit.

How we represent it

Gravity–Magnetism Comparison

	Gravitational	Magnetic
Direction of these forces on other matter (in the space where we are located)	Towards the center of Earth	Earth's magnetic north
Type(s) of matter it acts on	All matter	Magnets and some metals
What produces it?	All matter	Some magnets, changing electric fields, Earth's mantle
Magnitude of force vs. distance from Earth		

Navigation to Next Lesson: If we know some amount of gravity extends forever through space, what prevents the Moon and satellites from falling into Earth or Earth from falling into the Sun?

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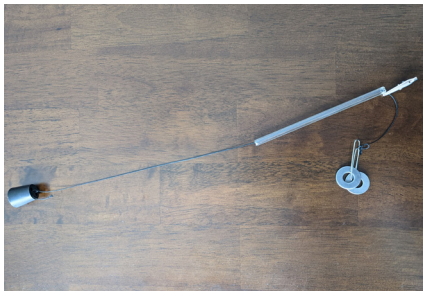
LESSON 3

How does gravity cause only some objects to orbit?

Investigation **2 days**

Phenomenon or design problem

Some objects in the solar system orbit others in regular patterns of circular motion, which we can emulate in the lab using simple equipment or simulations.



What we do and figure out

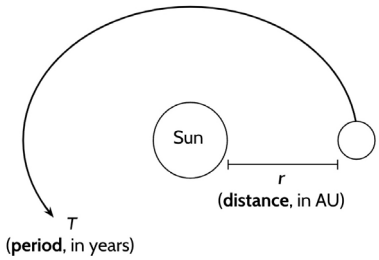
We use a simulation to figure out the relationship between velocity and force necessary for orbit. We investigate how the distance between two objects affects this relationship and identify the period of revolution of an object to predict its orbital motion. We identify a relationship between period and orbital radius. We figure out:

- Some planets orbit the Sun in nearly circular orbits.
- An object must have the right velocity in order to orbit a star or planet. If it is moving too fast, it will continue into space. If it is moving too slow, it will fall toward the star or planet.
- The relationship between the gravitational force on an object and its velocity depends on the distance from the object it orbits.
- The relationship (T^2/a^3) of orbital period (T) to radius (a) is constant for all objects orbiting the same body.

How we represent it

This relationship is referred to by scientists as **Kepler's third law.**

$$\frac{T^2}{a^3} = constant$$



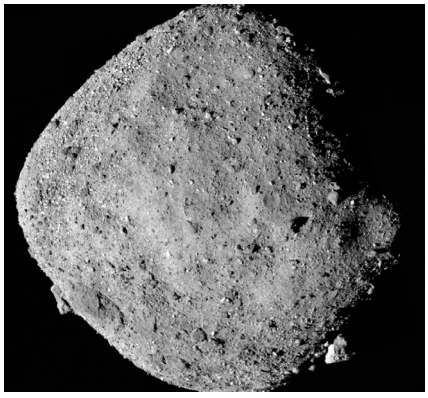
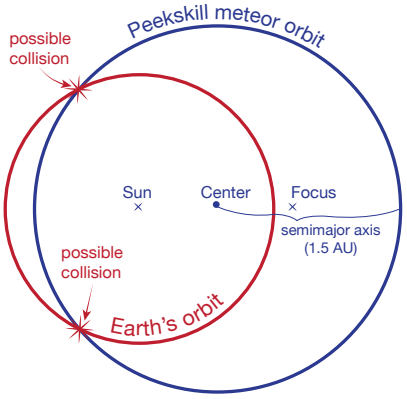
Navigation to Next Lesson: If objects orbit in predictable circular paths, then why do they sometimes hit each other?

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LESSON 4

Why do objects sometimes collide in space?

Investigation **2 days**

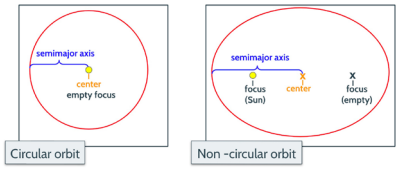
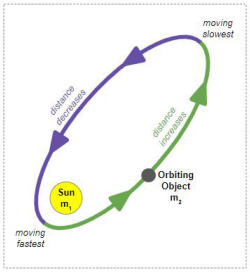
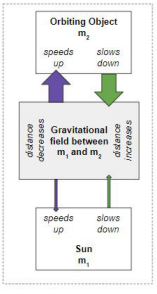
Phenomenon or design problem	What we do and figure out	How we represent it
Objects orbit the Sun with elliptical orbits ranging from near circular to very stretched out. Sometimes orbital paths of objects cross.  NASA/Goddard/University of Arizona	We explore elliptical orbits and their properties. We read about objects in space that may have the potential to collide with Earth, and we model the orbits of Earth and the Peekskill meteor to explain their collision. We wonder how to know if objects on crossing orbits will actually meet at the crossing point and collide. We figure out: • Orbits are elliptical in shape with the Sun located at one of the foci. • Objects in space are at risk of colliding if their orbit paths cross. • Asteroids, comets, and meteor showers are different types of objects in space that have the potential to collide with Earth.	

Navigation to Next Lesson: We figure out that orbits are elliptical in shape and that collisions are possible if two orbits cross each other in space. We wonder how we know when the objects will be at this intersection point of orbits so we can know if there will be a collision.

LESSON 5

How do objects travel within their orbit paths?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
The speed of an orbiting object varies with its distance from the Sun. 	We want to know more about how to predict the motion of orbiting objects. We look at a simulation of orbits and notice that the speed of objects in elliptical orbits changes along the path. We use energy thinking to make sense of this and construct energy transfer diagrams to model this change. We make predictions about the Chelyabinsk meteor's orbit to compare with scientists' predictions next time. We figure out: • Orbiting objects move faster when closer to the Sun and slower when farther away. • Speed changes of orbiting objects are related to the distance between the orbiting object and the Sun and are due to energy transfer between the object and the Sun and the gravitational field between them.	 

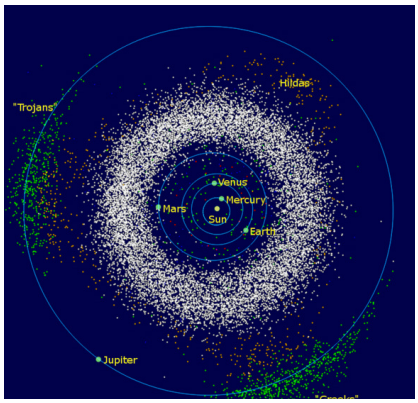
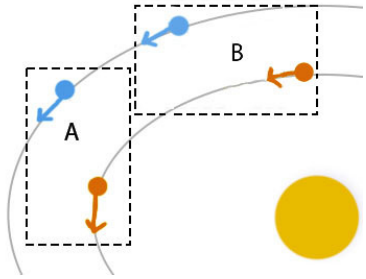
Navigation to Next Lesson: We think that the Chelyabinsk meteor probably had a very eccentric orbit, which is why it hit Earth. We want to compare our predictions against scientists' predictions next time.

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LESSON 6

How can force interactions in space change the orbital path of a space object?

Investigation **1 day**

Phenomenon or design problem	What we do and figure out	How we represent it
The Chelyabinsk meteor originated from the asteroid belt before it was redirected by force interactions in space.  Adapted from: Mdf at English Wikipedia	We are wondering if gravitational forces can change orbital paths and consider the limitations of our two-object models. We look at an image of our solar system with the asteroid belt and make predictions as to what could have led to the redirection of the Chelyabinsk meteor from the asteroid belt toward Earth. We develop models for the two possibilities: gravitational forces from other objects or a collision with another asteroid. We figure out: • Scientists believe that the Chelyabinsk meteor was likely redirected by a combination of collisions and gravitational forces from nearby objects. • Many meteors that collide with Earth come from the asteroid belt, from where they could have been redirected by collisions with other asteroids or by the gravitational forces from nearby objects.	

Navigation to Next Lesson: We figured out that there are many different interactions between objects in our solar system and that some of these interactions can lead to collisions with Earth. We are wondering how often Earth is collided with and how collisions have shaped the planet we know today.

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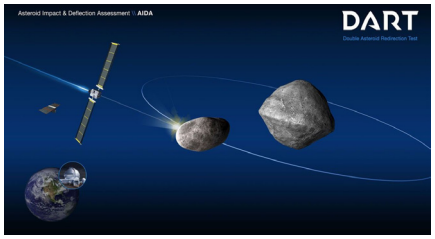
LESSON 7

What can we do if an orbiting object poses a significant risk for Earth?

Putting Pieces Together **1 day**

Phenomenon or design problem

NASA and other space agencies are developing and testing strategies intended to deflect hazardous impactors on a collision course with Earth.



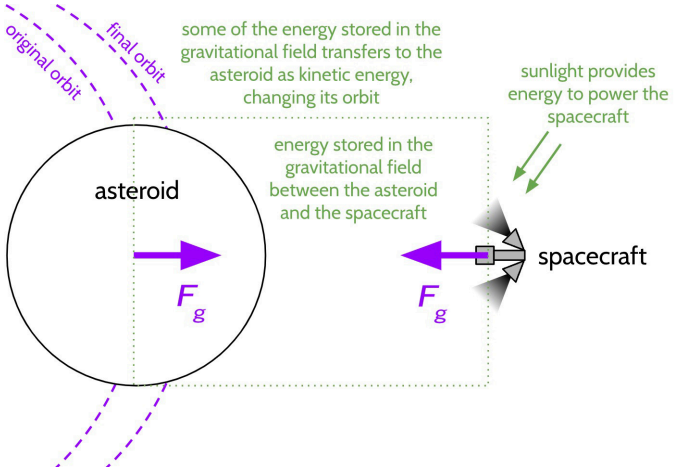
NASA/Johns Hopkins Applied Physics Lab

What we do and figure out

We read about two strategies designed to deflect hazardous impactors on a collision course with Earth. We use data collected by scientists and some of the mathematical models we have developed in this unit to explain how these strategies work. We figure out:

- Scientists are developing and testing strategies intended to deflect hazardous impactors on a collision course with Earth.
- A small spacecraft traveling at high speed can have enough kinetic energy to change the orbit of an impactor.
- A gravity tractor can slowly move an impactor into a different orbit by using the force of gravity acting between the spacecraft and the impactor.

How we represent it



Navigation to Next Lesson: We wonder how often impactors like the Chelyabinsk meteor hit Earth.

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Lesson Set 2: How can we know if Earth is at risk for future large-scale, high-energy collisions?

LESSON 8

What is the probability of a future or past meteor event impacting Earth?

Investigation **1 day**

Phenomenon or design problem

Cameras, telescopes, and sound detectors have detected many different-sized objects that have entered Earth's atmosphere over a 28-year period.

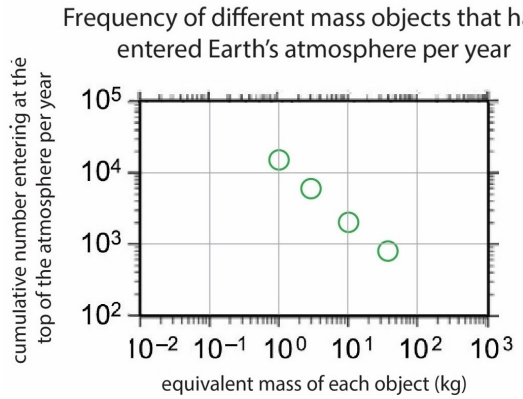
Meteor size (kg)	Frequency per year	Frequency of a single event	Kinetic energy (in J)
10,000,000	0.01	1 per 100 years	2×10^{8} J
100,000,000	0.001	1 per 1,000 years	2×10^{10} J
1,000,000,000	0.0001	1 per 10,000 years	2×10^{12} J
1×10^{10}	0.00001	1 per 1×10^{5} years	2×10^{13} J
1×10^{11}	0.000001	1 per 1×10^{6} years	2×10^{14} J
1×10^{12}	0.0000001	1 per 1×10^{7} years	2×10^{15} J
1×10^{13}	0.00000001	1 per 1×10^{8} years	2×10^{16} J
1×10^{14}	0.000000001	1 per 1×10^{9} years	2×10^{17} J
1×10^{15}	0.0000000001	1 per 1×10^{10} years	2×10^{18} J

What we do and figure out

We construct a line that best fits a graph of objects that have entered Earth's atmosphere and use it to predict the frequency of large-mass objects reaching Earth's atmosphere. Using kinetic energy calculations, we estimate the potential damage these could inflict. We argue for why we should continue to invest in DART-like technologies and what this might imply about Earth's past. We figure out:

- Large meteors are rare and unlikely, but they could alter human history.
- The mathematical relationship we have established should guide our future plans.
- While these relationships offer insights into Earth's 4.5-billion-year history, more data are needed to confirm or refute their historical predictions.

How we represent it



Data source: Halliday, I. (2001)

Navigation to Next Lesson: We know that we can predict the likelihood of an impact that poses a significant risk to Earth. We wonder about potential strategies for protecting Earth from a future impact.

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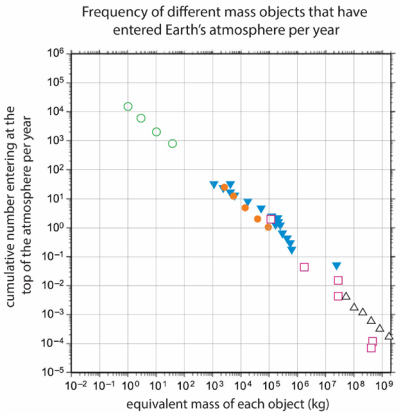
LESSON 9

What happened to all the meteors that reached Earth over its history?

Investigation **1 day**

Phenomenon or design problem

The frequency of meteors that reach Earth versus their mass follows a relatively linear trend for the period of time we have observed them.



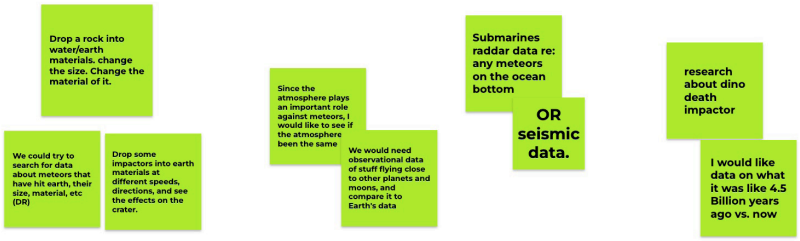
What we do and figure out

We share initial explanations for what might have happened to all the objects of different sizes that reached Earth from space over its 4.5-billion-year history. We brainstorm factors besides mass that might affect what happens to these objects when they reach Earth. We record new questions we have and sources of data and investigations that could help us answer these questions. We figure out:

- The mass of a meteor (or space object) probably affects whether anything impacts Earth's surface or whether it all burns up in the atmosphere.
- There are additional factors besides mass (e.g., speed, angle, or trajectory, material of the meteor, and where it hits) that may also affect the outcome.
- We are not certain that our mathematical model from the last lesson holds for earlier in Earth's history or for moons and other planets.

How we represent it

Ideas for additional data/investigations that could help answer our new questions



Navigation to Next Lesson: While we have a lot of new lines of questions and ideas for investigations, we plan on starting our next lesson with the line of investigations related to what makes meteors more damaging.

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LESSON 10

What determines the size of the crater made on impact?

Investigation **2 days**

Phenomenon or design problem

Dropping impactors of different masses and from different heights in flour generates craters of different sizes.

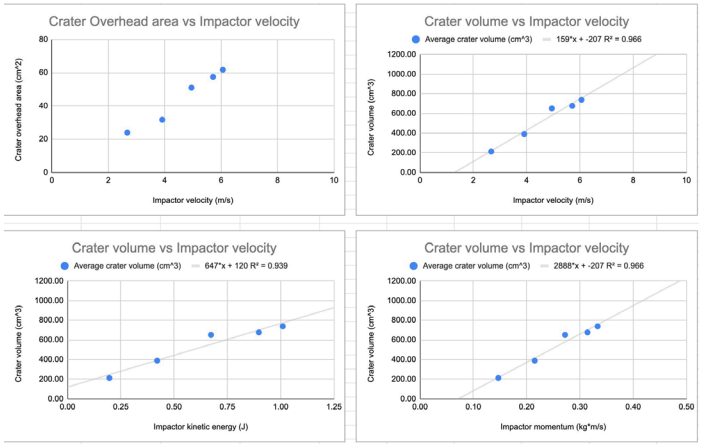


What we do and figure out

We investigate whether the velocity or the mass of a meteor better predicts the size of the crater it forms. We analyze our results using the coefficient of correlation and establish that the velocity of an impactor better predicts the size of the crater. We learn that meteors with enough kinetic energy can vaporize upon impact with the surface. We explain the changes in matter and energy within the meteor–Earth system. We figure out:

- Craters are not exact imprints of the impactor; they are larger than the impactor.
- Craters are surrounded by areas of ejecta.
- The kinetic energy of an impactor is a good predictor of the size of a crater.
- In comparison to mass, the velocity of an impactor has a stronger relationship with the size of the crater it creates.
- Increasing the mass also increases the size of the crater.
- Impactors with enough kinetic energy can vaporize upon surface impact.

How we represent it



Navigation to Next Lesson: Since sometimes the rocks that come toward Earth hit the ground and sometimes they do not, we wondered what determines whether a rock hits the ground and how often this happens.

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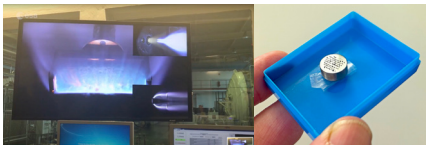
LESSON 11

What happens to the thousands of objects the size of the Chelyabinsk meteor and smaller that enter Earth's atmosphere every year?

Investigation **1 day**

Phenomenon or design problem

High-speed wind tunnels are used to simulate what will happen to some satellites upon reentry. Some hobbyists use magnets to find small fragments of iron meteors scattered across Earth's surface.



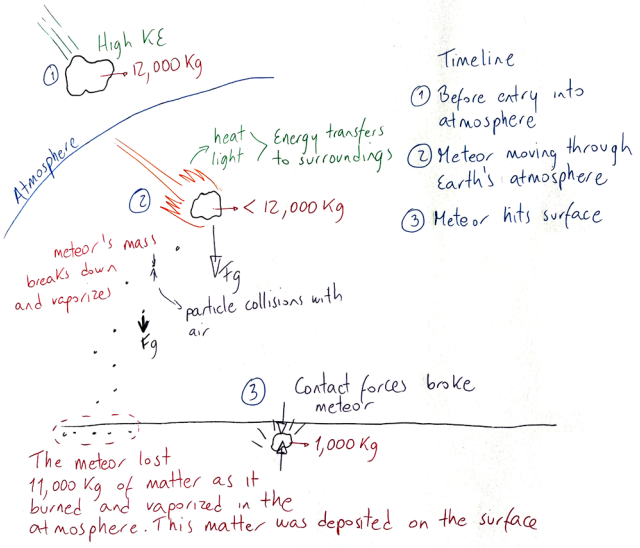
© ESA/DLR/Belstead Research, Jon Larson, Project Stardust

What we do and figure out

We analyze data from a video of a satellite being tested in a high-speed wind tunnel. We develop an explanation for why only a relatively small amount of the Chelyabinsk meteor's matter was still in solid pieces when it reached the surface. We argue that only a small amount of the matter that enters Earth's atmosphere ends up leaving an impact on its surface. We figure out:

- As objects from space move through the atmosphere at high speeds, they collide with air particles, causing changes in both matter and energy along their paths.
- All the matter that melts, vaporizes, or breaks off in solid pieces in this process will eventually end up deposited across Earth's surface.
- Only a fraction of the matter that enters Earth's atmosphere leaves an impact on the surface because it either has so little mass to begin with or is in really small pieces by the time it reaches the surface.

How we represent it



Navigation to Next Lesson: We predicted that the frequency and size of impacts from meteors would be much larger if we did not have an atmosphere, which led us to want to look at some data from planets or moons that have little or no atmosphere to see if they support or refute our predictions.

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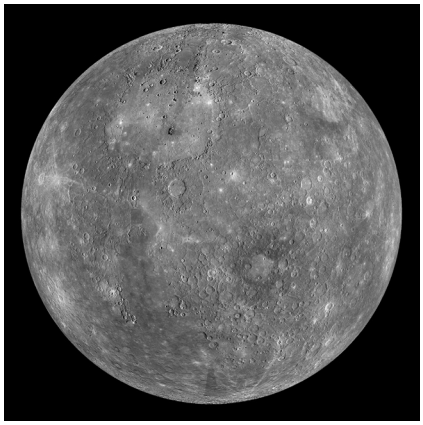
LESSON 12

What happens when rocks hit planets or moons with minimal atmosphere?

Investigation **2 days**

Phenomenon or design problem

There are many craters on objects in the solar system that are varied in size and age and do not have the impactors in the craters.



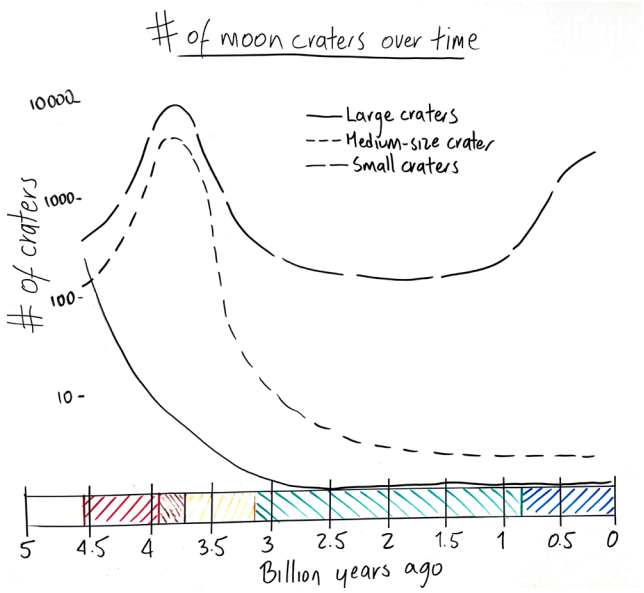
NASA Visualization Technology Applications and Development (VTAD)

What we do and figure out

We examine images of objects in space that lack atmospheres to see what happens when objects fall into them without burning up in an atmosphere. We make observations of cratering activity on the Moon over its history and find periods with high and low cratering activity. We consider why we don't see evidence of large meteor impacts on the Moon. We figure out:

- There are a lot of craters on other space objects created over billions of years.
- Evidence from other space objects suggests there must have also been a large number of things that came toward Earth (many of which probably burned up in the atmosphere).
- The age distribution of large craters on the Moon has decreased over time, while the age distribution of small and medium-size craters has fluctuated.

How we represent it



Navigation to Next Lesson: We figured out that the surfaces of numerous planets and moons are dotted with craters, both large and small. We wonder why Earth's surface does not look like that.

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LESSON 13

Why don't we see many craters on the surface of Earth?

Investigation **2 days**

Phenomenon or design problem

The record of terrestrial craters exhibits a pattern of relatively recent cratering activity that sharply declines after 650 million years.

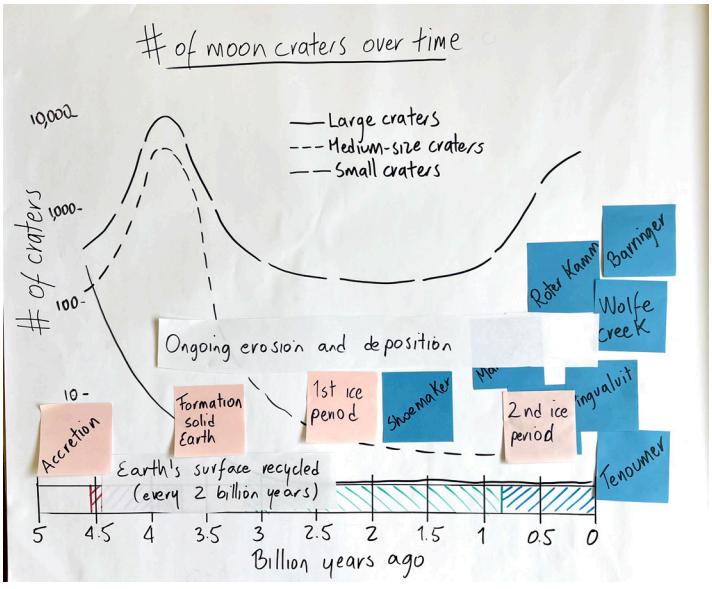


What we do and figure out

We will analyze data and find that visible impact cratering is absent in over half of Earth's timeline. We will use images of terrestrial craters to observe that older ones have less-clear features. We will use an erosion model to test how the surface can change. We will read about geological processes and will use these ideas to explain differences in cratering evidence between the Moon and Earth. We figure out:

- We see that visible Earth craters have been found mostly in the last 650 million years of our 4.5-billion-year history.
- We see that Earth's craters are less well-defined than those of the Moon.
- We learn about four Earth processes or mechanisms that shaped Earth's landform throughout its history.
- Approximately 65 million years ago, a meteor with enough kinetic energy to create a crater 112 miles (200 km) in diameter collided with Earth.

How we represent it



Navigation to Next Lesson: The historical record shows that Earth has been hit by large meteors. We wonder how an impact from an object in space could cause a mass extinction on Earth.

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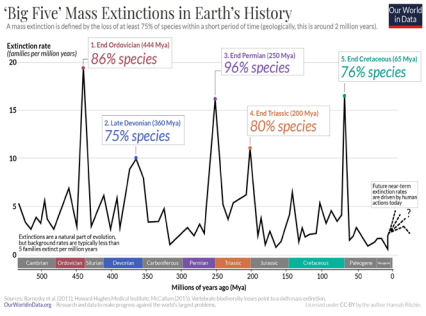
LESSON 14

How could an impactor have killed off some types of life on Earth but not all?

Investigation **3 days**

Phenomenon or design problem

A layer of ~1-cm-thick sedimentary rock found all over the world has a concentration of iridium in it that matches what is found in meteors and has been radioactively dated to be 65–66 million years old. Many types of fossils found in the layer below it don't appear anywhere in the layers above it.



Hannah Ritchie

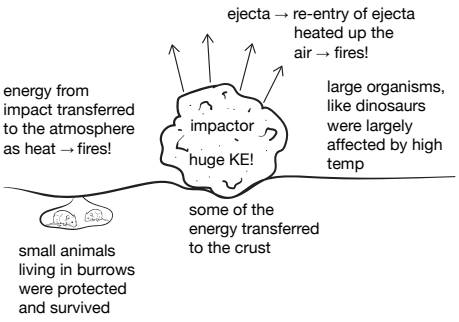
What we do and figure out

We analyze a graph showing mass extinctions in Earth's history. We develop a model to explain how an impactor collision leads to mass extinctions. We gather information about the Chicxulub crater formation. We use a Gotta-Have-It Checklist to revise the model to explain how some but not all types of organisms go extinct. We figure out:

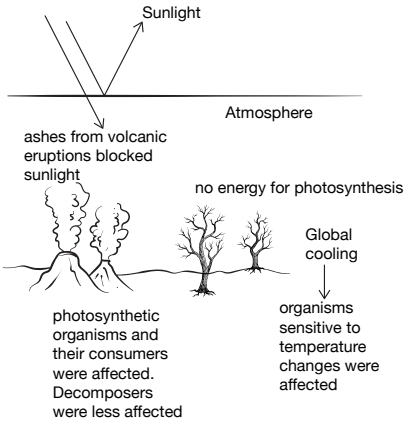
- The fossil record provides evidence that some types of organisms went extinct around the time of the impact, while others survived.
- There are alternate mechanisms to explain how the impactor affected energy transfers and matter flows in and through other earth systems (global forests, oceans, mantle, atmosphere).
- There would be longer-term effects on the energy flow to photosynthetic organisms and through food chains due to the longer-term changes in matter in different earth systems that would have resulted from the impactor.

How we represent it

During the impact



After the impact



Navigation to Next Lesson: While we explained the effects of a 10-km-wide object colliding with Earth 65 million years ago. We now have a lot of new questions about the effects of a 6,000-km-wide object that scientists believe collided with Earth even longer ago. We plan to investigate and answer some of these questions as part of a final transfer task and assessment to wrap up the unit in the next lesson.

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LESSON 15

How can we use our science ideas to explain the formation of the Moon?

Putting Pieces Together **1 day**

Phenomenon or design problem

Scientists believe the Moon was formed after Theia, a planet from the young solar system, collided with Earth.



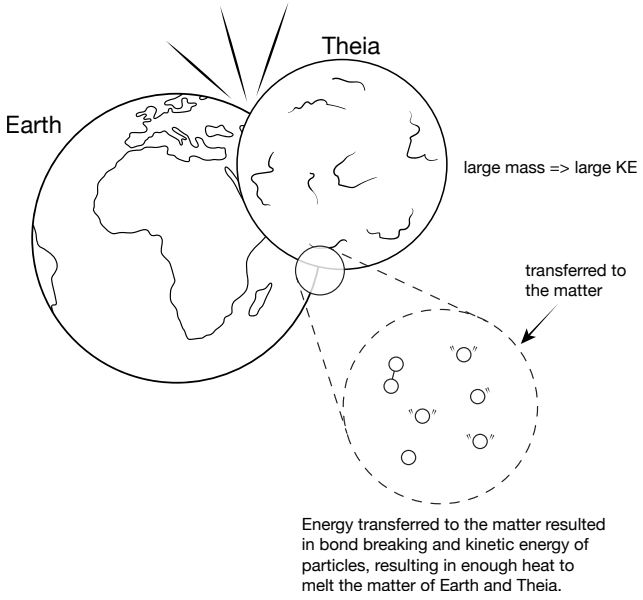
NASA/JPL-Caltech

What we do and figure out

We return to the DQB to evaluate which questions we have answered in this unit. We work through an assessment task where we assess whether the evidence from moon rocks supports scientists' ideas about the formation of the Moon from a giant impact between Earth and another planet known as Theia. We figure out:

- The Moon was formed after Theia, a planet from the young solar system, collided with Earth.
- Ideas about matter changes, forces acting on matter, and energy flow can be used to assess whether the available evidence supports ideas about the formation of the Moon.

How we represent it



Navigation to Next Lesson: This is the last lesson of the unit.

Lessons 1–15 **26 Days Total**

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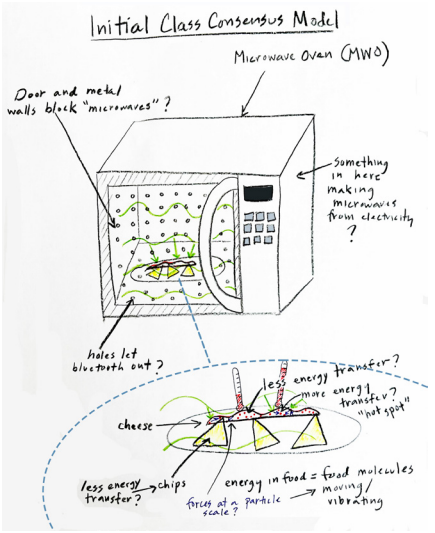
Unit Storyline

Lesson Set 1: How does a microwave oven heat up food?

LESSON 1

How do microwave ovens function, and why does their structure affect wireless signals?

Anchoring Phenomenon **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Wireless communication signals are affected when they pass through the walls and door of a microwave oven. The microwave oven cooks food quickly and without an obvious heat source. 	We read an article about an interesting trend—people are storing their phones, keys, and other electronic devices in their microwave ovens. We observe a Bluetooth speaker paired to a device inside a closed microwave oven, read the *Microwave Oven Manual*, and then safely heat food and make additional observations. We model the structure and function of the microwave oven, build a Driving Question Board, and brainstorm future investigations and data we need. We figure out: • The structure of a microwave oven blocks or somehow affects wireless signals, but not completely. • The function of a microwave oven is to heat (transfer energy into) liquid/food. • Using a microwave oven requires attention to safety.	

Navigation to Next Lesson: We have a lot of questions about microwave ovens and wireless technology, and a lot of ideas for investigations we want to do to answer our questions.

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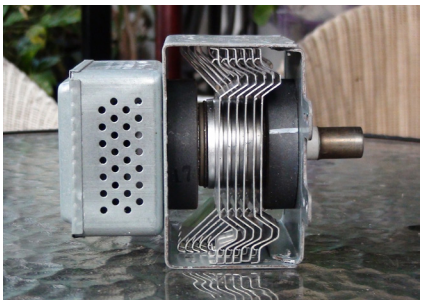
LESSON 2

How does a microwave oven use electricity to produce microwave radiation?

Investigation **1 day**

Phenomenon or design problem

When a microwave oven is taken apart, we find a magnetron with an antenna. This antenna probably changes fields inside the cooking area, but to be sure we need to know more about how the magnetron works.



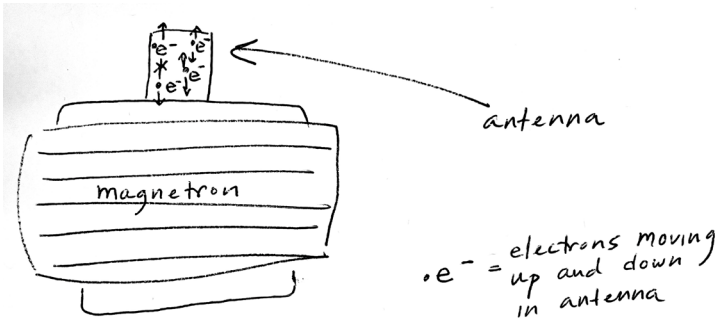
rgouveia, Pixabay

What we do and figure out

We integrate information from our *Microwave Oven Manual*, a video of a magnetron being dissected, a reading, and a brief investigation to identify a relationship between moving electrons and changing electric fields. We figure out:

- Electrons vibrate inside the antenna of a magnetron.
- Vibrating charged particles change electric fields.
- Changing electric fields carry energy across space.
- The microwave oven is designed so the magnetron antenna changes electric fields near the oven's cooking area. This energy transfers across space and somehow reaches the food.

How we represent it



Navigation to Next Lesson: We have many ideas about how the changing electric fields emitted from the magnetron transfer energy from the antenna to the food. We recognize that we need to know more about waves to investigate these ideas in more detail.

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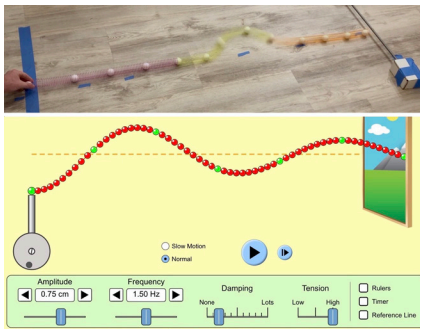
LESSON 3

How does energy transfer through a wave?

Investigation **3 days**

Phenomenon or design problem

Shaking the end of a spring creates a wave pattern. A computer simulation of a wave on a string produces similar patterns.

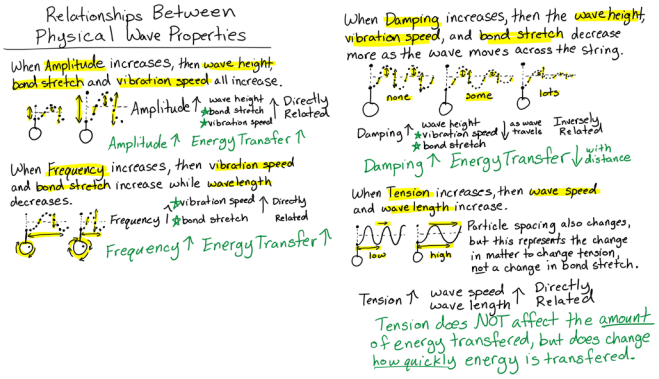


What we do and figure out

We recall examples of physical waves and produce waves with a spring. We develop a model of how physical waves transfer energy through solids. We use a computer simulation to plan and carry out four investigations. Using our results, we make claims for how various wave properties affect energy transfer. We develop a mathematical model of the relationship between some of these properties. We figure out:

- Energy is transferred through waves on a string by the stretching of electric fields (bonds) and by the forces between these fields and the matter of the string.
- A larger amplitude transfers more energy along the wave.
- A larger frequency transfers more energy along the wave.
- The wavelength of a wave can be determined by the wave speed across the medium and its frequency.

How we represent it



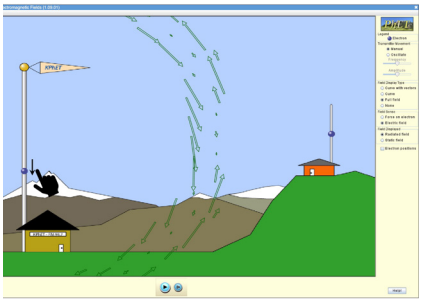
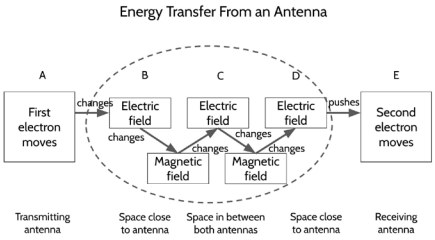
Navigation to Next Lesson: We think that the multiple perspectives (M–E–F) we have used to explain energy transfer in physical waves could also help us make sense of how energy transfers from the magnetron to the food inside the microwave oven.

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LESSON 4

How does an antenna transfer energy to matter at a distance?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Electromagnetic radiation can be visualized as changing electric and magnetic fields rippling outward from a moving charge. 	We investigate how moving electrons in an antenna cause energy to transfer. We use and evaluate different representations of electromagnetic radiation propagating through space, and we read about the mechanism that generates electric and magnetic fields from a vibrating charged particle. We develop a mechanistic explanation of electromagnetic radiation and use it to predict its interactions with matter inside the microwave oven. We figure out: • Moving electrons create electric fields that change. • These changing electric fields, in turn, create changing magnetic fields, which generate changing electric fields again. This wavelike cycle continues, resulting in the formation of electromagnetic radiation. • Electromagnetic radiation can travel through empty space without needing matter to move through. • The energy in changing electric and magnetic fields spreads out as waves travel, becoming weaker the farther they go.	

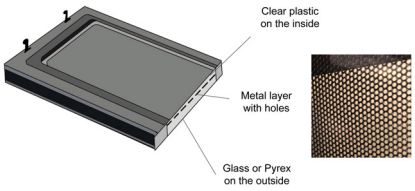
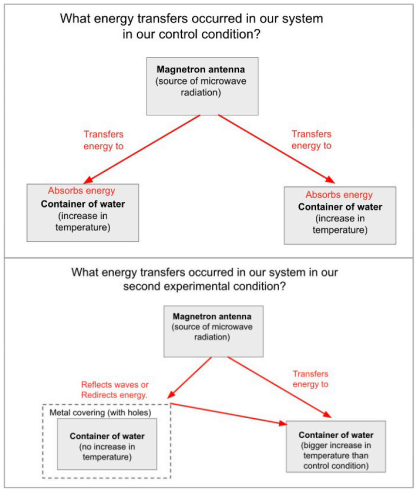
Navigation to Next Lesson: We figured out how electromagnetic waves transfer energy through space, but we wonder how microwaves interact with the matter inside the microwave oven.

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LESSON 5

How does radiation interact with the parts of the microwave oven system?

Investigation **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
When bowls of water wrapped in foil or in foil with small holes are in a running microwave oven for 15 seconds, their temperature does not increase.  	We argue for, plan, and carry out investigations to determine what happens to microwave radiation when it reaches the material(s) in the microwave oven door and walls. We develop a model to explain the results of our investigations, showing what happens to the energy transferred by these waves when they interact with these parts of the system. We figure out: • The energy transferred by microwave radiation can be absorbed (food heating up), reflected (off metal walls), and/or transmitted by matter. • We all have an ethical responsibility to consider the possible personal, societal, and environmental impacts of any scientific investigation we plan or engineering solution we design. • The window in the microwave oven door transmits one type of EM radiation (visible light) through it, but transmits none (or very little) of another type of EM radiation (microwave radiation).	

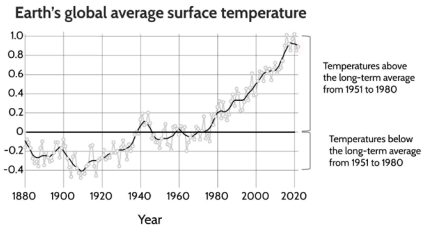
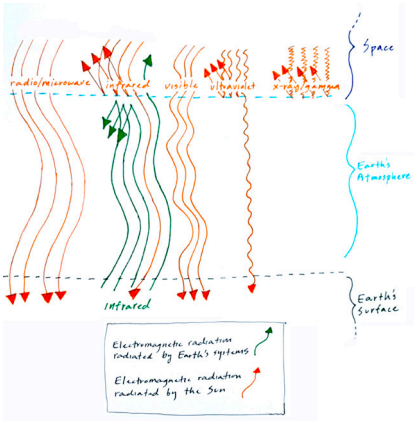
Navigation to Next Lesson: Though we were able to determine how microwave radiation interacts with some materials, we still have questions about why it interacts the way it does and how other materials (e.g., different foods) interact with it.

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LESSON 6

How can we use interactions between matter and electromagnetic radiation to explain the increase in global temperatures?

Putting Pieces Together **1 day**

Phenomenon or design problem	What we do and figure out	How we represent it
Greenhouse gases and global temperatures have increased over the last century, but the amount of solar radiation has not.  Data Source: NASA/GISS	We add new questions to the Driving Question Board and use our science ideas about the interactions of different types of EM radiation with different types of matter to explain how an increase in greenhouse gases could be contributing to the overall increase in global temperatures. We figure out: • EM radiation is emitted by the Sun. • A percentage of that EM radiation is absorbed, reflected, or transmitted when it enters Earth's atmosphere. • After EM radiation reaches Earth, matter on the surface absorbs it and then emits infrared radiation that is more readily absorbed by the greenhouse gases in the atmosphere. • Because of the prevalence and longevity of carbon in the atmosphere, carbon has contributed to the increased temperatures globally and will continue to do.	

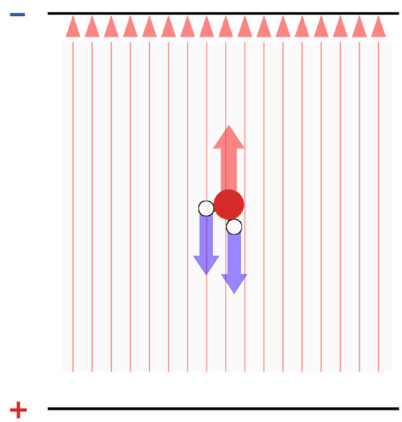
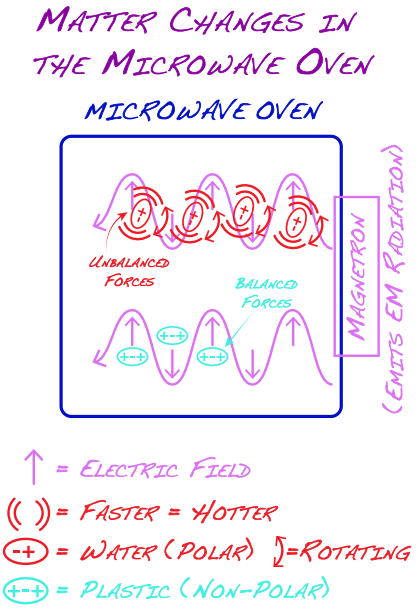
Navigation to Next Lesson: We revisited our Driving Question Board and realized we still have many questions about other types of EM radiation, their safety, and their interactions with various types of matter, such as food and other objects.

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LESSON 7

Why do some substances heat up faster than other materials in a microwave oven?

Investigation, Putting Pieces Together **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Different materials respond differently when heated inside the microwave oven. Water heats up, plastic doesn't, and aluminum foil creates sparks. 	We use simulations to model how matter of different materials (water, plastic, metal) interacts with changing electric fields of different frequencies. We connect this particle-scale evidence to macroscopic evidence about materials heating up in the microwave oven, then model our understanding. We read articles to consider whether metal in the microwave oven is safe, and consider the validity and reliability of these claims. We figure out: • The forces from changing electric fields in the microwave oven will cause polar molecules, such as water, to rotate in the direction of those fields. • The interaction between the microwave radiation and the water molecules transfers energy out of the fields and into thermal or kinetic energy of the water. • Electrons can move inside conductors, such as metal, when pushed by changing electric fields in microwave radiation, which can cause reflection, or dangerous arcing in some cases.	

Navigation to Next Lesson: We wonder what causes the patterns of melted and unmelted cheese when we heat nachos in the microwave oven.

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LESSON 8

Why do we see patterns of hot and cold spots in the microwave oven?

Investigation, Putting Pieces Together **3 days**

Phenomenon or design problem

When many small light bulbs are placed across the microwave oven while it is running, some light up and some do not.

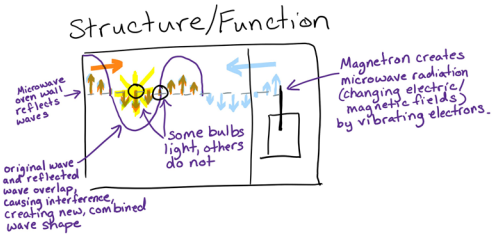


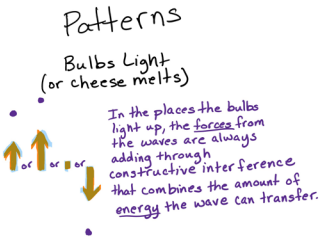
What we do and figure out

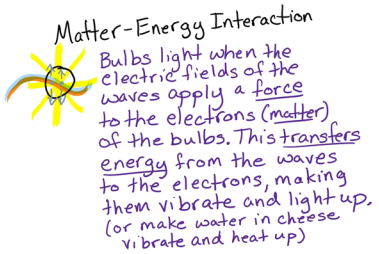
We observe a pattern when light bulbs are placed in the microwave oven. We use simulations to make sense of wave interference. We model wave interference from an energy perspective to explain hot and cold spots in the microwave oven. We revise our initial consensus model from the anchor phenomenon and our Driving Question Board. We figure out:

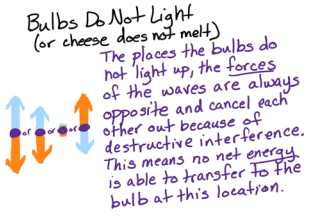
- When two waves meet in space, they can produce a new wave through either constructive or destructive interference, but the total combined energy of the original waves is conserved.
- The microwave oven produces hot and cold spots due to constructive and destructive wave interference between the waves emitted from the magnetron and those reflected off of the oven's interior walls.
- The turntable in the microwave oven is designed to move food between hot and cold spots to provide more even heating.

How we represent it









Navigation to Next Lesson: We can explain how electromagnetic radiation can transfer energy to food in a microwave oven, but we cannot explain how it can be used to transfer information between wireless devices.

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Lesson Set 2: How do we use electromagnetic radiation safely in our lives?

LESSON 9

What other types of EM radiation are there, and how do we use them?

Investigation, Problematizing **2 days**

Phenomenon or design problem

The electromagnetic spectrum includes various types of radiation with a wide range of frequencies, wavelengths, and uses, such as communication and medical imaging, but some types can also pose health risks.



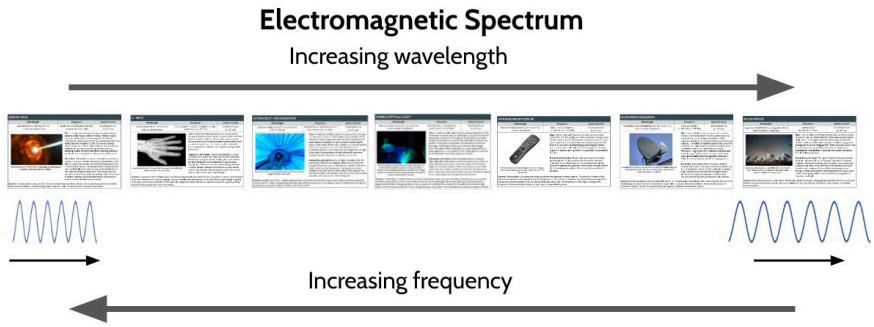
European Southern Observatory (ESO)/C. Malin

What we do and figure out

We examine the remaining categories of DQB questions and construct the EM spectrum using the wavelength and frequency of various types of EM radiation. We write an argument about the relationship between the frequency and wavelength of EM radiation and its interactions with matter, and how this relationship helps explain some of the uses of EM radiation. We add new questions to the DQB. We figure out:

- The EM radiation spectrum is arranged from high- to low-frequency (short to long wavelength) EM waves.
- Different types of EM radiation have different interactions with matter, including heating it up, ionizing it, or breaking apart its molecules.
- These interactions can be harnessed for various applications, such as medical imaging, telecommunications, and energy production.
- Ionizing radiation can harm living organisms.

How we represent it



Navigation to Next Lesson: We are wondering why some types of EM radiation can damage or kill living organisms and others do not.

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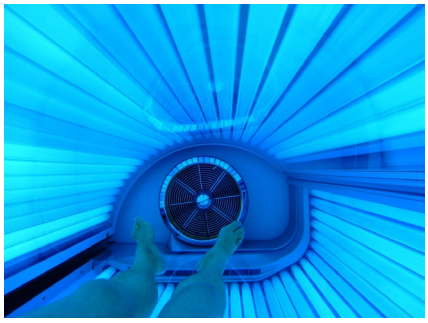
LESSON 10

Does all electromagnetic radiation cause damage?

Investigation **2 days**

Phenomenon or design problem

Not all frequencies and amplitudes of light are linked to skin cancer.



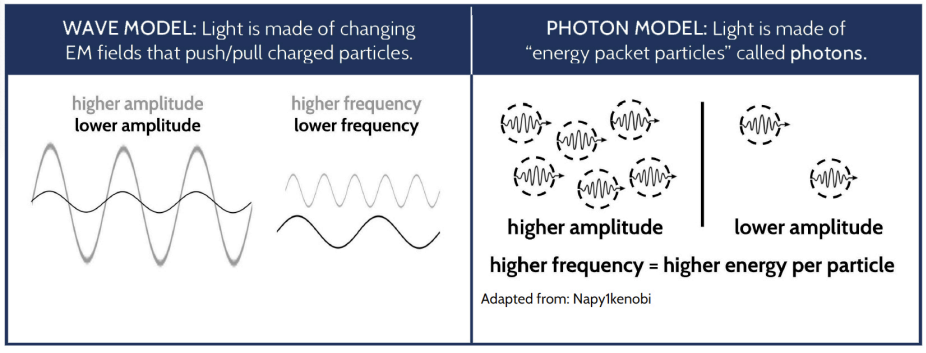
Tho-Ge, Pixabay

What we do and figure out

We question whether higher frequency or higher amplitude EM radiation leads to an increase in skin cancer. We use multiple sources of evidence to try to identify patterns in frequency, amplitude, and skin cancer. We use both a wave model and a photon model to try to explain our evidence. We figure out:

- The photons of high-frequency EM radiation have enough energy to knock out electrons, causing changes in the molecular structure of the DNA molecule.
- More high-frequency, ionizing radiation puts you at greater risk of cancer, but how much the risk increases depends on the type of radiation and the total exposure time.
- The photon model of EM radiation can better explain the interactions of high-frequency EM radiation and matter.

How we represent it



Navigation to Next Lesson: We wonder about why we still use high-frequency radiation in multiple technologies if it is so dangerous.

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LESSON 11

How can we use EM radiation to create and store digital images?

Investigation **1 day**

Phenomenon or design problem

Digital radiography uses electronic detectors to capture X-rays for creating and storing digital images of our bodies' internal structures.

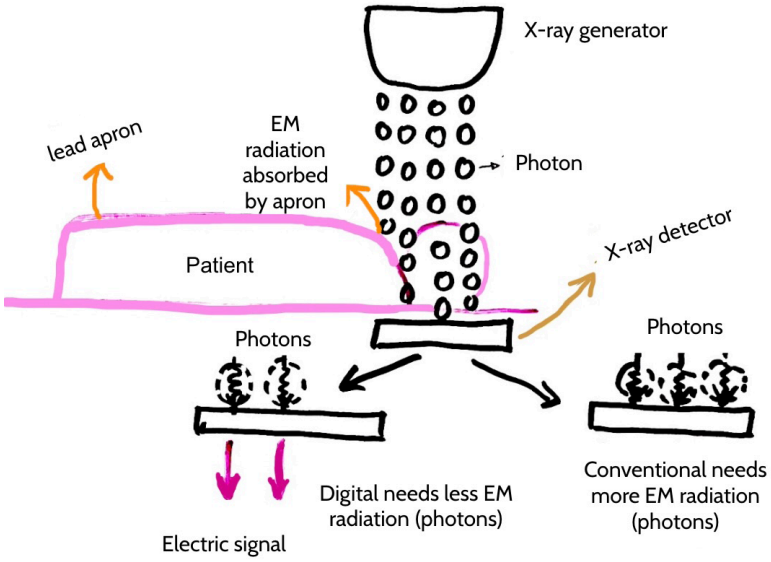


What we do and figure out

We wonder how EM radiation is used to create and store digital images. We read about how the interactions of X-rays with matter can be harnessed to create images of the internal structure of our body, and about the advantages and disadvantages of digital versus conventional radiography. We wonder how EM radiation is used in wireless communication to transmit information. We figure out:

- Sensors that respond to EM radiation are very sensitive and can trigger electric currents that can be used to create digital images.
- Digital images can be reliably stored in our computers.
- Digital technologies can reduce the time of exposure to the ionizing radiation necessary in medical applications.

How we represent it



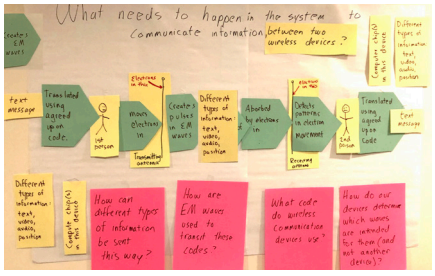
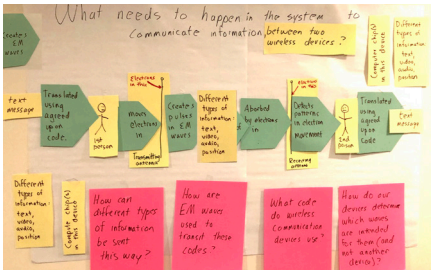
Navigation to Next Lesson: We figure out that the interactions of X-rays with matter can be harnessed to create digital images for medical applications while reducing the time of exposure needed, and thus, reducing the potential harm they can cause us. We wonder how the interactions between EM radiation and matter are used in communication technologies.

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LESSON 12

How are our wireless electronic devices designed to use EM waves to reliably communicate different types of information?

Investigation **2.5 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Pulses of sound, light, and other EM waves have been used in the past to communicate text messages over long distances. 	We develop ways to send messages with EM waves using a simulation. We develop a model for how this system works and compare it to digital communication systems. We gather information from multiple sources in various formats from four different stations. We integrate this information with our model to summarize how our wireless electronic devices are designed to use EM waves to reliably communicate various types of information. We figure out: • The majority of modern wireless communication uses binary code (digital transmission) to represent information, such as text, audio, photos/video, and location. • Binary code is a combination of "on" and "off" states; it can be represented in EM radiation by varying the energy in the wave, using changes in the wave's amplitude or frequency to communicate "on" and "off." • If a wireless message is encrypted, only the intended receiver can decode the information.	

Navigation to Next Lesson: We consider the argument that scientists and engineers are making that using even higher frequency EM radiation in future wireless communication technologies could provide some advantages. We can already see some trade-offs related to doing this.

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LESSON 13

Is communication technology that uses radiation safe?

Putting Pieces Together **1.5 days**

Phenomenon or design problem

EM radiation affects different materials in different ways.

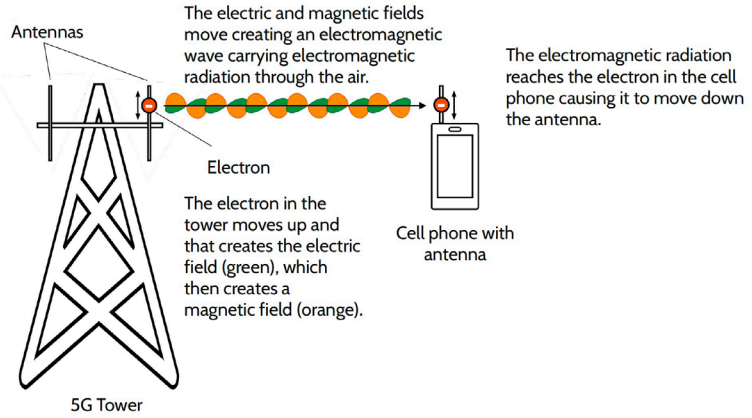


What we do and figure out

We return to the Driving Question Board to take stock of where we have been and what questions we have answered. We work through an assessment task in which we evaluate two social media posts about 5G radiation, and we use our model for EM radiation to argue from evidence about whether this technology is safe. We figure out:

- We have answered many of our questions about EM radiation.
- 5G technology is most likely not dangerous because it is not a form of ionizing radiation, but long-term exposure could lead to potential health consequences.

How we represent it



Navigation to Next Lesson: This is the last lesson of the unit.

Lessons 1–13 **27 Days Total**

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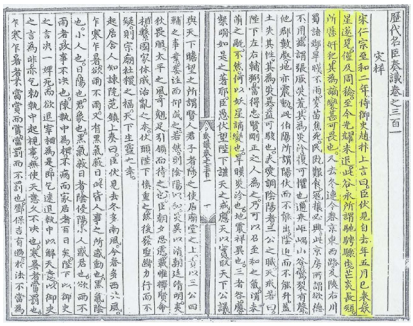
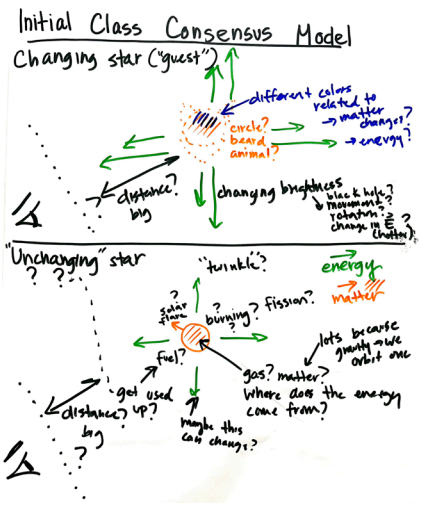
Unit Storyline

Lesson Set 1: How are stars born, and how do they die?

LESSON 1

Why do some stars seem unchanging, while others appear briefly, change dramatically, and fade away?

Anchoring Phenomenon **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Several times in history, a star has appeared in the sky suddenly and disappeared after a short time. These events were recorded in writings, petroglyphs, and more recently in photographs. 	We examine historical evidence that some stars appear in the night sky even though we could not see a star there previously. The star fades away and seems to disappear. We map these events on a star map and look for patterns. We figure out: • A guest star is a star that appears and then seems to disappear a short time later. • Guest stars are distributed across the sky but seem to be concentrated along the plane of our galaxy (the Milky Way).	

Navigation to Next Lesson: What do we see when we point a telescope at the locations that we have mapped?

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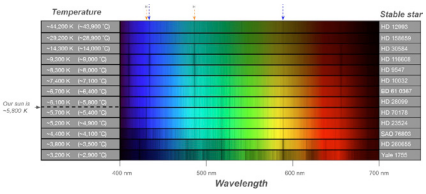
LESSON 2

How does the matter in guest stars compare to stable stars?

Investigation **1 day**

Phenomenon or design problem

Semi-spherical shaped clouds of dust and gas can be seen in telescopic images from locations in the sky where guest stars were once observed.

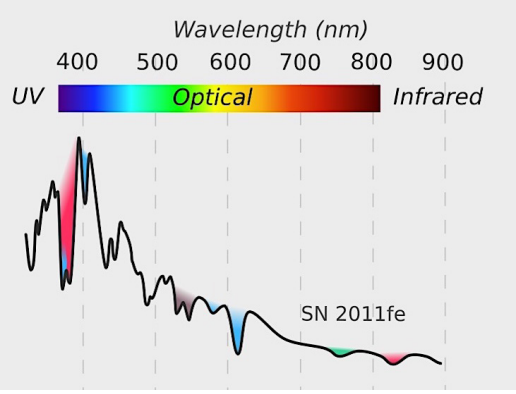


What we do and figure out

We compare photos of the parts of the sky where some of these guest star events were observed and notice remnants of what looks like gas or dust. We analyze spectra to determine the composition of the matter that these remnants are made of and its temperature. We compare the spectra of stable stars to the spectra of remnants and add to our Progress Trackers. We ask new questions and add them to our Driving Question Board. We figure out:

- Stable stars are made of mostly hydrogen and helium.
- Hydrogen and helium are the two lowest-mass elements.
- Temperatures of stable stars range from thousands to ten thousands °C or °F. Temperatures of guest star remnants are millions °C or °F.
- Guest star remnants contain elements other than hydrogen and helium and in some cases no hydrogen and helium.

How we represent it



Adapted from: Dr. Heloise F. Stefanie

Navigation to Next Lesson: We have new questions about if/how stars and guest stars change, and what keeps most stars stable, that are related to matter and energy perspectives.

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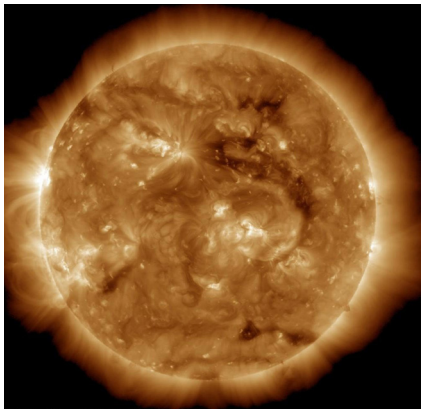
LESSON 3

What is happening with matter and energy in stable stars, like our Sun, and how does this help us understand guest stars?

Investigation **2 days**

Phenomenon or design problem

Stars like the Sun are very hot and transfer energy out toward the Earth. The remnant cloud of gas left over after a guest star event also appears to transfer energy and contain different types of matter than stable stars.

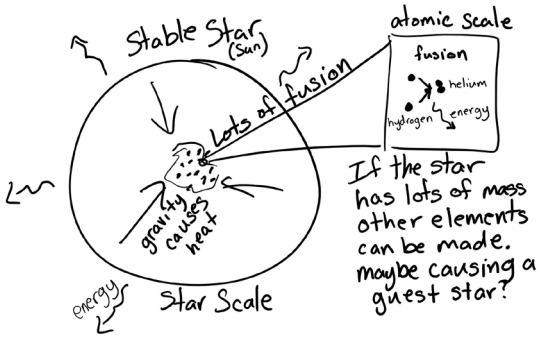


What we do and figure out

We consider how studying energy and matter in stable stars, including the Sun, could help us answer our questions about guest stars and form research groups. We are introduced to the *Planning for Obtaining Information Tool* and consider the credibility of sources. We use a new tool called the Obtaining Information Tool to keep track of what we find out. We come to consensus around the answers to our research questions and record our ideas in our Progress Trackers and Personal Glossaries. We revisit questions on the DQB. We figure out:

- A star is an object that is massive enough to ignite fusion.
- Energy from fusion causes stars to emit electromagnetic energy.
- Fusion creates new elements as multiple nuclei become one.

How we represent it



Navigation to Next Lesson: We are wondering about what could happen to cause a stable star to become unstable and possibly become a guest star.

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LESSON 4

How does running out of fuel cause a star to change?

Investigation **3 days**

Phenomenon or design problem

A model of the balance between the force of gravity and the force from fusion doesn't explain what will happen if there is not sufficient fuel for fusion.

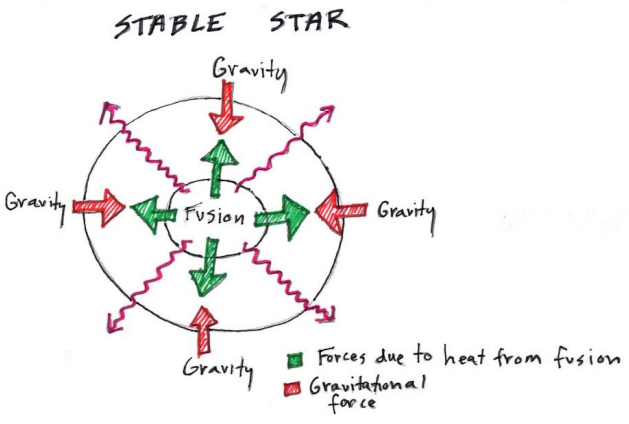


What we do and figure out

We model the macro forces of a star to help us figure out what keeps stars stable and make sense of the balance between gravity and pressure in stable stars. We develop research questions and are introduced to a new tool: the *Evaluating Sources of Information Tool*. We gather information and communicate our findings in a gallery tour. We come to consensus on what causes stars to remain stable or become unstable and change, and we record those ideas in our Progress Trackers. We figure out:

- Stars exist because of a feedback loop between gravity forces pushing inward and the outward-pushing forces caused by the energy released by fusion.
- Stars, including our Sun, will eventually run out of fuel, and the equilibrium will be broken. What happens next depends on the mass of the star and what heavier elements it can fuse.
- When a very massive star fuses iron in its core, the star collapses and bounces back in what is called a supernova.

How we represent it



Navigation to Next Lesson: We will put the pieces together next time to see if we can model and explain guest stars and if we have answered all our questions yet.

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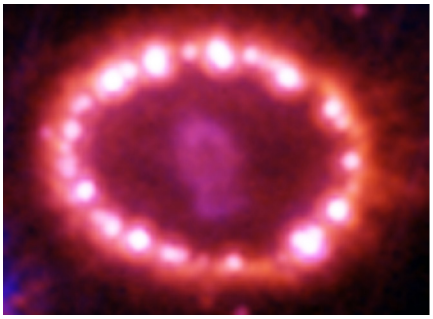
LESSON 5

Why do some stars seem unchanging, while others appear briefly, change dramatically, and fade away?

Putting Pieces Together 2 days

Phenomenon or design problem

A guest star appears and then disappears, but other stars shine with steady light. The cloud left over after a supernova is hotter than the original star and contains different matter.

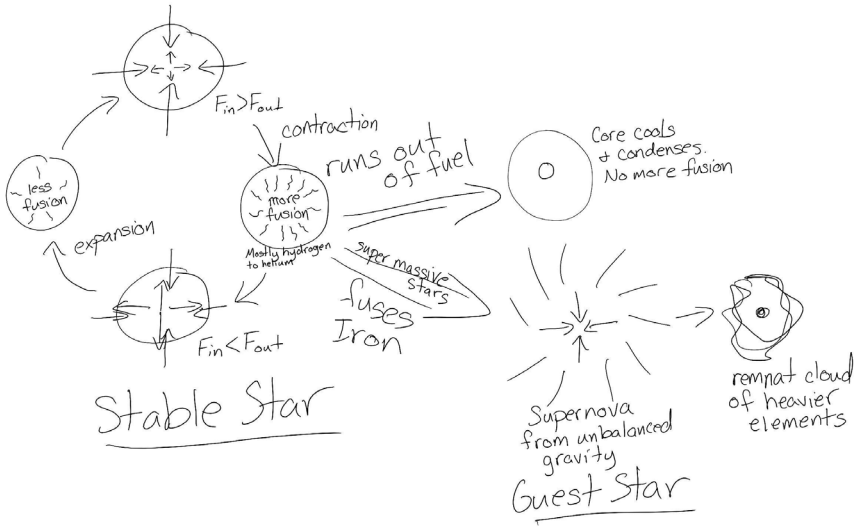


What we do and figure out

We create a Gotta-Have-It Checklist to explain what cause–effect relationships occur within stars. We individually, then collectively, model the feedback loop that keeps stars stable and what happens when this loop is disrupted. We update the Scale Chart and revisit the DQB. We begin to wonder where the stuff for the first stars came from. We figure out:

- A guest star is a star that tried to fuse iron in its core, breaking the feedback loop that keeps it stable.
- The stable period for a star ranges from a few million years for the most massive to trillions of years for the least massive.
- When a super-massive star dies, it collapses and bounces back out, releasing a lot of energy and fusing elements heavier than iron. When this happens, the star in the sky appears very bright.
- After this event, the energy will move outward into space, and the star will fade away as the gas begins to disperse into a remnant cloud of heavier elements.

How we represent it



Navigation to Next Lesson: We figured out that over millions or even billions of years, stars convert lighter elements like hydrogen and helium into heavier and heavier elements. We are wondering how these matter changes could affect the matter in the Universe over time, and we think that by measuring the composition of the whole Universe, we might get some clues.

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Lesson Set 2: How has the matter in the Universe changed over time?

LESSON 6

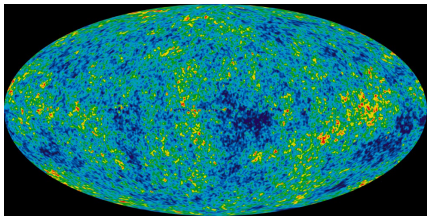
How has the matter in the Universe changed over time, and how do we know?

Investigation **4 days**



Phenomenon or design problem

When we look at spectra of stars, galaxies, and empty space, we notice puzzling patterns that cannot yet be explained by our model.



What we do and figure out

We look at spectra of stars, galaxies, and empty space and notice puzzling patterns in each that might hold clues to how the matter in the Universe has changed over time. We are introduced to the *Planning for Communicating Information Tool* and use all four research tools in small groups to obtain, evaluate, and communicate our ideas. We come to consensus about the evidence we uncovered, which points to an event called the Big Bang, and read about what it means that people call the Big Bang a "theory." Finally, we add to our Progress Trackers and our Personal Glossaries. We figure out:

- The Big Bang theory is supported by evidence.
- Evidence for the Big Bang includes observations of distant galaxies moving away from us, the measured composition of stars, and maps of spectra of the cosmic microwave background, which all match Big Bang models.

How we represent it

Planning for Communicating Information Tool

Communicating Information Planning Tool		
Goals and questions	What are the questions you were trying to answer? What are some of the additional questions you had to answer first or terms you had to define?	
Audience and purpose	Who is your audience, and how will you make sure they can understand the information you are presenting? What is the purpose of communicating information with this audience?	
Formats	What formats could be effective ways to achieve your goals in communicating with your audience? How might you combine formats to improve your communication? Will you use speech, written words, diagrams, mathematical equations, or something else? Why?	
Citing resources	Identify which credible resources you used to answer your questions. Cite those resources in your communication of information. Check with your teacher about how to properly cite resources.	
Still wondering	What questions do you still have, or that you were not able to find a satisfying answer for? What new questions do you have after the research cycle?	

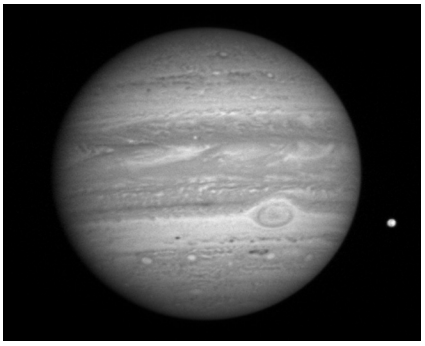
Navigation to Next Lesson: We are ready to wrap up the unit (and the course and the program) and return to our DQB.

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LESSON 7

How can we use the practices and crosscutting concepts we have developed to figure things out on our own?

Putting Pieces Together 1 day

Phenomenon or design problem	What we do and figure out	How we represent it
We have so many questions about phenomena that we would like to explore in the future. 	We consider how the M–E–F triangle frames and our understanding of stability and change help us make sense of our phenomena. We record questions we still want answered on our DQB and then broaden to think about questions we have about other types of phenomena. We reflect on what investigations we can through online research, future science classes, a career in STEM, and/or a lifetime of curiosity. We then engage in a final transfer task. We figure out: • Stability and change and the M–E–F triangle frames are valuable tools for making sense of our natural world. • We can use the lenses we have developed and our research tools to continue to investigate our questions outside of class and beyond high school.	

Navigation to Next Lesson: This is the last lesson in the unit, course, and program.

Lessons 1–7 **15 Days Total**

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