Planning for engagement with important science ideas

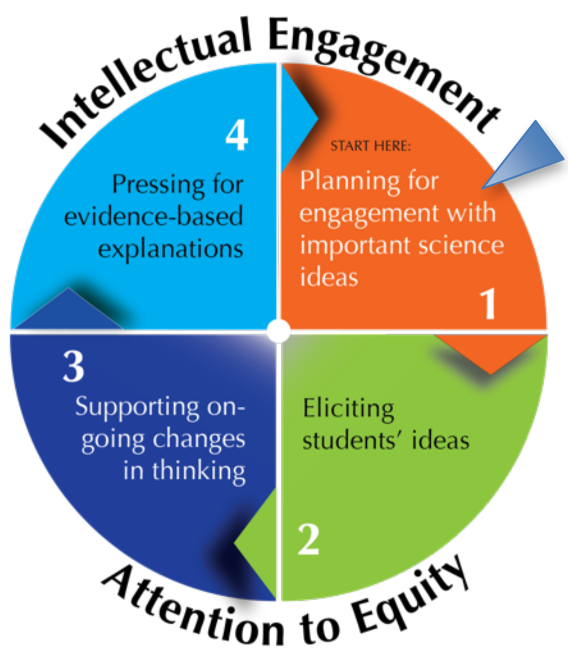
Overview

Consider three very common problems for students trying to learn science:

1) They often experience instruction as a series of unrelated and isolated lessons, one after another. They don't understand how readings or new concepts fit in with bigger science ideas.
2) They don't know *why* they are doing particular science activities—when asked they will say "Because the teacher wants me to."
3) They don't see how science relates to their everyday experiences or how their lived experiences can be used as resources to help them and others learn important science ideas.

The root of all three of these problems is that there is *nothing on the horizon* for students to focus on. There is no genuine puzzlement, interest, or larger learning goal that they are aware of. Consequently the motivation for learning dissipates and they disengage from learning activities.

In our Framework for Ambitious Science Teaching, the first phase in any unit of instruction is the teacher planning to engage students in big science ideas. Only when teachers understand where they are going in the unit can they begin to design instruction, and then take the journey with students through the other three essential practices of the Framework.

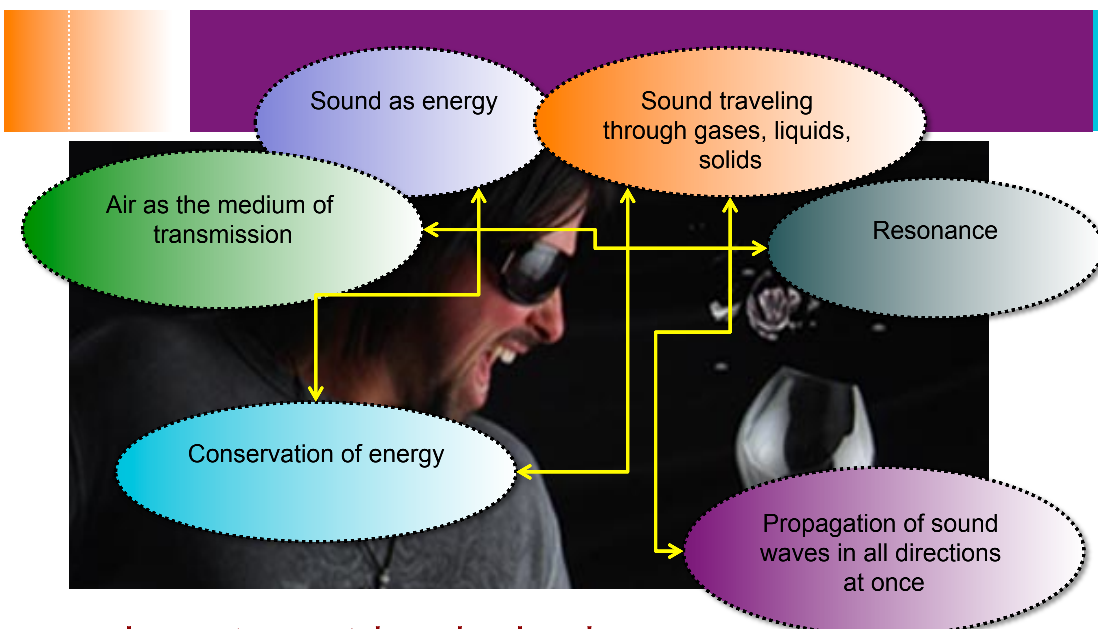


All four of the teaching practices in the Framework focus on helping students to participate in modeling and the construction of evidence-based explanations. Modeling and causal explanation are at the heart of what scientists do and also at the core of ambitious teaching.

Here's an example. Our scenario involves a 3rd grade teacher whose students were about to investigate sound as energy. She considered a phenomenon (event or process) that could anchor her unit (when we say units, we refer to two to four weeks of instruction focusing on a related set of important science ideas).

This teacher chose the situation of a singer breaking a glass with the sound energy from his voice. She thought that, as students were developing an explanatory model for this phenomenon, they would have to wrestle with the ideas of 1) sound as energy, 2) air as a medium of transmission, 3) the characteristics of sound waves at the unobservable level (wavelength, amplitude, frequency) 4) and at the observable level (pitch, volume, the propagation of sound in all directions at once) and 5) resonance. Her third graders would not only have to "know about" each of these ideas, but they would have to integrate each of these ideas into an explanatory model for why the glass broke in a particular way, at a particular moment, and under particular conditions. These "particular" conditions are we mean by selecting a phenomenon that is contextualized, and not generic. This is also what makes carefully designed units, based on causal explanations, far more rigorous than simply "covering curriculum."

This teacher's pre-planning also helped her see what parts of her curriculum kit would be relevant to students' final explanations and which parts would be set aside. The teacher started her first day of the unit with the video of a singer shattering the glass. Students were immediately intrigued and offered observations without prompting: "He yelled right at the glass", "I saw the glass shaking", "Only the top of the glass broke!" After some conversation about what they could see and hear in the video, the teacher shifted their attention to what they thought was going on that they could not directly observe. Following this discussion, students drew some initial models using a before-during-after template supplied by the teacher.



What science ideas had to be "pulled together" by our 3rd graders?

After this first day of the unit, the teacher engaged her students in a series of lessons, some involving combinations of: introducing new ideas (such as air being made out of particles), activities (using tuning forks to understand what frequency means), discussions (about why they think sound is energy), and debates (about whether sound travels equally fast in all directions from the source). Much of her standard curriculum was used, but some lesson were re-arranged, some were re-purposed, and some thrown out entirely because they contributed little to the final explanatory models. All these decisions were based on two considerations: 1) What ideas and experiences were necessary for the final explanations and models, and 2) What were students thinking currently?

As you can see in this example, anchoring events can help you organize your instruction over multiple lessons and help students understand that everything they are doing has a larger purpose. They are keeping their eyes on the horizon.

Even for experienced teachers, coming up with anchoring events requires extra reading, a constant focus on learning goals, and regular reflection on how those learning goals match up with big science ideas. The process will *test your content knowledge to its limits* and inevitably *push you to deepen* your understanding of even the most fundamental ideas of science.

This guide will help you move away from teaching topics to teaching big science ideas. To do this we will address the following questions:

- What *is* it about curriculum topics [earthquakes, optics, inheritance, or acids and bases] that is so important?"
- Is it the *topic* that is important? Or is it something *more fundamental and dynamic* about the topic that my students should really understand?
- What are important observable phenomena that students will need to interpret or explain?
- How might students represent a model that organizes and helps them make sense of the ideas in a curriculum?
- How can anchoring events be made relevant to students' interests and lives?

What is an anchoring event?

Phenomena are events or processes ("things that happen") that are observable by the senses, or detectable by instruments.

- If you are a biology teacher, examples of phenomena might be the evolution of different shapes of finches' beaks, water moving into or out of a cell, or the invasion of non-native species into a habitat.

- If you are teaching earth science, examples of phenomena might be an earthquake, the process of sedimentation, or solar eclipses.

- If you are a chemistry teacher, examples of phenomena might be phase changes in water, the diffusion of dye in a beaker, or the rusting of iron.

- If you are teaching physics, examples of phenomena might be motion of a pendulum, the changing temperature of a cup of coffee left on a countertop, or the way light**Word did not find any entries for your table of contents.** behaves when it passes though lenses.

Anchoring events are specific instances of a phenomenon that require students to pull together a number of science ideas in order to explain. The singer shattering the glass was an example of an anchoring event. As another example, to engage students in understanding cells, high school teachers we have worked with have asked young learners to draw and refine models of the spread of cancer in human body tissues. Although these students certainly needed to know the names and functions of particular cell organelles, we did not ask them to re-create textbook representations of these parts, using plastic baggies and pipe cleaners. We focused them instead on how and why cell structures contribute to healthy functioning or to disease.

To cite another example, the earth-moon-sun system is a thing. It is possible to create scale models of its parts—many students do—but this is not the kind of modeling that scientists do, nor does it engage students to do more than simply reproduce textbook ideas. In contrast, it is possible to use the earth-moon-sun system to identify an event or process that one could create a dynamic explanation of, then test and revise it over time. Such events might be captured in the questions "What causes the seasons?", "Why are there no seasons if you live near the equator?", "Why do planets and moons maintain the orbits they currently have?", or "Why are solar eclipses so rare?"

Important! The anchoring event should be context-rich, meaning that it is about a *specific* event that happens in a *specific* place and time under *specific* conditions. These "specifics" are precisely what make the situation interesting to students. Explaining how all these contextual features affect the event is also what makes the explanations much more rigorous (not copy-able from a textbook).

What is an underlying explanation?

Every anchoring event or process should have an underlying explanation. These explanations—we also refer to these as *explanatory models*—always involve things that are not directly observable. Explanations, or explanatory models, have the following characteristics:

- They portray storylines about *why* observable events happen, not just descriptions of *how* they happen or *that* they happen.

- They almost always involve a cast of unseen characters, events, and processes that operate at a more fundamental level than the phenomenon itself. These characters, events, and processes may not be directly observable for several reasons:

    - they exist at such a small scale (atomic bonding)
    - they happen so quickly (electricity moving through a circuit)
    - they happen so slowly (evolution, glaciations)
    - they are inaccessible (the interior of the earth, neurons firing in the brain),
    - they are abstract (like unbalanced forces, concentration gradients, or alleles).

- These causal explanations may take several forms, they may be labeled drawings, written paragraphs, flow charts, or physical models.

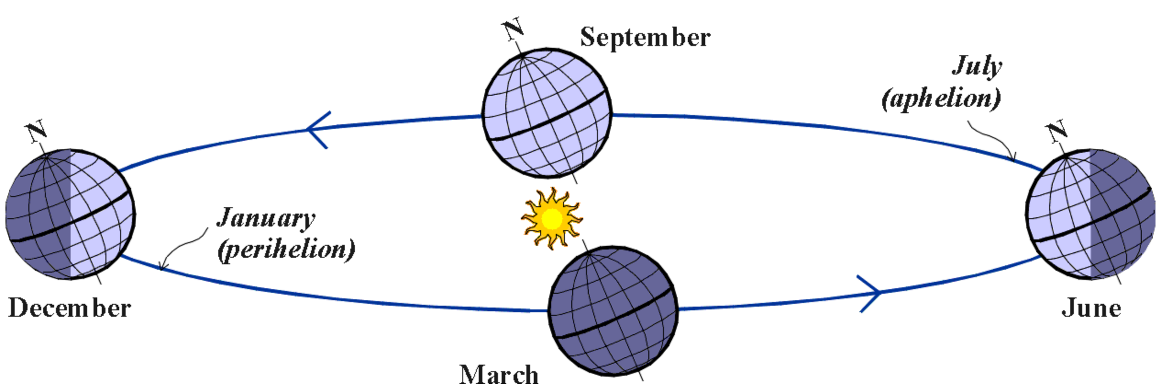
• The causal storyline—or the "why" explanation—is powerful in science because it helps us understand a whole *range of related phenomena* in the world.

Developing causal explanations is a centerpiece of classroom activity. This is because constructing explanations for natural events is at the core of what scientists do. But it is also because this is the most demanding kind of intellectual work you can ask students to do. The major struggle by students is to develop rich, gapless explanations. This requires that they link many science ideas together and understand how evidence supports the explanation. The development of these types of explanations takes two to four weeks, and requires students to explore many ideas along the way.

Here's an example of a rich, gapless explanation about what causes the seasons. It is what a middle school teacher might produce before a unit starts, in order to select activities and readings for students as they develop their own explanations (rather than just re-producing yours). You likely have seen "explanations" for the seasons before, they look something like this: "The seasons occur because the Earth is tilted at 23 degrees." Or, "Different parts of the Earth get more direct sunlight than others at different times of the year." Both of these explanations are weak, not just because they are brief, but because they lack any causal storyline. They fail to include the basic mechanisms that produce the effect we call the seasons; consequently there are lots of gaps. Accepting these types of explanations really lets students off the hook for thinking. It paints an overly simplistic view of how the world really works. Students can reproduce such explanations with no scientific understanding whatsoever—having learned nothing.

Below is a richer, more gapless storyline, something that would help a teacher plan a unit. Let's start with how the earth and sun are situated in space. The Earth revolves around the sun. The Earth's orbit is roughly on the same plane as all the other planets. This is the plane of the ecliptic. The earth travels around the sun, taking a year to make a round trip. As it travels through space it also spins on its axis.

But the axis is not aligned straight up and down in comparison to the plane of the ecliptic. The North and South Poles are tilted at 23 degrees from vertical. This tilt never varies, because there are no forces that could cause the tilt to change during the year. Because of this tilt, during the winter part of the round trip that the Earth makes, the northern hemisphere is pointed slightly away from the sun's rays. During another part of the year (about six months later), the Northern hemisphere it pointed slightly more directly towards the sun's rays.



There's more. The radiant energy that the sun produces has a range that we call the electromagnetic spectrum, but only visible light (generally speaking) and radio waves actually make it through our atmosphere. It is the visible light that can strike surfaces like land and water and get transformed into heat energy.

However, because of the tilt of the earth at different times during the year, these rays of visible light interact with the Earth differently. It is like a flashlight that is pointed directly down at a floor from a distance of about 5 feet. You can see the energy from the flashlight concentrated in a beam a few inches in diameter. But if you put the flashlight at an angle, let's say 45 degrees (still 5 feet away), then look at how the light hits the floor, you can see that the same amount of energy is now spread out over a much larger area. This latter example is like the Northern hemisphere during winter, when it is tilted away from the sun. The sun's rays are spread out over a much larger area—they are less concentrated, even though the total amount of light from the sun remains the same all year. During our winter the light also has to cut at a more oblique angle through more of our atmosphere—many more miles of it— before it reaches the Earth's surface. This also decreases the amount of light energy that reaches the surface.

During the winter, cold air masses build up over North America, Europe, and Asia, due to the low intensity of sunlight. The oceanic air masses are much less affected by the seasons because circulations in the upper ocean replenish warm surface water if it has been cooled.

All these events, starting at the sun's surface and ending in the air and water masses of the earth, contribute to the day length, the warmer temperatures, the different patterns of weather in our summer versus winter, and all the biological effects that we collectively characterize as the seasons.

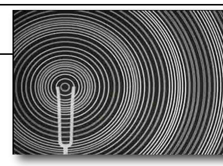
At this point we want to be clear—anchoring events are always developed out of some type of explanatory model. Even though it is phenomena that tends to capture the students' interests—like the exploding hydrogen balloon, the tornado video, the dilating pupil of the eye—your instruction should focus on what unseen mechanisms are at work. By the end of the unit, you want your students to have constructed explanatory models for your anchoring event. This is what makes an idea or model powerful in science—its *generalizability*—that it can be used to explain and even unify a range of different phenomena.

Developing essential questions to go with your anchoring events

To maximize student engagement teachers can "hang" all activities in a unit on an essential question that relates to students' lives and previous experiences. An essential question cannot be answered with a yes/no response, but rather it requires a complex synthesis of concepts learned. Each activity students do in a unit of instruction is in service of answering this question, and students constantly revisit this question throughout the unit. By constantly revisiting a relevant essential question, teachers are able to do more than just "hook" students at the beginning of a unit. A sample essential question for a unit on cells in biology might be "What makes wounds heal in different ways?" For a unit on the respiratory system an essential question might be "Why is asthma so prevalent in poor urban comminuties?" For a unit on oxidation in chemistry an essential question might be "What keeps things from rusting, and why?" For a unit on forces in physical science an essential question might be "How does a pulley help me lift something heavier than I am?"

Some examples

Here we present three different cases of how a typical ***topic*** found in a curriculum or textbook, might be linked to a ***anchoring event*** of importance, and a ***causal story*** (explanatory model) for that phenomenon, what you really want your students to understand, and ***another phenomenon*** that the explanatory model can be generalized to.

Physics example	
Topic found in text or curriculum	Sound 
Anchoring event of interest that can motivate students	The teacher could show a video of a person breaking a glass with their voice, and a video of a glass vibrating from sound. Students would then try and explain why sound is capable of breaking glass, and what kinds of sound might be able to do this.
Causal story (explanatory model)	How can sound cause a glass to distort and eventually break? A glass has a natural resonance, a frequency at which it will vibrate easily. To find the resonance of the glass, ping the glass with your finger or tuning fork and listen to the sound. In order to induce vibrations in the glass, one can replicate the natural frequency of the glass using sound waves. Sound waves (like all waves) have energy. When the sound waves hit the glass, the energy of the sound waves is transmitted to the glass, thus causing the molecules in the glass to vibrate. However, the frequency alone is not the only factor – amplitude (volume) is also important. The louder the sound (i.e. the greater the amplitude of the sound waves), the larger the vibrations of the glass will be. When the amplitude of the sound waves causes the glass to vibrate so much that the glass exceeds its elastic limit, the glass will shatter. The elastic limit is exceeded when the vibrations cause the bonds between molecules to break apart.
What you really want students to understand	The big idea that underlies this phenomenon is the relationship between waves and energy. Waves have energy and can travel through different media. When the wave encounters an object, the energy of the wave can be transferred to the object. Students need to understand that phenomena often have unobservable underlying causes. In this example, students need to understand that the sound waves emitted by the person or the device can travel through air and have energy. If students can understand that waves travel through a medium and that waves have energy, and that energy can be transferred from the wave to an object, students could explain why, for example, hitting a tuning fork and then placing the tuning fork near water causes water to splash.
Another phenomenon causal model could explain	How car radios that have very loud speakers installed can make objects at a distance shake, OR, how the mechanisms behind how loud noises can cause deafness.

Chemistry example	
Topic found in text or curriculum	Chemical reactions: specifically oxidation-reduction
Anchoring event that can motivate students	The teacher could tell a story about leaving a bicycle out in the rain and the metal rusting. The teacher could also distribute nails to students prior to the unit and have them place one in a location where they believe it will rust, and one in a location where it will not rust.
Causal story (explanatory model)	Rust forms due to a reaction between iron and water, and is called **oxidation**. If water is absent, iron will still corrode. However, if water is present, it can speed up the rusting process. Water molecules can penetrate the microscopic cracks in metal. The hydrogen atoms present in water combine with other elements in the metal alloy to form acids, which eventually expose the iron in the metal alloy to oxygen. Once oxygen comes into contact with iron, the oxidation process begins. There are always two distinct chemical reactions when iron corrodes. The first is the **dissolution** of iron into **solution** (water): Fe -----> Fe_2+ + 2e-. Next, there is a **reduction** of oxygen dissolved into water: O_2 + $2H_2O$ + 4e- ----> 4OH-. The final reaction between iron and hydroxide is: Fe_2+ + 2OH- -----> $Fe(OH)_2$. As the iron oxide continues to react with oxygen, the reddish color appears as the iron corrodes. The original iron (Fe) is no longer iron, and has changed to a new substance.
What you really want students to understand	The big science idea here is that chemical processes can cause a change in the physical properties of substances. Students need to understand that chemical reactions result in different products than were originally used. If students can understand that chemical reactions can cause a change in one substance, they should be able to say why, for example, acid rain causes corrosion of various substances, given information about the chemistry of the substances.
Another phenomenon causal model could explain	How did acid rain cause damage to this statue at the top of this table?

	Biology example 
Topic found in text	Inheritance from sexual reproduction
Anchoring event	Teacher brings in pictures of a litter of puppies. The students compare and contrast their physical features with the parents' physical features. Students hypothesize why they look similar but not exactly like their parents.
Causal story (explanatory model)	Since the DNA from the egg and the DNA from the sperm combine together to form new chromosomes, the new DNA includes a combination of genes from both the mother and father dog. Genes are comprised of different **alleles**, and each allele can be either **dominant** or **recessive**. If a physical feature is determined by a dominant allele, the gene only needs to have 1 dominant allele for the trait to be displayed. If a physical feature is determined by recessive alleles, the gene must have 2 recessive alleles for the trait to be displayed. Each individual sperm and egg carries a different and random combination of alleles. When the zygote is formed, the alleles combine to form new genes, which will determine the physical characteristics of the offspring, depending on the combination of dominant and recessive alleles from the sperm and the egg.
What you really want students to understand	Parents' alleles, which form genes, are randomly combined together when sperm and egg combine to make a puppy. Therefore, the puppy will have a different, but similar, combination of alleles as their parents. Students need to understand that each sex cell has a random combination of alleles, and that different combinations of sex cells would result in different combinations of alleles, and hence, different physical characteristics. If students know that genes, made of alleles, are passed on to offspring by each parent, and that each offspring can look different, students should be able to explain, for example, why a litter of puppies can look drastically different.
Another phenomenon causal model could explain	The teacher can show students pictures of fraternal and identical twins, asking why there are some pairs that are exactly the same (apparently) and others are quite different.

Anchoring events always have conceptual content

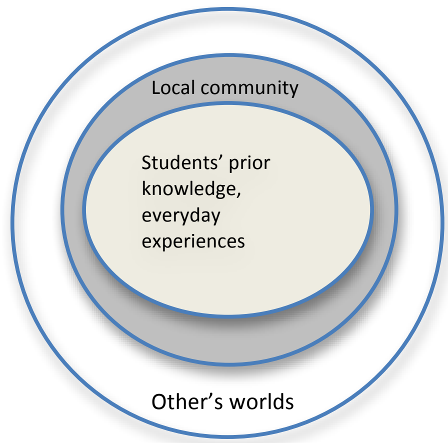
Because anchoring events are always paired with their explanatory models, it means that there should always be some conceptual content involved with the event or process—that is, something to explain. This means that the following ***do not count*** as anchoring events:

- practices such as experimentation, developing hypotheses, or evidence-based arguments
- safety in the classroom
- learning how to calculate things like molarities, how much force is needed to move an object, or where the epicenter of an earthquake is located
- creating and interpreting graphs
- using conceptual tools like Punnett Squares, vector diagrams, or half-life tables
- building technological solutions to everyday problems

We are *not* saying that these ideas are unimportant, rather we are saying that ideas like methods of gathering data, lab safety, or using equations should always be *taught in the context of some larger "big ideas" with conceptual content*. All other ideas support the development of explanations for the anchoring event.

Making anchoring events relevant

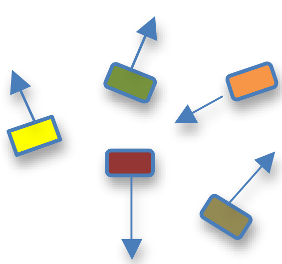
Anchoring events not only need to be important scientifically, but whenever possible, it helps to make these events or situations relatable to students' interests as well. This ensures that students are motivated to learn and have the best opportunity to capitalize on their background knowledge and everyday experiences. There are three ways to think about relevance to students' lives. Picture a dart board and reference the diagram below. The most relevant context for study would be some aspect of most students' lived experiences (i.e. relating to students' home, school, or peer culture). The second most relevant context is one's local context (i.e. relating to local community or physical geography or the history of a region where students' live). The third most relevant context may not currently be connected to students' worlds but it could be important to their interactions beyond school. All three contexts are important and could be a part of a unit.

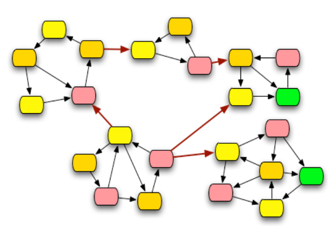


Starting to work with anchoring events

When you start working on anchoring events, you'll reach the limit of your own subject matter understanding very quickly. You should begin looking at various resources on the Web or in texts to expand what you know about the topic. As professionals we can never assume that we know enough about the subject. It is important also to work with your colleagues, asking them how they understand the explanations, models, and other ideas related to the topic in the curriculum.

One habit of mind that all great teachers have is that they take the opportunity to test and deepen their own content knowledge on a regular basis. They think of big ideas as the focus of what and how they plan, teach, and assess; and they use anchoring events to give those big science ideas relevant context and meaningful connections to one another.



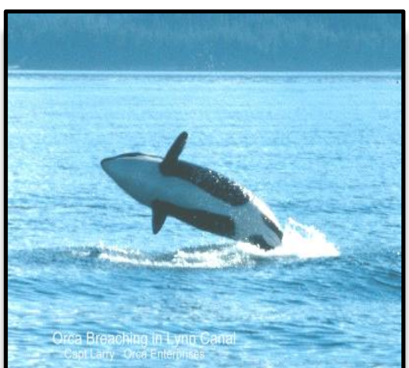


Research on how beginning teachers plan instruction clearly shows the importance of recognizing big ideas in science. In short, being able to identify anchoring events and their explanatory models is a fundamental skill for teachers. Anchoring events allow students to connect big science ideas to one another and give those ideas context rather than learning isolated lists of facts.

Final examples of successful anchoring events

Here we leave you with seven examples of complex phenomena that have anchored units of instruction successfully in science classrooms. We provide the original science topic, the event, and the essential question the teacher posed (or students proposed).

Topic from curriculum: Gas Laws
Anchoring event: Railroad tanker car implodes after being steam cleaned
Essential question: Where did the energy come from to make this steel car collapse on itself?

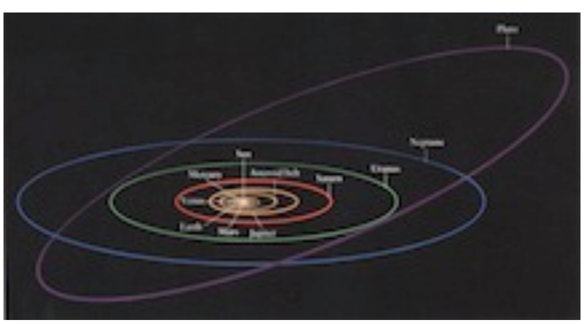


Topic from curriculum: Ecosystems
Anchoring event: Orca population declines in Puget Sound
Essential question: What is out of whack in this aquatic ecosystem?

Topic from curriculum: Homeostasis in human body systems
Anchoring event: These are comparative cases—a female ultra-marathoner and a female with bulimia, how their bodies respond to stress over time
Essential question: How can a woman who is a “picture of athletic health” and a woman who is a “picture of disease” experience the same responses to physical stress over time?

Topic from curriculum: Force and motion
Anchoring event: Boy runs up to wall and does a back flip, lands on feet
Essential question: How can he do this, what is required?

Topic from curriculum: Sound as energy
Anchoring event: Blind young men are able to echo-locate around objects
Essential question: How can these boys "see" if they are blind?



Topic from curriculum: Solar system
Anchoring event: Pluto's erratic orbit
Essential question: How does gravity shape the bodies and the movements of these bodies our solar system?