Combustion of Rocket Propellants Playlist Storyline Outline

Playlist Driving Question: How did the Ariane 5 rocket launch and deliver the JWST to Lagrange 2?

4 Lessons - 7, 50-minute class periods

Lesson Question	Phenomena/LLPE	Lesson Snapshot and What Students Will Figure Out
L1. How did the Ariane 5 rocket launch and deliver the JWST to Lagrange 2? Time: 2, 50-minute class periods	An Ariane 5 rocket launched with a payload of the James Webb Space Telescope on December 25th, 2021 at 9:20 a.m. local time in French Guiana. The James Webb Space Telescope (JWST) arrived at the second Sun-Earth Lagrange point, or L2, on January 24, 2022. The telescope entered a halo orbit around L2 on that date. Ask questions about the launch and orbit of the JWST to begin developing a model explaining the rocket system at different scales and how chemical reactions involving solid and liquid propellants generate thrust.	**Lesson Snapshot** High school students, as scientists, will apply middle school ideas about Chemical Reactions and Forces and Motion to answer the driving question: How did the Ariane 5 rocket launch and deliver the JWST to Lagrange 2? The lesson begins with students sharing their background knowledge of the James Webb Space Telescope (JWST) and the information it provides. Next, students watch a video of the rocket carrying the James Webb Space Telescope (JWST) being launched into space and generate questions about the phenomenon. Students consider related phenomena and how they can investigate questions about rocket fuel. Next, they evaluate information about the Ariane 5 + JWST system and generate additional questions about how the JWST was launched into space. Finally, students develop an initial model explaining how the JWST was delivered to L2 using their ideas about chemical reactions, energy, and forces. **What Students Will Figure Out** ● Make observations and ask questions about the launch of the James Webb Space Telescope. ● Ask questions about the launch of the JWST and how they launched a heavy object into space.
Navigation: *We know that the solid propellant generated a large enough force (thrust) to lift the rocket off the ground. However, it seems like we have many questions about the different types of propellant, how each propellant generates the "right" amount of thrust, and how the JWST got to L2. Let's start with the launch. There must be a large force (thrust) generated to get the Ariane 5+ JWST system into space. How did the solid propellant generate this thrust?"*		

L2. How do propellants generate thrust? Time: 5, 50-minute class periods	When the solid propellant of a model rocket burns it releases more energy to the surroundings than was used to light the engine. Develop a model at different scales to explain how the bonds broken and formed during a chemical reaction affect the total change in energy in the system and a reaction's classification as exothermic or endothermic. Develop a model to illustrate breaking and making connections between atoms using magnets and use this model to illustrate and/or predict the relationships between rearrangements of atoms in chemical reactions and changes in energy.	**Lesson Snapshot** High school students, as scientists, investigate what happens at the macroscopic and atomic scale of chemical reactions to answer questions that students have about generating thrust. Students launch a model rocket and see a slow-motion video to observe the fuel burning. Next, they plan a simulation using magnets to model changes in energy that occur when connections between atoms (bonds) are broken or formed. **What Students Will Figure Out** ● Burning is a chemical reaction in which matter's atoms rearrange to make new substances with different properties. ● Based on what the speed changes we observed, breaking bonds seems to require energy IN, and making bonds appears to result in energy OUT. ● Our models of bond making and breaking show that particles slow down as bonds are broken and they move away from each other, and speed up as they move toward each other when bonds are made. ● The total change in energy in the system requires us to look at both the bonds broken and formed. If it took more energy to break bonds than was released when bonds were made, then the reaction was endothermic. If more energy was released than was required to break bonds then the reaction was exothermic- it released energy.
Navigation: Invite students to plan design specifications for a computer simulation that could be used to address the gaps in their current explanation and the potential misrepresentations from the magnet marble system. Ask students to record these specifications in the table on the last page of the Student Activity Sheet packet and let them know they will continue their investigation in the next lesson. **Suggested Prompts** What materials would you need to represent from our marble track experiments in order to simulate both bond making and bond breaking? What kind of interactions between parts of the system would you want to be able to amplify or remove? What kind of measurement tools would you want to build into the system to help us understand more about the amount of energy that is being transferred?		
L3. How can we track the flow of energy when propellant is burned?	When the solid propellant of a model rocket burns it releases more energy to the surroundings	**Lesson Snapshot** High school students, as scientists, build and apply ideas about chemical reactions to answer the driving question: How can we track the flow of energy when propellant is burned? Students use NetLogo and magnetic marble models of bond making and bond breaking to investigate particle speed. Students observe that particles slow down as bonds are broken and the particles move away from each other.

Time: 3, 50-minute class periods	than was used to light the engine.	Students also observe that particles speed up as they move toward each other to form bonds. Students figure out that whether a chemical reaction results in a net increase or decrease in energy depends on the difference between the energy used to break bonds and the energy released when new bonds are made. **What Students Will Figure Out:** ● There's an average or typical amount of energy associated with breaking/making a given bond, which varies depending on the length of the bond (a result of atoms' arranging so that attractive and repulsive forces between atoms find a 'balance point') ● Bonds with shorter lengths tend to be stronger and more stable than bonds with longer lengths, and atoms rearrange in chemical reactions in order to form these more stable bonds.
Navigation: When we return to class, we will use what we figured out here to revise our models, create our class consensus model, and then see if we can use the consensus model to explain the launch of the Ariane 5 rocket.		
L4.How did the solid and liquid propellants generate the right amount of thrust for each phase of the Ariane 5 + JWST system's flight path? Time: 2, 50-minute class periods	An Ariane 5 rocket launched with a payload of the James Webb Space Telescope on December 25th, 2021 at 9:20 a.m. local time in French Guiana. The James Webb Space Telescope (JWST) arrived at the second Sun-Earth Lagrange point, or L2, on January 24, 2022. The telescope entered a halo orbit around L2 on that date. Revise a model based on evidence to illustrate and predict the relationships between particle position and energy and stability *of a bond* Develop a model at the atomic and macroscopic scales that explains why different types of propellants release different amounts of energy during	**Lesson Snapshot** High school students, as scientists, will apply ideas about chemical reactions and forces and motion to answer the driving question: How did the solid and liquid propellants generate the right amount of thrust for each phase of the Ariane 5 + JWST system's flight path? Students begin by summarizing the patterns they have observed related to chemical reactions, energy, and forces and consider how they can apply this understanding to the launch of the JWST. Students identify the need for additional information about the JWST+Ariane 5 system and the solid and liquid propellants used to generate thrust. Next, students evaluate information about solid and liquid propellants and generate a "Gotta Have It Checklist" for a model explaining how the Ariane 5 rocket launched and delivered the JWST to Lagrange 2. Finally, students use what they have learned throughout this playlist to write an explanation of how the Ariane 5 rocket launched and delivered the JWST to Lagrange 2. Students return to their initial Driving Question Board to determine which of the questions they had can now be answered. **What Students Will Figure Out:** ● Each phase of the Ariane 5 + JWST system's flight path has different thrust needs based on the total mass of the system, atmospheric resistance, and gravity. ● During combustion, new chemical substances are created from a chemical reaction involving the fuel and the oxidizer. ● The fuel reacts with the oxidizer and releases energy through the formation of strong bonds. ● Solid Propellants have benefits and tradeoffs ○ Solid propellants contain both fuel and oxidizer in a single compact package. They burn quickly, producing a large volume of gas, which generates substantial thrust in a short amount of time. ○ Once combustion starts, it proceeds until all the solid propellant is exhausted. So it is not easy to throttle or adjust the amount of thrust generated by solid propellants mid-flight.

	combustion. Compare, integrate, and evaluate information about the Ariane 5 + JWST system as well as chemical reaction patterns at the macroscopic and atomic scale to explain how the solid and liquid propellants generated the right amount of thrust for each phase of the system's flight path.	● Liquid Propellants have benefits and tradeoffs ○ The liquid fuel and oxidizer are kept in separate chambers. When thrust is needed in Phase 2, specific amounts of each can be sent to the combustion chamber based on how much you open the valves. This affects the amount of energy released, which affects the thrust generated. ○ If the reaction needs to be stopped, the liquid oxygen pumps can be turned off, the reaction will stop because it requires oxygen. ○ The ability to throttle or adjust the thrust generated helps ensure the rocket doesn't go past the JWST delivery point.