7. Fuel Properties: The Campfire Challenge

Lesson Overview: In this activity, students explore how different properties of fuels affect fire behavior – especially how hard it is to ignite fuels, how long they are likely to burn, and how completely they consume the fuels available. Students consider various combinations of fuels ("fuel recipes"), predict how they will burn, then test their hypotheses. Then students demonstrate what they have learned in discussion and in writing.

Subjects: Science, Health and Safety, and Speaking/Listening
Duration: Two to three half-hour sessions
Group size: Teams of 3-4
Setting: Outdoors or laboratory with good ventilation
Vocabulary: *duff, fuel arrangement, fuel load, fuel moisture*

Lesson Goal: Increase students' understanding of properties of wildland fuels and how they affect fire spread, fire duration, and burn completeness.

Objectives:

- Students can arrange specific fuels in a way that will maximize their ignitability, the fire's duration, and the completeness of the burn.
- Students can discuss the ignition and burning of various combinations of wildland fuels in relation to 4 properties: amount, size, moisture, and spatial arrangement.

Standards:		**6th**	**7th**	**8th**
CCSS	Reading Informational Text	1, 2, 4, 7, 10	1, 2, 4, 10	1, 2, 4, 10
	Writing	2, 4, 7, 10	2, 4, 7, 10	2, 4, 7, 10
	Speaking/Listening	1, 2, 4, 6	1, 2, 4, 6	1, 2, 4, 6
	Language	1, 2, 3, 4, 6	1, 2, 3, 4, 6	1, 2, 3, 4, 6
	Reading Standards Science/Tech	1, 2, 3, 4, 7, 10	1, 2, 3, 4, 6	1, 2, 3, 4, 6
	Math	MP.4	MP.4	MP.4
NGSS	Matter and Its Interactions	PS1.A, ETS1.B		
	Earth's Systems	ESS2.D		
	Earth and Human Activity	ESS3.A, ESS3.B, ESS3.C		
	Engineering Design	ETS1.B		
EEEGL	Strand 1	A, B, C, E, F, G		

Teacher Background: Anyone who has built a campfire knows that you have to choose your fuels wisely and arrange them carefully. Four fuel properties influence fire behavior:

amount (known as fuel load or loading),
size,
moisture content, and
spatial arrangement.

These properties determine how the fuels are heated and how much oxygen contacts them, and thus how quickly they will ignite, how long they will burn, and how much fuel will be consumed. Information useful for your discussion is given below, with connections to the Fire Triangle in **bold print.**

1. How much fuel is there? All other things being equal, the more **fuel** you have, the longer your fire can burn and the more **heat** it can produce… if you can get the fuels to ignite.
2. What sizes are the fuels?
   - The smaller the fuel particles, the more easily **heat** can engulf them and raise their energy to ignition temperature. Also, the smaller the particles, the more **oxygen** available to their surface for burning. Example: Consider the challenge of igniting a big, dead log versus a dead pine needle. Small pieces are usually easiest to ignite (if they are dry, of course) because even a small **heat** plume can surround them and heat them up fast. Because they are small, they burn up quickly.
   - Large fuel particles tend to burn slowly because it takes time for the outside surface to burn away, exposing a new layer of fuel to **heat** and **oxygen**. If there isn't enough heat to sustain combustion, large particles will not burn completely.
3. How moist are the fuels? The drier the fuels, the less **heat** needed to dry them out, so the more easily they will ignite and the more completely they will burn. Moisture makes fuels hard to ignite, makes them burn slowly, and creates more smoke because they burn less efficiently. This is because incoming **heat** must remove the moisture before the particle can be heated to ignition temperature.
4. How are the fuels arranged?
   - How "fluffy" are the fuels? The fluffiness of fuels determines how much **oxygen** is available for combustion and whether **heat** is "trapped" in the complex of fuels rather than "escaping" into the open air. An important skill in building a campfire is to get the spatial arrangement of fuels "just right" so heat reaches the **unburned fuels** and plenty of oxygen is available among fuel particles. Fuels have to be somewhat near each other for fire to spread from one piece to another. The pieces can be too loosely packed for heat to reach from one particle to the next, making it hard for fire to spread. For example, if you crumple up 20 pieces of newspaper and scatter them across a large room, the **heat** from one burning piece will "escape" into the open air rather than heating other pieces of newspaper. Thus the fire will not spread from one piece to another. But the pieces can also be too tightly packed for **oxygen** to be available as they are heated up. For example, a tightly piled stack of newspapers is hard to start on fire and burns slowly. It may smolder for a long time or go out (leaving much of the fuel unburned), depending on the amount of heat and the availability of oxygen.

- <u>How fuels arranged vertically?</u> If easy-to-ignite fuels are placed below hard-to-ignite fuels, the rising **heat** is trapped in the complex of the fuels above and helps ignite them. We use this principle in building a campfire when we place small particles (“fine fuels” such as newspaper and kindling) near the bottom of the fuel bed and large (“coarse”) fuels above. Land owners who want to prevent crown fires notice heat’s tendency to rise too, so they make sure there are big gaps between surface fuels (grass, shrubs, small trees) and tree crowns. Heat will disperse from the fuels in these gaps and escape into the open air. If the gaps are small, the heat is trapped and combustion continues, spreading up through ladder fuels and reaching the tree crowns. Students examined this principle experimentally in **Activity M06.**

This activity investigates one aspect of the Fire Behavior Triangle directly: fuels. Indirectly, it also investigates weather (which controls the moisture of fuels) and topography (which influences the dispersal of heat).

Materials and preparation:
This activity is best done outdoors because it can be messy and smoky; however, do not do the activity outdoors on a windy day. Use a large area that is far from dry grass, bark chips, and other fuels. Have a bucket of water and a hose available, with the water turned on. Have another adult help “patrol” for safe use of matches and watch burning materials. If you do the activity indoors, use a laboratory with good ventilation (i.e., a hood).

- At least two days ahead of time, obtain enough of these dead fuels to do the activity—that is, about a dozen “handfuls” of each:
  - dead conifer needles
  - small twigs (less than 0.5 centimeter in diameter)
  - large sticks (about 2-3 centimeters in diameter)

  Spread them out in a dry place so they are uniformly dry by the time you use them.
- Make sure you have enough dry peat moss (representing duff) to do the activity. Some is usually included in the trunk.
- The day before you do the activity, remind students to dress appropriately for burning. Post and refer to the FireWorks safety poster (***M02_FireWorks_Safety_poster.pptx***).
- The day before you do the activity, collect enough green conifer needles to do the activity.
- Project ***FuelRecipesToDisplay.pdf*** or copy the ingredients for the fuel recipes onto the board (or a poster, if you plan to do the activity outdoors):

Recipe	Ingredients
1	Dead, dry conifer needles Duff Green conifer needles
2	Dead, dry conifer needles Small twigs Big sticks
3	Small twigs Duff Big sticks
4	Duff Big sticks Green conifer needles

- Set up your teacher area with:
    - The Fuel Recipe box (from the trunk – or print it yourself from here). Be sure to select the recipes labeled "M" for Middle School students.
    - 5 boxes or grocery bags containing fuels (dead, dry conifer needles; small twigs (<0.5 cm diameter); dry peat moss, which serves as duff; big sticks (2-3 cm diameter); green needles). (Some of these fuels may be available in the trunk.) Label the bags. You can use the tie-on labels from the trunk.
    - Fire extinguisher.
    - 2 spray bottles (from the trunk), filled with water, and additional water (bucket, charged hose, etc.) to ensure you can easily put a fire out.

- Set up 4 student work stations on lab benches or other surface that will not be damaged by heat. Each station needs:
    - one 9" diameter aluminum pie tin with tilted edges
    - 1 match box with **7 matches**
    - 1 ashtray (from the trunk)
    - 1 pair of safety goggles (from the trunk)
    - 1 oven mitt (from the trunk)

- Have a METAL TRASH CAN WITHOUT A PLASTIC LINER on hand.

Procedures:

1. Explain: Students will work in teams to build small "campfires" using specific combinations of fuels. This is an investigation rather than a competition. The experimental questions are:
    - What kinds of fuels are easiest to ignite?
    - What kinds of fuels burn longest?
    - What kinds of fuels are most likely to burn up completely, and what kinds are likely to go out leaving some material unburned?

2. Explain what duff is: partly decomposed plant and animal matter lying on or in the soil. There can be a huge amount of duff on the ground – as under an old tree or in a peat bog that may have “organic soils” a meter deep or more. Or there can be very little duff – as in dry places where plants grow slowly. Remember from **Activity M05** that a fire burning in the duff is called a ground fire. In this experiment, dried peat moss can be used to represent duff.

3. Refer to the recipes written on the board or projected (***FuelRecipesToDisplay.pdf***). Ask students to “vote” on:

   - which will be easiest and hardest to start on fire
   - which will burn out in the shortest time and which will last longest
   - which will burn the fuels most completely and which will leave the most fuel unburned

   Record the votes on the board. These represent the class’s hypotheses.

4. Group students into 4 teams.

5. Do a safety check. The whole team is responsible for safety. If any student is injured, the team must alert the teacher and use water to put out their campfire.

6. Explain: Each team will…

   a. Draw a recipe from the Recipe Box.

   b. Collect the three ingredients on their recipe from the labeled ingredient bags. Fuels are “measured” by the “handful,” which is subjective, but the point is to use about the same amount of each fuel in a campfire.

   c. Discuss and work together to arrange the fuels. **Your goal is to make the fuels ignite as easily as possible and burn as completely as possible**. The fuels must fit inside the pie tin; they may not spill over the sides. **Your 7 matches** can be used to ignite the campfire or added into the fuel array. Obviously, at least one must be used for ignition.

   d. Have a teacher or other adult verify that you have met the requirements before ignition.

   e. After ignition, do not rearrange the fuels, but you may blow on the fire. Dispose of burned matches in the ashtray or in the campfire.

7. Have the students ignite their campfires. Monitor their progress and watch for safe practices.

8. After all teams have either burned all their fuels or used all their matches, have each team explain to the class their strategy for arranging fuels and how they might do it differently the next time. Note that some campfires may still be burning.

9. **Clean up:** Make sure all burned materials and matches are completely out before you dispose of them – that is, there is no smoke and no heat being released. Especially check large sticks and duff, which can smolder for a long time. Stir the fuels and feel for heat. Use an empty metal trash can without a plastic liner. If in doubt, dump fuels in a bucket of water and leave them there overnight before draining and putting in trash.

Assessment: The first part of the assessment is based on discussion. (OPTION A is based on informal discussion, OPTION B on highly structured discussion.) The second part of the assessment is written. **Base discussion on the following questions:**

- Were any of our hypotheses correct? Were any incorrect?
- Which recipe was easiest to start on fire? Which was hardest? Use the Fire Triangle to explain.
- Which recipe burned out quickest? Which recipe burned longest? Use the Fire Triangle to explain.
- Which recipe burned the fuels most completely? Which recipe left the most fuel unburned? Use the Fire Triangle to explain.
- How did fuel amount – i.e., loading - affect fire?
- How did fuel moisture affect fire?
- How did fuel size affect fire?
- How did the fluffiness of fuels affect fire?
- How did the vertical arrangement of fuels affect fire?

Information for guiding the discussion is in the **Teacher Background** above.

OPTION A: Unstructured. Ask: How do the results of your experiments confirm or contradict the hypotheses that the class developed (see Step 3 above)? Discussion.

OPTION B: Highly structured. Set up the following "Dynamic Socratic Circle with Brilliance Board." In this activity, students will discuss the class's hypotheses, fuel properties, heat transfer, and concepts from the Fire Triangle. Instructions:

a. Divide the class into three groups (A, B, C). Then arrange the chairs in the room to make an inner circle of chairs (enough chairs for each student in group A) and an outer circle of chairs (enough chairs for each student in group B). Have each student in group C stand by the board and be ready to write.

b. Give the individuals in the inner circle a question that they must discuss. All must contribute to the discussion. Students in the outer circle can join the conversation in the inner circle by tapping the shoulder of a student in the inner circle who has contributed. Then these two students will switch places. While groups A and B (inner and outer circle) are speaking and listening, group C at the board is writing down brilliant and important points and questions that come up during the conversation. Tell Group C that it is good to repeat points because after the discussion the class will analyze the board for trends.

c. Rotate the groups so each has had a turn at each station. When there is little left to be said or information is being repeated, change the question.

Evaluation:

1. Participation in OPTION A or OPTION B above. If you used OPTION B, use the table below for evaluation.

2. Have each student write down the specific recipe his/her team used and then use the four fuel properties (amount, size, moisture, arrangement) to explain why this recipe burned as it did (easy or hard to ignite, burning out quickly or slowly, burning completely or incompletely).

<u>Use for OPTION B</u>, Dynamic Socratic Circle with Brilliance Board				
	Excellent	**Good**	**Fair**	**Poor**
Inner Circle	Built upon peers' comments, contributed to conversation, and encouraged others to speak.	Contributed to conversation.	Did not contribute but was actively listening.	Disruptive to conversation
Outer Circle	Tapped in once a student had spoken, encouraged others to tap into the inner circle.	Student was willing to leave the inner circle when tapped out.	Did not tap in but was actively listening	Disruptive to conversation
Brilliance Board	Consistently wrote brilliant points and questions on the board.	Student was actively listening and occasionally wrote on the board.	Did not participate but was actively listening.	Disruptive written remarks.
Written explanation of recipe's success	Addressed 4 fuel properties in regard to experimental fire. Addressed ease of ignition, duration of burning, and completeness of combustion.	Addressed 3 fuel properties in regard to experimental fire. Addressed 2 of these: ease of ignition, duration of burning, completeness of combustion.	Addressed 1-2 fuel properties. Addressed 2 of these: ease of ignition, duration of burning, completeness of combustion.	Assessed 0-1 fuel property. Addressed 0-1 of these: ease of ignition, duration of burning, completeness of combustion.