8A. Fire Environment Triangle and Fire Spread: The Matchstick Forest Model (Option A)

****Note: This lesson has goals and objectives similar to those of Activity 8B, The Landscape Matchstick Model****

Lesson Overview: In this activity, students design and conduct an experiment to investigate how slope and the density of trees (or other kinds of standing fuels) affects fire spread.

Lesson Goal: Increase students' understanding of experimental methods and wildland fire spread.

Subjects: Science, Mathematics, Health and Safety, Writing, Speaking and Listening

Duration: 45-90 minutes

Group size: lab groups

Setting: Indoor laboratory or outdoors

Vocabulary: *controlled experiment, Fire Environment Triangle, slope, stand/forest stand/standing fuels, stand density, trial, treatment*

Objectives:

- Students will design a controlled experiment to investigate relationships among slope, stand density, and fire spread.
- Students will write a hypothesis, conduct an experiment, summarize results, and draw conclusions.
- Students will compare their experiment and results to those of their classmates.

Standards:		9th	10th	11th	12th
CCSS	Writing	2, 4, 6, 7, 10		2, 4, 6, 7, 10	
	Speaking/Listening	1, 2, 4, 6		1, 2, 4, 6	
	Language	1, 2, 3, 4, 6		1, 2, 3, 4, 6	
	Writing Standards Science/Tech	1, 4, 6, 7, 10		1, 4, 6, 7, 10	
NGSS	Earth's Systems	ESS2.D			
	Earth and Human Activity	ESS2.D, ESS3.A, ESS3.B, ESS3.C, ETS1.B			
EEEGL	Strand 1	A, B, C, E, F, G			

Teacher Background: In this activity, students build physical models of fuel arrays in which standing fuels are represented by individual matches. Because the models provide a graphic demonstration of the way running crown fires behave in a forest, we call it the "matchstick forest" model. However, it could represent any array of standing fuels, including shrubs with highly flammable crowns and even a dense stand of grasses.

Note that the flames in these experiments can reach 30-40 cm in height. Plan accordingly. If you choose to do the experiment outdoors, keep in mind that even the slightest breeze will dramatically affect fire spread. Outdoor experiments may illustrate mainly that fire spread is complex and often unpredictable.

Students can use their matchstick models to investigate variables that affect the spread of wildland fire (and are aspects of the Fire Environment Triangle), such as:

Slope: If a fire is burning on a hillside, the fuels above it tend to be dried and warmed by its convective heat, and the flames are quite close to the uphill fuels. They are likely to ignite very quickly. The fuels below the fire are affected very little – at least until burning materials roll downhill and ignite new fires there. Thus fires tend to spread upslope, and a fire that starts at the bottom of a hill is likely to spread faster than one that starts on a hilltop.

Fuel density and contagion: If a fire is burning in dense forest, it may spread from treetop to treetop (crown fire). In more open forests, crown fires are less likely. Here is a caveat, however: Surface fires may spread more rapidly in open than dense forests because the wind speed is usually greater in openings. Stand density has the same effect in other standing fuels, such as shrublands and thick grasslands; in all of these fuels, fire spread can be extremely rapid.

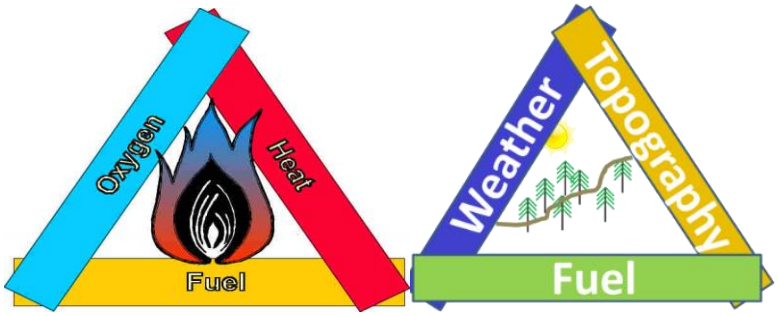
Wind: The effect of wind on fire spread is analogous to that of slope: Wind bends the flames and the heat plume so they are no longer vertical but instead lean downwind into the fuels, heating them more rapidly and increasing the rate of fire spread.

Materials and preparation:

Do this activity in a lab or outdoors. Note that even the air currents created by the lab's ventilation system will affect the experimental results, and air movement outdoors will affect them even more.

- The day before the activity, remind students to follow safety guidelines about clothing and hair when they get ready for school tomorrow. Use the ***FireWorks_Safety_poster.pptx*** in **Activity H02.**
- Get four boxes of wooden kitchen matches (not provided in the trunk).

- Display the Fire Triangle poster (left) and Fire Environment Triangle poster (right) (***FireTrianglePoster.pptx*** and ***FireEnvironmentTrianglePoster.pptx***).



- Make 1 copy/student or lab group of **Handout H08a-1**.
- Have a fully charged fire extinguisher handy.
- Have an empty METAL trash can WITHOUT A PLASTIC LINER available.
- Set up a lab bench or other safe space for each student team[1], using the following equipment:
  - 1 metal tray (i.e., cookie sheet)
  - 1 ashtray
  - 1 spray bottle, filled with water
  - 1 box of matches
  - 1 matchstick forest board
  - 1 ruler
  - A short, medium, and long bolt and 1 nut from the matchstick forest kit
  - A small nail for removing burned match stubs from the board
- Make sure each student team has a time keeping device.

Procedure:

INTRODUCTION.

1. Do a **safety checkup** with students using the FireWorks Safety poster (***FireWorks_Safety_poster.pptx*** in **Activity H02**).
2. Refer to the posters for the Fire Triangle and the Fire Environment Triangle (***FireTrianglePoster.pptx*** and ***FireEnvironmentTrianglePoster.pptx***) - or draw/ project them. Explain: We've been studying the chemistry of combustion. We used the model of the Fire Triangle, which can be applied to any fire – from a campfire to the fire in an internal combustion engine. Now we'll narrow our focus to combustion in wildlands, and we'll use a slightly different model, the Fire Environment Triangle (also known as the Fire Behavior Triangle). This model reminds fire managers and firefighters of the three things in the environment that control how wildland fires behave: **fuel, weather, and topography**.

[1] The trunk is supplied with 4 sets of equipment.

3. Explain: You will design and carry out controlled experiments to learn about the relationships between fire spread and specific variables in the Fire Environment Triangle. "Controlled" means that you will change just 1 thing about the procedure each time you repeat it (that is, in each trial), "controlling" everything else so you can find out how that one aspect of the Fire Environment Triangle, the experimental variable, affects your results.
4. Ask students for some specific aspects of the Fire Environment Triangle that affect the behavior of wildland fires. Examples:
    - **Topography:** slope steepness, aspect, position in relation to heat source, number and location of ignition points, potential for heat to escape (open slope vs. within canyon)
    - **Fuels:** arrangement (both vertical and horizontal), moisture, amount, height, density, patchiness (vs. uniform spatial arrangement)
    - **Weather:** wind direction and strength, relative humidity, temperature, precipitation amount and duration
5. Give each student or team a copy of **Handout H08a-1**.

PART 1- Discuss an example using a thought experiment.

6. Using **Handout H08a-1**, discuss how to design an experiment that investigates one aspect of fire behavior. Do a "thought experiment" using an intuitively obvious example for the experimental variable, such as snow. Go through Steps A-G in the handout, discussing how to set up a controlled experiment to investigate the relationship between snow (the experimental variable) and fire behavior.
7. In the context of the thought experiment, review these terms:
    - **Experimental variable**-the variable that they are testing by changing it from one trial to the next (e.g., snow).
    - **Treatment**- the way they change that experimental variable from one trial to the next (e.g., no snow, light snow, moderate snow, very deep snow).
    - **Trial-** an individual "run" of the experiment,
    - **Variables measured**- the measurable results from trials in the experiment. These are things that are observable and measurable about fire behavior (e.g., matches burned, burning time, flame height).

PART 2-Students design and conduct experiments to measure fire spread.

8. Explain: Student groups will design and conduct their own experiments to examine relationships between parts of the Fire Environment Triangle and fire behavior. After the experiments are complete, each group will describe their experiment and report their results so the entire class can learn how from all of the experiments.
9. Assign an experimental variable to each group. You may use the student answers from question 4 above, from the table below, or create your own.

10. Instruct students to use **Handout H08a-1** to investigate their experimental variable. Have them answer the questions A-G, then **get your approval** for their experimental design before proceeding. Suggest that they try their methods in a couple of test burns before doing the full experiment. Here are some examples of possible tables for results.

Example 1- Experimental variable: Density	Treatments	Burning time (sec)	Max flame height (cm)
	49 matches		
	37 matches		
	25 matches		
	12 matches		

Example 2- Experimental variable: Slope	Treatments	Matches burned (%)	Max flame height (cm)
	Very steep		
	Steep		
	Moderately steep		
	Flat		

Example 3- Experimental variable: Ladder fuels	Treatments	Matches burned (%)	Burning time (sec)
	No Ladder fuels (all full matches)		
	Some matches cut shorter		
	Some matches are cut to different lengths		

Example 4- Experimental variable: Ignition location	Treatments	Matches burned (%)	Burning time (sec)	Max flame height (cm)
	Ignite top row			
	Ignite outside column (start with top match, work down)			
	Ignite middle column (start with top match, work down)			
	Ignite bottom row			

11. As the groups proceed, check their experimental designs. **Emphasize that, in their design and completion of the experiment, they can change only their experimental variable while keeping all others constant.** If they don't, they won't be able to attribute their results to the experimental variable alone.
12. Monitor for safety while they conduct their experiments.
13. As the groups complete their experiments, have them prepare to project their results or have them copy their results to the board (Step H on the handout).
14. Ask each group to describe their experiment and results to the class (Step I on the handout).

Assessment: Have each student write a formal report (Step J on the handout).

Evaluation: Assess students' responses to the questions in section J using these guidelines:

Question(s)	Highly successful	Moderately successful	Unsuccessful
1-2	Hypothesis addresses question.	Hypothesis addresses question.	Hypothesis does not address question.
3	Refers to experimental results that demonstrate or contradict hypothesis.	Reports experimental results but does not interpret appropriately.	Does not address hypothesis or interpret experimental results appropriately.
4	Answer is clear and refers to Question 1.	Answer refers to Question 1.	Answer is unclear or does not refer to Question 1.
5	Student listed 2 or more questions.	Student listed 1 question.	Student listed no questions.
6	Student made at least 1 clear recommendation to each of the 3 groups.	Student made at least 1 suggestion to 1-2 groups, or suggestions were unclear.	Student either made no suggestions or made suggestion to just 1 group.
7	Student answered all 3 questions with specifics.	Student answered 1-2 questions or answers were unclear.	Student answered 1 question or none.

Handout H08A-1.

Name(s): _____

INSTRUCTIONS:

Develop your experimental plan (this page).
Get the teacher's approval to proceed (bottom of this page).
Carry out your experiment.
Share your results (next page).
Write and submit your report (next page).

OUR EXPERIMENTAL PLAN:

A. Our experimental question: What is the effect of _____ on fire behavior?

B. Our hypothesis:

C. Our *experimental variable,* the one thing that we will change from one trial to the next (take this from "A" above):

D. Our *treatments*, the way we change our experimental variable from one trial to the next:

E. Our *controlled conditions*, things that we will not change from one trial to the next:

F. The things we will observe and measure – which will be our experimental *results*:

G. Our table for recording record data from each trial burn.

TEACHER'S APPROVAL: Teacher's initials approving our experimental design: _____

SHARING EXPERIMENTAL RESULTS

H. When you have finished your experiment, project your results or copy them onto the board.

I. Describe your experiment and results to the class. Indicate if there are any changes that you would make if you were to redo you experiment. Create two questions to ask the class about the data you collected. These questions should make your peers think critically about your experiment.

WRITE AND SUBMIT FINAL REPORT

J. **Formal Report:**

1. What is your question about fire? What are you trying to find out about fire behavior?
2. What is your hypothesis?
3. Do you accept or reject your hypothesis? Show how your results justify your answer.
4. Did your results help answer your question about fire? If so, how?
5. Did any new experimental questions emerge during your experiment? If so, what are they?
6. Based on your results, what practices would you recommend to (a) firefighters, (b) people with homes in forests, and (c) wildland managers?
7. (a) What are some limitations of the matchstick forest model? (b) What "real-world" influences on fire spread could not be tested with this model? (c) Could you revise the model or develop a different model to test them?

Handout H08A-1. Example Answer Key – using density as example of the experimental variable

Actual answers will vary, depending on students' experimental variables and designs.

A. Our experimental question: What is the effect of density on fire spread?

B. Our hypothesis:

If the matchstick boards are densely packed, then fire will spread more quickly and more matchstick tops will burn than if the fuels are sparse.

C. Our *experimental variable,* the one thing that we will change from one trial to the next.

Stand density (number of matchsticks on the board).

D. Our treatments, the way we change our experimental variable from one trial to the next:

Treatment 1 (high density): 49 matches

Treatment 2 (medium density): 37 matches

Treatment 3 (low density): 25 matches

Treatment 4 (least dense): 12 matches

E. Our *controlled conditions*, things that we will not change from one trial to the next:

Ignition point, slope, moisture, matchstick height, wind, etc.

F. The things (variables) we will observe and measure – which become our experimental *results*:

Maximum flame height, start time, stop time (or duration – using a stopwatch), number of match tips burned.

G. This is our table for recording data from each burn: **Suggest that students do a couple of preliminary trials to fine-tune their measuring procedures and data table. You may ask that each team have you review these before they begin the full experiment.**

	Least dense (12 matches)	Low density (25 matches)	Medium density (37 matches)	High density (49 matches)
Max. flame Height (cm)				
Start time				
End time				
Duration (sec)				
Number of matches burned				

H. When you have finished your experiment, project your results or copy them onto the board.

I. Describe your experiment and results to the class. Indicate if there are any changes that you would make if you were to redo you experiment. Create two questions to ask the class about the data you collected. These questions should make your peers think critically about your experiment.

J. **Formal Report:**

1. What is your question about fire? That is, what are you trying to find out about fire behavior?
   How does stand density affect fire behavior?

2. What is your hypothesis?
   The denser the "forest," the faster fire will spread, the higher the flames will be, and the more match tips will be consumed.

3. Do you accept or reject your hypothesis? Show how your results justify your answer.
   I accept my hypothesis because, as predicted, the model forest with only a few matches burned more slowly, had shorter flames, and burned fewer matches than the forest with lots more matches.

4. Did your results help answer your question about fire? If so, how?
   Yes, my results showed three ways in which stand density affects fire behavior.

5. Did any new experimental questions emerge during your experiment? If so, what are they?
   What if there's wind? What if the trees are different heights? How do real trees differ from matches?

6. Based on your results, what practices would you recommend to (a) firefighters, (b) people with homes in forests, and (c) wildland managers?

   (a) Firefighters should use extreme caution when fires are burning in dense forests. They may not be able to work safely on these fires when it is very dry or hot, or if the wind is strong. (In fact, firefighters are cautioned against "direct attack" when flame lengths are high. That is, they cannot work right at the edge of the fire, especially not at the leading edge. Instead, they might use other techniques such as setting backfires or using water drops from aircraft. (National Wildfire Coordinating Group. 2014. Incident response pocket guide. PMS 461. National Wildfire Coordinating Group. 112 p.))

   (b) People with homes in the forest (especially dense forest) should clear an area around their homes and perhaps thin the forest nearby. (It is recommended that home owners reduce fuels for at least 200 feet from their house (National Fire Protection Association, Firewise Communities. 2016. The basics of defensible space and the "home ignition

zone. National Fire Protection Association. Available: https://www.nfpa.org/Public-Education/By-topic/Wildfire/Preparing-homes-for-wildfire)).

(c) Wildland managers could consider thinning forests or creating wide fuel breaks to reduce flame heights and slow the spread of fire in dense forests that are near homes or other valuable resources.

7. (a) What are some limitations of the matchstick forest model? (b) What "real-world" influences on fire spread could not be tested with this model? (c) Could you revise the model or develop a different model to test them?

(a) The model doesn't include surface fuels. The model tree crowns are much easier to ignite than actual tree crowns. Trees are distributed uniformly in the model, unlike in real forests. The topography is completely uniform – no gullies or ridges. Trees tilt with the slope. The board is very small, whereas real forests can extend for many miles…

(b) Real wildland fuels were not tested. Uneven topography could not be tested. Large-scale fire spread was not tested…

(c) I would revise the model to use a larger board, perhaps add uneven terrain. I would use real wildland fuels. I would add surface fuels…