5. How Do Wildland Fires Spread? The Matchstick Forest Model

Lesson Overview: In this activity, students use a physical model to learn how slope and the density of trees (or other kinds of standing fuels) affect fire spread.

Lesson Goal: Increase students' understanding of wildland fire spread in forests and other kinds of standing fuels.

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

Duration: Two to three half-hour sessions

Group size: Whole class, working in 4 teams to prepare demonstrations

Setting: Indoor laboratory or outdoors

Vocabulary: *backing fire, crown fire, density/stand density, experimental variable, ground fire, head fire, slope, stand, standing fuels, surface fire, topography*

Objectives:

- Students plan experiments and make observations to investigate the effect of one variable at a time on fire spread.
- Students use the Fire Triangle (from **Unit II**) to explain how slope and density of trees (or other standing fuels) affect fire spread.

Standards:		**6th**	**7th**	**8th**
CCSS	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
	Writing Standards Science/Tech	1, 2, 4, 7, 10	1, 2, 4, 7, 10	1, 2, 4, 7, 10
	Math	MP.4	MP.4	MP.4
NGSS	Matter and Its Interactions	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: Now that students understand the basic principles of combustion as described by the Fire Triangle, they will apply that understanding to how fires behave in wildlands. In this activity, they will use a physical model called the "matchstick forest" to investigate two of sides of the Fire Environment Triangle (also called Fire Behavior Triangle):

- slope (a feature of topography)
- the density of trees or other standing fuels

In the matchstick forest model, standing fuels are represented by single matches. For safety's sake, it is important to note that the flames in this experiment can reach a foot or more in height. Plan accordingly. If you do the burning outdoors, even the slightest breeze will dramatically affect fire spread. In this case, the experiments may illustrate mainly that fire spread is complex and often unpredictable. You can investigate the effects of wind on fire behavior in Activity M08.

The activity consists of 2 experiment sets. Experiment Set 1 investigates the effect of slope on fire behavior. We suggest you discuss the experimental design, hypotheses, and measurements as a class while you do Set 1, to prepare students for doing the same thing on their own in Experiment Set 2. Set 2 investigates the effect of stand density (the spatial arrangement of trees or other standing fuels).

While the activity is especially well suited to studying tree density, the principles apply to any vertical fuel array – tall shrubs or grasses, for example. Here are explanations for the fire behavior that you may see in the experiments:

> **Experiment 1.** 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 these fuels, while the fuels below are affected very little – at least until burning materials roll downhill and ignite new fires below. 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.
>
> **Experiment 2.** 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 stands because the wind speed is usually greater in openings.

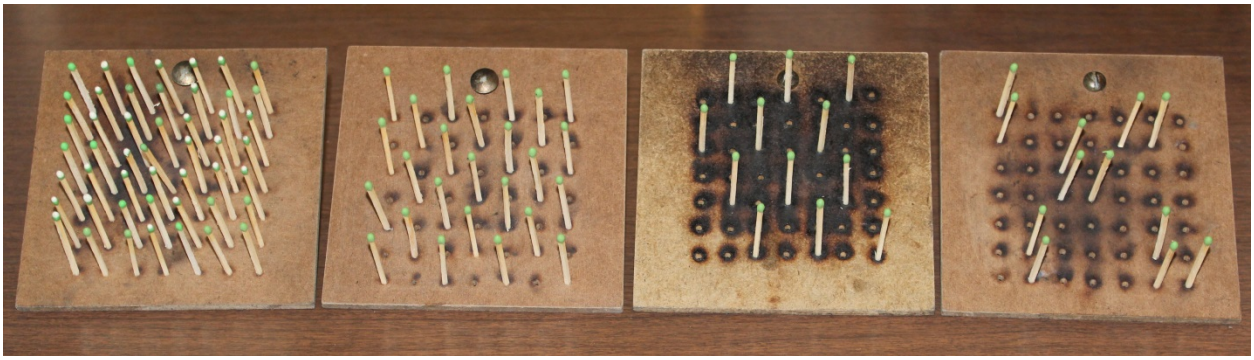
Table M05-1: describes the experiments included in this activity. Use Experiment Set 1 to learn about the effect of slope. Then use either Experiment Set 2A or 2B to learn about the effect of stand density. Students' directions for each experiment set, which you can project as needed, are in ***M05_MatchstickForestExperimentDesigns.pptx***.

- Use Experiment Set 2A if you want students to learn about stand density as it applies to ALL kinds of plant communities subject to fire (ANY kind of forest, woodland, shrubland, or even grassland, the world over).
- Use Experiment Set 2B if you want students to learn about stand density as it applies to specific kinds of fire histories in your geographic area. In this version of FireWorks, this demonstration covers dense lodgepole pine forests, open ponderosa pine forests, and high-elevation whitebark pine forests.

Table M05-1: Experiments for investigating the effect of slope and density of standing fuels on fire spread.

Experiment Set & Experimental Question	Potential hypotheses & explanations	Experimental setup
Experiment Set 1. How does slope affect fire spread?	Fires moving uphill tend to spread faster and burn more completely than fires moving downhill. **Explanation:** As heat moves upward by convection, it dries and heats the fuels above. In addition, flames are closer to uphill fuels than to those on level ground or downslope.	Use 4 boards (4 experiments). Use 49 matches/board. Lay 1 board flat. Use a short bolt to model a forest on a moderate slope. Use long bolts to model 2 forests on steep slopes. Ignite an entire row of matches along the edge of each board: • On flat board, ignite one side. • On the moderately steep board, ignite from the bottom row (head fire) • On one steep board, ignite from the top row (backing fire). • On one steep board, ignite one row from bottom (head fire).
Use EITHER Experiment Set 2A or 2B.		
Experiment Set 2A. How does stand density affect fire spread?	Fires generally spread faster and combustion is more complete in dense standing fuels than in sparse fuels. Thus crown fire is more likely in dense than sparse forests. Clumping of fuels also affects potential for crown fire. **Explanation:** In a dense stand, heat and flames are more likely to reach nearby fuels.	Use long bolts for all models. Use the following matchstick densities/board (Figure M05-1): • 49 matches • 25 matches (50%), distributed evenly • 12 matches (25%), distributed evenly • 12 matches (25%) in clusters Ignite all boards from the bottom row.
Experiment Set 2B. How does stand density resulting from different fire histories affect fire spread?	Fires generally spread faster and combustion is more complete in dense forest stands, such as lodgepole pine stands that have not burned in a long time, than in more open forests, such as ponderosa pine stands that have been burned frequently. When trees occur in clusters, as in whitebark pine stands, an entire cluster may burn but the fire may not spread to others clusters. **Explanation:** Heat and flames are more likely to reach fuels	Use long bolts (to create steep slopes) for all models. A single board represents about 1/40 hectare, an area about 16 meters on a side. Use the following matchstick densities/board: • 49 matches to represent dense lodgepole pine stands that originated 50-100 years ago after a crown fire • 49 matches, some short and some tall, to represent a stand with a mixture of pines and firs that has not had a fire in 100 years or more • 5 matches, spaced far apart, to represent open-grown ponderosa pine stands that have experienced frequent fires

	that are close together, drying them out and igniting them. Frequent fires tend to reduce stand density by killing small trees and those of fire-sensitive species. Frequent fires also reduce fuels, both horizontally and vertically, so fires are not likely to be severe enough to kill most of the trees.	• 13 matches, distributed in clusters, to represent high-elevation whitebark pine stands Ignite all boards from the bottom row.



Setup of matches for Experiment Set 2A.

Materials and preparation:

Choose your location carefully. If you burn indoors, be aware that the experiments can produce flames 30-40 centimeters long. Can you do this safely in your classroom and without setting off a smoke alarm? Can you take your students to a lab where it will be safer? If you burn outdoors, be prepared for variable results, since even very subtle breezes will change the fire spread pattern and may overwhelm the effects of slope and stand density. In windy outdoor conditions, consider using a fireplace lighter and having students hold poster board around the matchstick stand to protect it from wind.

Have students work in teams to <u>set up</u> the matchstick forests for this activity, then <u>*ignite*</u> *them one at a time* so all students can observe all fires. You could also have student volunteers set up the matchstick forests ahead of the class period.

- The day before doing this activity, display the FireWorks Safety poster (***M02_FireWorks_Safety_poster.pptx*** from **Activity M02**) and remind students to follow safety guidelines about clothing and hair when they get ready for school tomorrow.

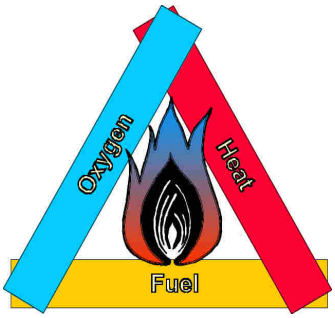
FireWorks Safety

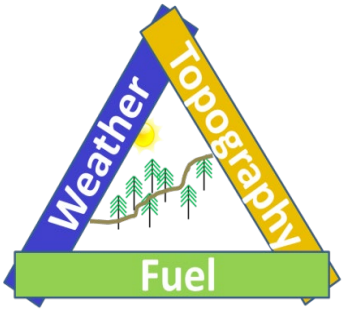
When you do experiments with fire…

1. **Wear cotton clothing. No synthetic pants, soccer shorts, etc.**
2. **Wear closed-toed shoes. No sandals or flipflops.**
3. **Tie back loose sleeves.**
4. **Tie back loose hair.**
5. **Make sure a fire extinguisher is close. Make sure it is charged. Know how to use it.**
6. **Make sure spray bottles are close and filled with water.**
7. **Wear safety goggles when burning.**
8. ***Never* lean over a fire.**
9. **Extinguish burned materials with water before putting them in the trash. *Fire is not out if there is any smoke or heat coming from the fuels.***
10. **If a fire starts on you, stop, drop, and roll.**

<u>Use fire ONLY if a responsible adult is working with you.</u>

- Get a package of hair bands to keep in your pocket so you can give them out as needed.
- Get four boxes of wooden kitchen matches (not provided in the trunk).
- Display the Fire Triangle poster (***Fire TrianglePoster.pdf***) and the Fire Environment Triangle poster (***M05_FireEnvironmentTriangle.pdf***)





- Download ***M05_MatchstickForestExperimentDesigns.pptx*.**
- Set up the teacher's lab bench with this equipment:
  - Fire extinguisher, fully charged
  - Two spray bottles, filled with water
- Set up a lab bench or other safe space for each student team, using the following equipment (available in the trunk):
  - 1 metal tray (i.e., cookie sheet)
  - 1 ashtray
  - 1 box of matches
  - 1 matchstick forest board
  - 1 ruler
  - A short and long bolt and 1 nut from the matchstick forest kit
  - 1 pair safety goggles
  - 1 nail (for removing burned matches from boards)
- 1 copy of **Handout M05-1** for each student
- Have a <u>metal trash can without a plastic liner</u> available in the room.

Procedure:

1. Do a **safety checkup** with students using the FireWorks Safety poster (***M02_FireWorks_Safety_poster.pptx*** from **Activity M02**).

2. Explain, using both the Fire Triangle poster and the Fire Environment Triangle poster: You already know about the Fire Triangle, which describes the basic nature of combustion. Wildland fire professionals use the Fire Triangle to understand combustion. Fire professionals also use a second model, the Fire <u>Environment</u> Triangle (also called the Fire Behavior Triangle). This triangle describes the complexities of fire when it burns in wildland fuels – which are a lot messier than the tidy matches and candles that we've been studying. The Fire Environment Triangle reminds managers of three things that control how fires behave in wildlands: fuel, weather, and topography. In this activity, we'll study the effects of slope (one facet of topography) and different arrangements of standing fuels – that is, patches ("stands") of trees or other vegetation, such as shrubs that have long stems and thick crowns and even grasses. In these experiments, we'll try to <u>not</u> change anything about weather conditions, although we may not be able to control that completely.

3. Discuss experimental design with the class, including the idea that you change only one variable at a time to learn its effects. An experimental variable is whatever you're investigating – in this case, slope (Experiment Set 1) or stand density (Experiment Set 2).

4. Hand out copies of **Handout M05-1**. Explain: We'll do this first set of experiments together and talk through the answers (not writing them down). Then you'll do the second set of experiments on your own and use the handout. Read through it with me, but don't write on it now.

5. Show students your materials, especially the matches and the matchstick model (masonite board, nuts and bolts). Ask: Can you see how we could use these materials as a model of a forest? Brainstorm. Here is the way the materials are used in this activity: The board represents the ground surface. Individual matches represent individual trees or other standing fuels. Match tips represent tree crowns.

6. Ask: What aspects of fire behavior can we try to investigate with this model? Brainstorm. Here are some possibilities: Slope, location of fire origin (from the side, bottom, top), extent of ignition (1 match on fire, a group of matches, a whole row of matches).

7. The model is most often used to investigate crown fires, that is, fires that burn through the tops of trees or shrubs, as opposed fires that burn on the forest floor (called surface fires) or in the organic material of the soil (called ground fires). We don't think of grass fires as crown fires, but the matchstick forest results can be applied to these standing fuels too.

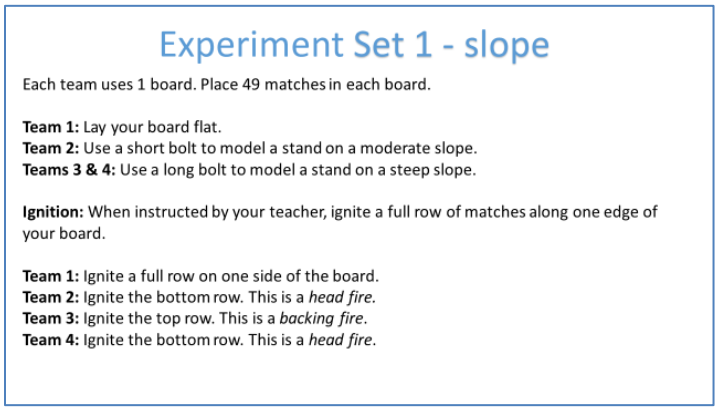
8. Read **Question 1** on the handout. Explain: In the upcoming demonstration, we'll investigate the effect of slope on fire spread. When you do your individual experiments, you'll investigate at least 1 other variable.

9. Read **Question 2**. Ask students for hypotheses about how slope will affect fire spread. Write them on the board.

10. Read **Question 3**: What observations do we need to test the hypothesis? We suggest:

    - Time of ignition and time when fire goes out (used to calculate fire duration) or fire duration measured by stopwatch/timer
    - Number of match tips burned
    - Approximate maximum flame length (estimated at safe distance from flames)

11. Project **Slide 1** in ***M05_MatchstickForestExperimentDesigns.pptx***. Assign one part of the experiment to each student team. Explain: We'll ignite the matchstick forests one at a time, so the whole class can observe and record data from all 4 fires.



12. On the board, make 4 blocks for recording data, as shown below. Explain: This is the way you'll report data on your hand out during the second experiment. For this part of the activity, we'll make observations and record data from each team on the board:

Question 4:	**Team 1**	**Team 2**	**Team 3**	**Team 4**
a. Condition of experimental variable:				
b. Measurements & calculations:				

13. Have each team assign roles: Igniter (unless you want to do this yourself), timer, flame measurer, and data recorder. Remind students to dispose of burned matches in the ashtray or on the metal tray.

14. When all teams are ready, <u>one team at a time</u>:

    - Have them describe their setup.
    - <u>One board at a time,</u> have students ignite the boards by <u>lighting a full row of matches.</u>
    - <u>Have the team members make the measurements and record them on the board</u>.

15. After all 4 teams have burned their board of matches, complete any calculations (such as duration of burning). Then Discuss **Questions 5-6** on the handout together

16. Ask: How is this model like a real forest? It has flammable fuels with spaces between, highly ignitable "crowns" – which occur in some wildlands and not others ….

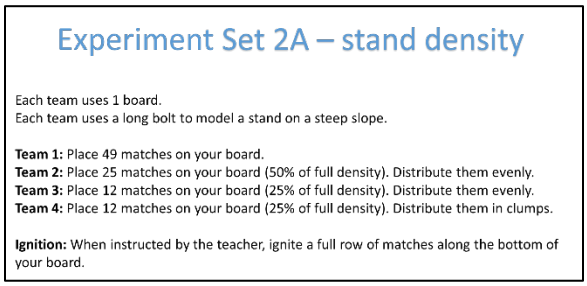
17. Ask: How is the model <u>not</u> like a real forest? There are no surface fuels. Trees are uniformly distributed across the area.…

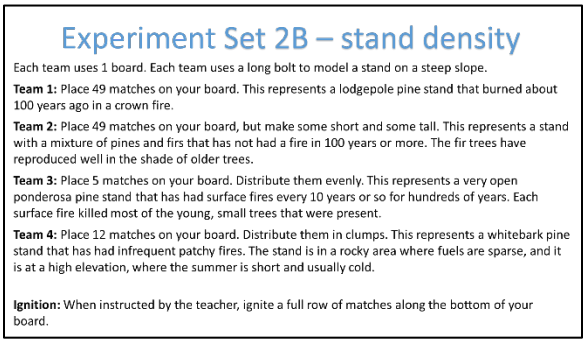
18. Ask: How is the board <u>not</u> like a patch of land? The terrain is even and uniform. Trees tilt with the slope….

Assessment:

1. Explain: Now we'll investigate the effect of a different variable - stand density - on fire spread. Stand density is the arrangement of standing fuels on a patch of land. Now it is time to write on your handout.
2. Have students answer **Questions 1-3** on the handout.

3. Project either **Slide 2** or **Slide 3** from ***M05_MatchstickForestExperimentDesigns.pptx***, depending on which experiment set you plan to use:





4. Explain: Each team will set up one part of the experiment. When all are ready, we'll burn the setups one at a time, so we can all observe every fire and share data.
5. Assign each student team to prepare one of the experiments. Use either 2A or 2B.
6. When all boards are ready, have the teams burn them one team at a time. As the burns proceed, have students complete **Question 4** on their handouts – recording results from all four teams, not just their own.
7. Have students answer **Questions 5-6** on their own.
8. **Clean up:** Have students do cleanup. Make sure all burned materials and matches are out before you dispose of them – that is, there is no smoke and no heat being released. Use a metal trash can without a plastic liner. If in doubt, dump them in a bucket of water before putting in trash.

Evaluation. See the Answer Key below.

EXTENSION #1: After you do Experiments 1 and 2A or 2B, you can extend this activity to help students develop and test their own hypotheses. Here are some questions that they could explore using the same experimental materials:

1. What is the best placement and size for a fireline (where a swath of fuels is removed) in forests with various slopes and stand densities?
2. How does ignition pattern affect fire spread? (Compare ignition from a single point, a whole row of matches (from top, bottom, and sides), and all matches around the edge of the board.)
3. How useful is it to remove selected trees for the sake of reducing potential for crown fire on sites with different slopes?
4. If you were planning to build a home in this plot of land, what would be the best location for it? Would you make any changes to the tree density around the home?

EXTENSION #2: You can also extend this activity by exploring other variables that affect fire spread, such as moisture, matchstick height, wind, and location of fire start (corner, middle, single tree, multiple trees).

Handout M05-1: Matchstick Forest.

Name(s): _____

1. **Experimental question:** What is the effect of _____ on fire spread? This is the condition that will be changed – "varied" - from one experiment to the next, so it is called the *experimental variable.*

2. **Hypothesis:**

3. **Measurements needed:**

   Calculations needed, if any:

   How do you plan to ignite – from the top, side, or bottom row of matches?

4. The data blocks below (Teams 1-4) refer to each team's experimental trial. Record data from each team as they report it.

   Team 1:

   a. What is the condition of the experimental variable? That is, how many matches are being used and how are they arranged?

   b. Measurements and calculations:

   Team 2:

   a. What is the condition of the experimental variable?

   b. Measurements and calculations:

Team 3:

a. What is the condition of the experimental variable?

b. Measurements and calculations:

Team 4:

a. What is the condition of the experimental variable?

b. Measurements and calculations:

After all experiments are done, answer the following:

5. Review your hypothesis (Question 2 above). Based on your observations, do you think your hypothesis was correct? If not, write a better one here:

6. Write a paragraph that answers Question 1 above. Show how the results of your experiments demonstrate your answer. Use your understanding of the heat plume and the Fire Triangle to explain.

Handout M05-1: Matchstick Forest Answer Key.

1. **Experimental question:** What is the effect of stand density on fire spread?

2. **Potential hypotheses:**
   - Fire will spread more easily through a dense stand than through an open stand.
   - Fire will spread easily through clumps of trees but will not spread easily through big openings between clumps.
   - If a clump of trees is uphill from a burning clump, it will ignite more easily than if it is downhill than the burning clump.

3. **Measurements needed:**
   - duration of burning
   - maximum flame height
   - number of matches burned…

   Calculations needed, if any:
   - Percentage of trees burned
   - Duration of burning if measured with a start time and an end time. Not needed if measured with a stopwatch.

   How do you plan to ignite – from the top, side, or bottom row of matches?
   Bottom row of matches

4. Obtain from ***M05_MatchstickForestExperimentDesigns.pptx***, Slide 2 or 3. Obtain data from each team.

After all experiments are done, answer the following:

5. Review your hypothesis (Question 2 above). Based on your observations, do you think your hypothesis was correct? If not, write a better one ….

6. Write a paragraph that answers Question 1 above. Show how the results of your experiments demonstrate your answer. Use your understanding of the heat plume and the Fire Triangle to explain. Fires spread faster and burn more completely in dense standing fuels (like the boards with 49 matches) because heat and flames are more likely to reach nearby fuels. This is especially true when dense fuels are standing uphill from the burning fuels, because heat is rising convectively and heating the unburned fuels.