4. How Wildland Fires Spread 1: Experiment with a Matchstick Forest

Lesson Overview: 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, Writing, Health and Safety

Duration: One or two half-hour sessions

Group size: Whole class

Setting: Indoor laboratory or outdoors

New FireWorks vocabulary: *crown fire, density, slope, stand (stand density), standing fuels*

Objectives:

- Students can apply their theoretical understanding of the Fire Triangle (from Unit II) to a physical model of a forest stand.
- Students can understand how slope and density of trees (or other standing fuels) affect fire spread.
- Students can illustrate on a diagram how fire is likely to spread and why.

Standards:		1st	2nd	3rd	4th	5th
CCSS--ELA	Writing	1,8	1,8	1,8	1,8	1,8
	Speaking and Listening	1,3,5,6	1,3,5,6	1,3,5,6	1,3,5,6	1,3,5,6
	Language	1,2	1,2	1,2,6	1,2,6	1,2,6
CCSS--Math	Measurement/Data	4				
NGSS	Earth's Systems: Processes that Shape Earth		ESS1.C, ESS2.A, ETS1.C		ETS1.B, ESS3.B	
	Engineering Design		ETS1.C			ETS1.A,B,C
	Weather and Climate			ESS3.B		
EEEGL	Strand 1	A,B,C,E,F,G				A,B,C,E,F,G

Teacher Background: In this activity, students use a physical model called the "matchstick forest" to investigate two of the variables that affect the spread of wildland fire: slope and the density of trees or other standing fuels. The fuels are represented in the model by single matches. For safety's sake, please note that the flames in this experiment can reach more than a foot in height. Plan accordingly. In addition, note that even very light breezes affect the way matches burn in this experiment. If you are working outdoors, the demonstrations may illustrate mainly that fire spread is complex and sometimes unpredictable.

Fires tend to spread upslope, so a fire that starts at the bottom of a hill is likely to spread faster than one that starts on a hilltop (other conditions being equal). This is because:

- the fuels uphill from a fire tend to be dried and warmed by the rising heat plume
- the flames on a fire spreading uphill are quite close to the uphill fuels, while the flames are farther away from the fuels below the fire. Therefore, fuels below the fire are affected very little – at least until burning materials roll downhill and ignite new fires below.

If a fire is burning in dense forest, it may spread from treetop to treetop, that is, it may become a crown fire. In more open forests, fires are more likely to remain in the surface fuels, that is, remaining surface fires. However, surface fires tend to spread more rapidly in open than dense stands because the wind speed is usually greater in open stands.

Table 2 describes three demonstrations that can be used in this activity. We recommend that you start with Demonstration 1, which illustrates fire's tendency to burn uphill, and then use either Demonstration 2A or 2B:

- Demonstration 2A illustrates basic principles as they apply to all kinds of plant communities subject to fire (any kind of forest, woodland, or shrubland, the world over).
- Demonstration 2B illustrates the principles as they apply to forests with different fire histories – long intervals between fires and short intervals.

Table 2. Three demonstrations that use matchstick forest models

Experimental question	Potential hypotheses & explanations	Experimental setup
Demo. 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 uphill, it dries and warms the fuels above. In addition, flames are closer to uphill fuels than to fuels on level ground.	Use 49 matches/board. Lay 1 board flat. Set up 2 tilted boards using two long bolts (1 bolt in each board). Ignite by lighting a full row of matches along the edge of each board: • On flat board, ignite one side. • On one tilted board, ignite the top row. • On other tilted board, ignite the bottom row.
Use EITHER Demonstration 2A or 2B.		
Demo. 2A: How does density of a forest stand (or other standing fuels) affect fire spread?	Fires generally spread faster and combustion is more complete in dense stands than in more open stands. **Explanation:** Heat and flames are more likely to reach fuels that are close together, drying them out and igniting them.	Use long bolts (to create steep slopes) for all models. Use the following matchstick densities/board (see Figure E04-1: Setup of matches for Demonstration 2A) • 49 matches • 25 matches (50%), distributed evenly • 12 matches (25%), distributed evenly • 12 matches (25%) in clusters Ignite all boards from the bottom row.
Demo. 2B: How does tree density resulting from different fire histories affect fire spread?	Fires generally spread faster and combustion is more complete in dense forest stands, such as forests that have not burned in a long time, than in more open forests, such as stands that have been burned frequently. **Explanation:** Heat and flames are more likely to reach fuels 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.	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 stands that have not burned in a century. • 25 matches to represent a forest that has experienced low- and moderate-severity fires, creating a forest with evenly spaced trees. • 5 matches, spaced far apart, to represent open-grown forests that have experienced frequent fires. • 12 matches, distributed in clusters, to represent forests that have experienced patches of both severe fire and low-severity fire. Ignite all boards from the bottom row.

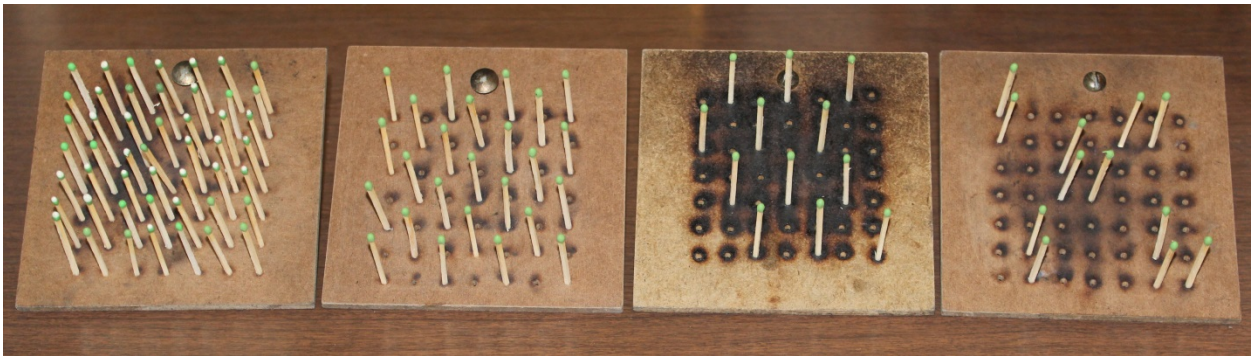


Figure E04-1: Setup of matches for Demonstration 2A.

Materials and preparation:
Do the two experiments as demonstrations. Students can help you set up the boards with the right number of matches. Ignite the matchstick forests one at a time from the bottom row of matches, so all students can observe all fires.

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 matchstick (stand) density.

- Download *E04_Downhill-UphillDiagram.pptx* to use in the assessment.
- Get plenty of wooden kitchen matches (not provided in the trunk). You will need at least 300.
- If you burn outside and it is windy, you may need to ignite with a lighter. It may be helpful to have 4-5 pieces of poster-board that students can hold at a safe distance to protect the flames from wind.
- Have fully-charged fire extinguisher handy.
- Set up your work station with this equipment (available in the trunk):
  - Two spray bottles. Fill them with water.
  - 1 metal tray (i.e., cookie sheet)
  - 1 ashtray
  - 4 masonite (“matchstick forest”) boards from the matchstick forest kit
  - Nuts and bolts from the matchstick forest kit
  - 1 pair of safety goggles
  - *FireWorks* safety poster
- Have a *metal* trash can *without a plastic liner* nearby.
- Stop watch or clock with a second hand.

Procedure:

1. Do a **safety checkup** with students using the *FireWorks safety* poster.
2. Explain a *crown fire*: A fire that moves from tree top to tree top.
3. Show students the matchstick forest model (masonite board, nuts and bolts). The board represents the ground surface; each match represents a tree or other standing fuel; the match tips represent tree crowns or other flammable fuels at the top of the standing fuel. Discuss the variables that can be investigated with this model.
4. Discuss experimental design with the class, including the principle of changing only one variable at a time to figure out cause-and-effect. Note that you'll change only slope in Demonstration 1 and only matchstick density in Demonstration 2.

Demonstration 1 (see Table 2 above for set-up and instructions).

5. Explain: A testable prediction or guess is called a hypothesis. Ask students to offer hypotheses – that is, to predict what will happen – when each board is burned. They may have several hypotheses. Write them all on the board.
6. Assign a student to record the start time and end time of each burn. Make sure a clock showing seconds is available or have the timer use a stopwatch. (If you have a stopwatch, you don't need the "Start time" and "End time" columns in the table below.)
7. Copy this table on the board:

Slope	Start time	End time	Duration (seconds)	Matches burned (tree crowns)
1. Flat				
2. Steep – burning downhill				
3. Steep – burning uphill				

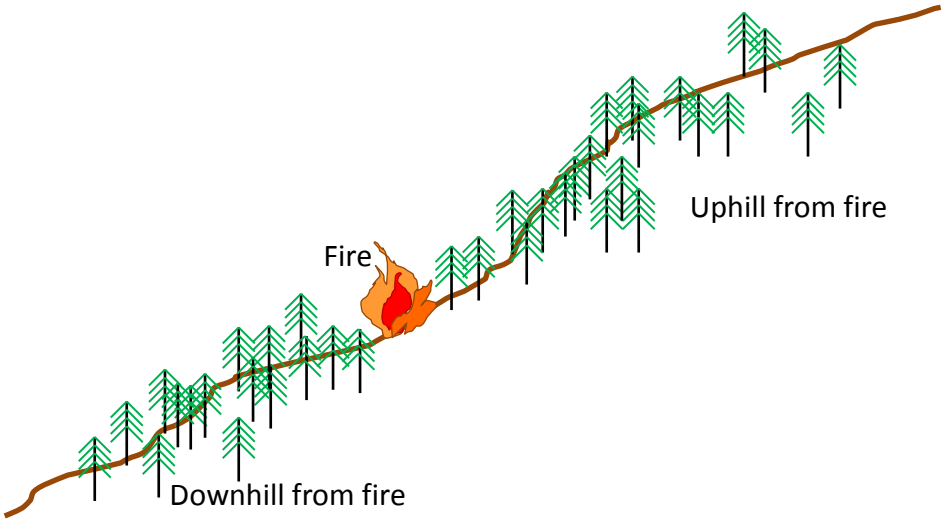
8. Refer to Table 2 for further instructions.
9. Dispose of burned matches in the ashtray or on the metal tray.
10. After all of three matchstick forests have burned, calculate the fire duration for each. Discuss the results. Were their hypotheses correct? Ask students to describe how the fire moved through the "tree crowns" or match heads.

Demonstration 2A or 2B (see Table 2 above for set-up and instructions). 2A focuses on the general concept of matchstick (stand) density, while 2B focuses on tree densities resulting from different fire histories.

11. Ask for hypotheses and write them on the board.

12. Change the first column of the table on the board to reflect the three matchstick densities you will use (Table 2, Demo 2A or 2B).
13. Ignite the matchstick forests one at a time, always by igniting the bottom row of matches.
14. After all boards have burned, calculate the fire duration for each. Discuss how the fire moved through the "tree crowns" (match heads).
15. Discuss the results. Were their hypotheses correct?
16. **Clean up:** Use a metal trash can without a plastic liner. If in doubt whether fire is out, dump materials in a bucket of water before putting them in the trash.

Assessment: Project *E04_Downhill-UphillDiagram.pptx* or sketch something like it on the board. Have students explain in writing or by drawing what direction the fire would be most likely to spread and what part of the forest would be most likely to have crown fire. Have them use complete sentences to explain why.



Evaluation:
Full Credit: Student indicated that the fire is more likely to spread uphill and crown on the hillside above the flames than on flat land or below the flames. Student indicated in complete sentence(s) that trees on the slope are dried and heated by the rising heat plume, and/or fuels are closer to the flames, and/or trees are most dense on the steep section above the flame. If the student suggested that cross-slope or down-slope winds could overwhelm the effects of slope or that embers rolling downhill could start a fast-moving fire below, those answers are also valid.
Partial Credit: Student indicated that fire is likely to crown uphill from the flames.
Less than Partial Credit: Student indicated that the fire is likely to spread faster on a flat area or downhill, and/or student did not indicate understanding of how slope affects fire spread and potential for crowning.