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A twist on the candle mystery

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Three candles of different heights are lit in a closed space. Surprisingly, the longest candle goes out first. Can you solve the mystery?

In a classic demonstration of the candle mystery, three lit candles of different heights are covered with a gas jar (see figure 1) and the tallest candle goes out first. This happens because carbon dioxide produced from burning has a higher temperature, so it rises and accumulates at the top of the jar. Then the carbon dioxide gas cools down, falls, and extinguishes the tallest candle first. This article builds on the classic demonstration of the candle mystery and advances it in three ways. Firstly, the 5E instructional model[1] is used to develop learning activities that require students to construct, revise, and apply scientific explanations in unpredictable contexts. Secondly, these activities aim to help students test their hypotheses by using and coordinating multiple pieces of evidence. Thirdly, these activities include experiments and discussion tasks to challenge students to predict and explain results. By adding variables to the candle mystery, you can engage students and promote critical thinking and scientific understanding.

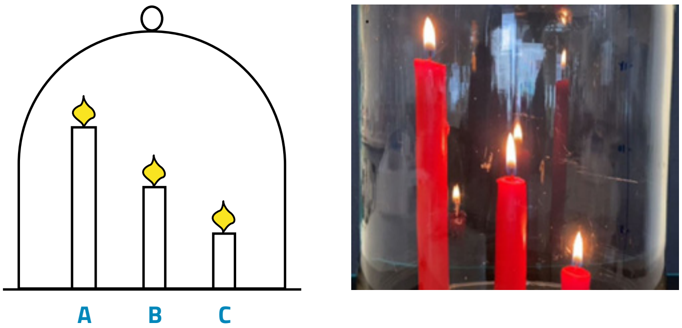

Figure 1: The classic candle experiment
Image courtesy of the author

The experiments can be conducted as demonstrations or as hands-on practical work for small groups of students. They are quick and easy. The activities can be used with students aged 11 to 16.

Safety notes

- Follow all fire safety regulations and have fire extinguishing materials on hand.
- Wear safety goggles throughout the experiments. If students are performing any steps themselves, they should do the same and be warned to take care around open flames.
- The gas jar can become very hot during and immediately after candles are extinguished. Students should be warned not to touch it with bare hands and care should be taken (e.g., wear heat-resistant gloves when lifting the hot gas jar and/or lift the gas jar when it has cooled to room temperature).
- Make sure all candles are extinguished after each experiment.
- Ensure sufficient ventilation, for example, by opening windows.

Activity 1: Engaging and exploring student ideas for the candle mystery

This activity aims to set up a scenario to engage students in inquiry. When three candles of different heights are lit and covered with a gas jar, students are prompted to predict and explain which candle they think will go out first. Allow 40 minutes for the prediction discussion, experiments, and collaboration.

Materials

- Large gas jar (large enough to cover three candles)
- Three candles of different heights
- Lighter
- Heat-proof mat
- Blade
- Hot-air gun, 240 V, 2000 W (optional: used to heat the blade to cut candles to different heights)
- Worksheet 1

Preparation

Before the lesson, the setup should be prepared by the teacher or teaching assistant.

1. Cut three candles to different lengths with a hot blade preheated by a hot-air gun (see figure 2).
2. Align the three candles on a heat-proof mat, close enough that they can be covered with the gas jar.
3. Cover the three candles with the gas jar (without lighting them, figure 3).

Figure 2: Cut the candle carefully
Image courtesy of the author

PRACTICAL TIPS:

- To ensure fair testing and expected results, ensure that the wicks are identical in length, and that the heights of the candles differ significantly.
- Perform a test run before the lesson to check that the setup works and to get a sense of how long it takes for the first candle to go out.

Procedure

1. Show the setup to students and encourage them to think about what would happen if we lit the candles (and replaced the gas jar). Ask them which candle they expect to go out first.
2. Have them write down their own ideas first (and record them in worksheet 1) and then optionally have them discuss this in groups and then with the class. Ask them which candle they expect to go out first.
3. Remove the jar, light the candles, and watch what happens. Depending on the setup (e.g., candle length, jar size), the candles should go out within a few minutes. Students often find the result (the tallest candle goes out first) mind-blowing.

Figure 3: Setup to demonstrate the classic candle mystery
Image courtesy of the author

4. Optional: have students repeat the experiment (or watch a recording) and record the times required for each candle to go out. Combine the results and draw a graph.
5. Discuss the results and encourage students to reflect on their initial predictions. Were students surprised by the results? Did the results match their predictions? Does it make them think differently about their explanation?
6. A more in-depth discussion about why the tallest candle goes out first follows in Activity 2. If Activity 2 is not being used, part 1 (Why does the tallest candle go out first?) of Activity 2 can be carried out here.

Watch a demonstration of Activity 1.

Discussion

You can adopt the think–pair–share approach to engage with student thinking in step 1. In this approach, students are asked to predict and explain individually which candle would go out first. They then share their predictions and explanations in groups of three or four, followed by a whole-class discussion. You can capture students' initial ideas and reasoning and stimulate students' thinking using the following questions:

- Why do you think the tallest or shortest candle goes out first, or why do you think the candles go out at similar times?
- After listening to your classmates' ideas, would you change your prediction?
- How would you convince others that your prediction is correct?

Activity 2: Explaining the candle mystery

Instead of explaining to students that hot carbon dioxide rises to the top of the jar and extinguishes the tallest candle first, a discussion to help them think it through themselves will lead to better understanding. It is important to allocate time and support for students to reflect thoughtfully. They can test the explanation by monitoring changes in carbon dioxide concentration[2] and the temperature inside the gas jar. The activity takes about 40 minutes.

Materials

- Large gas jar (large enough to cover three candles)
- Three candles of different heights
- Lighter
- Heat-proof mat
- Three plastic bottle caps
- Adhesive putty like Blu Tack or some adhesive tape
- Bicarbonate indicator solution (10 ml)
- Three temperature sensors (e.g., PASPORT chemistry sensor)
- Evidence cards
- Worksheet 2
- Timer (optional)

Procedure

Part 1: Why does the tallest candle go out first?

1. Ask students why they think the tallest candle goes out first. If they mention CO_2, you can prompt them to think about how to test their hypotheses.
2. If they don't have any ideas, you can prompt them with the following questions about the experiment:
   a. Why did the candles go out before they burned down?
   b. How does the air in the jar change as the candle burns?
   c. What chemical process creates flames? What are the outputs of combustion?
   d. What happens to gases when they're heated?

   You can also link this to the real-life situation of escaping from fires by asking questions like:

   e. What are the essential actions to be followed in case of a fire inside a building?
   f. Why do we stay low to crawl through smoke-filled rooms or corridors?
3. You can use the evidence cards (figure 4) to help guide the discussion.

① Burning requires fuel	② Burning requires oxygen	③ Burning requires carbon dioxide	④ Air does not have fixed shape
⑤ Air can flow	⑥ Burning produces water	⑦ Hot air floats	⑧ Cold air sinks

Figure 4: Evidence cards about candle burning
Image courtesy of the author

4. Once they have some ideas involving CO_2 build-up and temperature differences, ask how they would test their hypotheses. Encourage them to think about what variables would need to be kept the same to ensure a fair test.
5. The experiments in parts 2 and 3 can be used to investigate some of these variables, or you can come up with your own.

Figure 5: Monitoring the CO_2 concentration in the gas jar
Image courtesy of the author

Part 2: Monitor the carbon dioxide concentration

Safety note

A safe distance between the flame and Blu Tack/tape should be maintained to avoid melting of the Blu Tack/tape.

1. Set up the experiment as for Activity 1. You can use the same candles but ensure the wicks are the same lengths.
2. Fill three plastic bottle caps with bicarbonate indicator and use Blu Tack or tape to stick them at different levels inside the gas jar (figure 5).
3. Repeat the procedure detailed in Activity 1, and observe colour changes to the bicarbonate indicators at the end of the experiment (figure 6).

PRACTICAL TIP:
to ensure fair testing, the amounts of bicarbonate indicator added to the bottle caps need to be the same.

Watch a demonstration of Activity 2a.

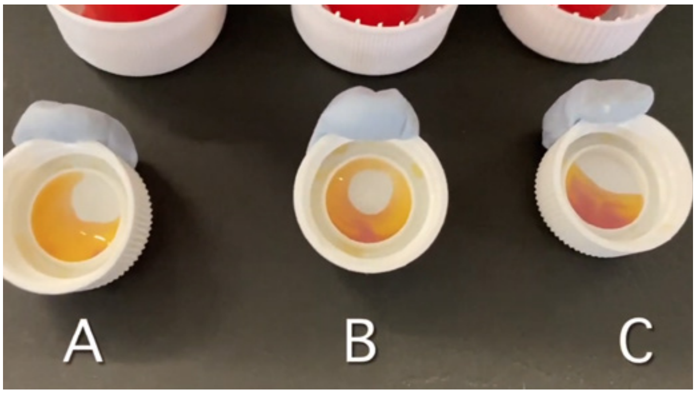

Figure 6: Expected results of CO_2 concentration at different heights (i.e., A: high; B: middle, C: low). The CO_2 released from the burning candles diffuses into the bicarbonate indicator solution and changes the colour from red to yellow. The more yellow the indicator becomes, the more CO_2 is present.
Image courtesy of the author

Part 3: Monitor the change of temperature

1. Calibrate the temperature sensors if necessary.
2. Set up the experiment as for Activity 1. You can use the same candles but ensure the wicks are the same lengths and the glass jar is replaced to ensure the experiment starts at room temperature.
3. Connect three temperature sensors and use Blu Tack or tape to stick the sensors at different levels inside the gas jar (figure 7).
4. Repeat the procedure detailed in Activity 1, and collect data for temperature changes at different levels inside the gas jar (figure 8).

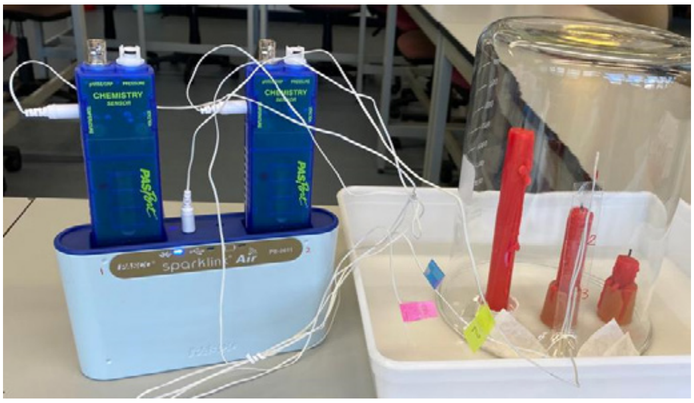

Figure 7: Monitoring the change in temperature
Image courtesy of the author

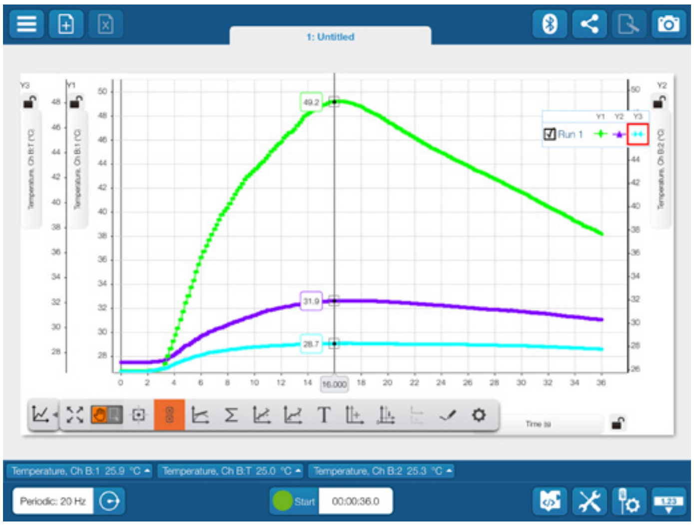

Figure 8: Expected results of temperature changes at different heights
Image courtesy of the author

Discussion

The results should show that the carbon dioxide levels and temperature rise more towards the top of the jar. Discuss with students whether these results support their explanations. Are there any alternative explanations that are consistent with the results?

Activity 3: Elaborating and evaluating student learning about the candle mystery

To assess students' deep understanding and ability to apply their explanations, you can introduce variations of the candle experiment in different contexts. Challenge your students to consider what they think might happen if we place the candles in separate jars.[3] Additionally, ask them to explore the results if we introduce an electric fan into the setup. This can be combined with another think–pair–share activity to promote discussion and evaluate their understanding of the concepts. Allow 40 minutes for the experiments and discussion.

Materials

- Large gas jar (large enough to cover three candles)
- Three candles of different heights
- Lighter
- Heat-proof mat
- Portable fan
- Timer
- Worksheet 3
- Activity 3 explanation

Procedure

Part 1: Burning candles in individual beakers

1. Ask the students what they think would happen if the candles were lit in individual jars. This can be done using the think–pair–share approach.
2. Secure three candles of different heights to the bench (this also works with two candles).
3. Light the candles and cover each with a separate beaker (figure 9).

Figure 9: Burning candles in individual beakers
Image courtesy of the author

4. Record the time required for each candle to go out.
5. Repeat the experiment to get more reliable data.

PRACTICAL TIP:
to ensure fair testing, the volume inside the beaker must remain the same throughout the experiment. If a candle needs to be cut, the cut pieces should be placed inside the beaker.

Watch a demonstration of Activity 3a.

Part 2: Burning candles near a small fan

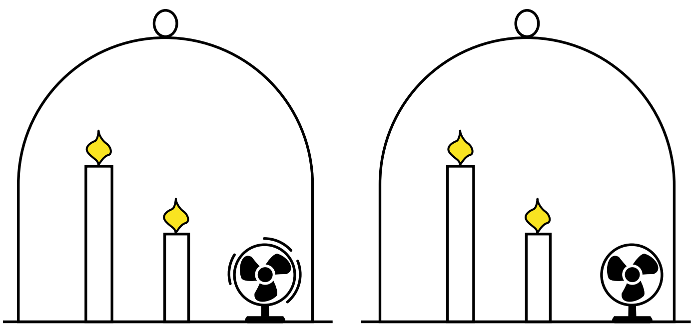

Figure 10: Burning candles near a small fan
Image courtesy of the author

1. Ask the students what they think would happen if a fan were placed in the jar. Place a portable fan near the three candles used in Activities 1 and 2, and turn the fan on.
2. Repeat the procedure detailed in Activity 1, and record the time that the candle goes out.
3. Repeat the experiment with the fan turned off.
4. Compare the time taken for the candle to go out when the fan is on and off.

PRACTICAL TIP:
to ensure fair testing, the volume inside the beaker must remain the same throughout the experiment. The electric fan should be placed inside the beaker, whether it is turned on or off. To repeat the experiment, you may fan the gas jar to restore it to room temperature and avoid the build-up of CO_2, or you can use a new gas jar.

Watch a demonstration of Activity 3b.

Discussion

The candles go out at similar times in the experimental setups with separate beakers or with an additional electric fan. The results contrast the experimental results in Activities 1 and 2. To ensure reliability of the results, students are encouraged to repeat their experiments, which can be performed within 5 minutes. Encourage students to provide explanations for their observations. Students are asked to construct explanations of how and why things happen in the setup using their explanations developed in Activity 2. You may give groups the model answer (Activity 3 explanation) at the end to compare it to their descriptions.

Conclusion

The activities based on simple twists to the classic candle experiment can serve to improve students' abilities to develop, revise, and apply scientific explanations, as well as to explore scientific skills such as control of variables, hypothesis testing, and coordinating multiple pieces of evidence. As an extension activity, you could encourage students to handle quantitative data in an in-depth discussion and demonstrate their learning through report writing and group presentation. The process of predicting and explaining different unfamiliar contexts can help create valuable teachable moments that motivate students to learn.

References

[1] Bybee RW (2015) *The BSCS 5E Instructional Model: Creating Teachable Moments.* National Science Teachers Association Press. ISBN-10: 194131600X

[2] Cheng MW (2006) Learning from students' performance in chemistry-related questions. In Yung BHW (ed.) *Learning from TIMSS: Implications for Teaching and Learning Science at the Junior Secondary Level* pp 51–74. Education and Manpower Bureau.

[3] Details for how to investigate candle burning: https://edu.rsc.org/resources/candle-burning-investigation-planning-an-experiment/619.article

Resources

- Watch demonstration videos of the experiments in Activities 1 (candle mystery), 2 (CO_2 concentration), and 3 (individual beakers and electric fan).

- Learn how to make convection currents visible using mist: Lim ZH, Shu A, Ng YH (2023) A misty way to see convection currents. *Science in School* **64**.
- Explore the nature of science by investigating a mystery box without peeking inside: Kranjc Horvat A et al. (2022) The mystery box challenge: explore the nature of science. *Science in School* **59**.
- Try some experiments with gases to illustrate stoichiometric reactions and combustion: Paternotte I, Wilock P (2022) Playing with fire: stoichiometric reactions and gas combustion. *Science in School* **59**.
- Learn about data visualization by sketching graphs from 'story' videos of everyday events: Reuterswärd E (2022) Graphing stories. *Science in School* **58**.
- Read about the environmental costs of fireworks: Le Guillou I (2021) The dark side of fireworks. *Science in School* **55**.

AUTHOR BIOGRAPHY

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