

The Flaming Candle

Experiential Learning in the Fourth Grade

by

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The following report was published in Ueli Aeschlimann's "Warum leuchtet die Kerzenflamme" [Why is the candle flame bright?], Schriftenreihe der Schweizerischen Wagenschein-Gesellschaft, Heft 4 (1993) [Series of the Swiss Wagenschein-Society, pamphlet 4]. Dr. Aeschlimann is a professor of physics and physics education for elementary school at the Bern Pedagogical University (Switzerland). His approach to physics education is inspired by the work and writings of Martin Wagenschein.

Teaching is the shared quiet beholding of a thing.

- Horst Rumpf

INTRODUCTION

Martin Wagenschein wrote: "Why must physics begin so late in the curriculum and then proceed according to its regular sequence rather than according to what arouses wonder?" The following report describes lessons on "Faraday's Candle" held in a fourth grade class (ten-year-old students). Margrit Küpfer made her class in the elementary school in Rüti, Switzerland, available to me. The goal of the lessons was not to teach chemistry in the fourth grade, but rather for the students to learn to observe closely, to ask questions, and to ponder these questions within a class discussion. It was clear to me that the candle was interesting enough to hold the attention of fourth graders. I was less certain about whether the students at this age would be able to see the logical connections, as is necessary for this topic, or at least be able to understand them. The lessons then showed that we succeeded to various degrees. André and Michel certainly succeeded, as the transcript of parts of our class discussion shows. Other students participated less in the discussions, but their notebook entries, which they did on their own without major instruction or help from me, prove that they understood essential aspects. There were a few students for whom the topic was too demanding. However, while they did not achieve all the desired results, this did not smother their joy in observing. These students mainly drew in their notebooks and wrote very little text, sometimes needing my help.

A double period in the afternoon once a week was set aside for these lessons. Originally we had planned three such double periods before Christmas (in 1992) during which, in class discussions, the students were to find out: "What burns, the wax or the wick? Why does a candle need a wick?" The success of the first three double periods led me to continue for two more sessions after Christmas during which we worked on the question: "Why is a candle flame bright?"

FIRST AFTERNOON: Solid – Liquid – Gaseous

Twenty-one lively, interested students sitting side by side in a half-circle surrounded me. I gave each of them a sheet of paper and asked them to draw a candle flame from memory. How often have we seen a burning candle and yet, sketching a flame from memory is difficult. Therefore, I was not surprised that the drawings were quite varied. The colors red and yellow appeared in almost all drawings. Many students recalled having seen the color blue, but where in the flame should it be drawn? And where does the flame begin, directly above the candle or above the wick? Does the wick extend into the flame? We sat in a circle again, laid the drawings on the floor in front of us and compared them. There were broad flames and pointed ones in various colors and

there were flames with or without a wick. The suspense intensified: What does a flame really look like? We lit a candle and observed it closely.



Michel: It looks like there are two flames, one within the other. The first one is dark, and the other one is bright.

André discovered that the flame is blue only at the bottom. Its shape was described: it was more pointed than round. My next impulse was to ask what seemed to be a simple question, but which proved to be a difficult one. I asked: "What is it that actually burns?"

André: The wick.

The teacher (hesitant): Do you all agree?

Michel: The gas from the lighter. (He referred to the lighter with which I had ignited the candle.)

Teacher: Yes, in a lighter it is the gas that burns. But what burns in a candle?

Several boys and girls together: The wick.

The teacher (questioningly): Is it really the wick?

Several boys and girls (convinced): Yes, yes, the wick burns.

André: The wick is made out of string, and strings burn.

Michel: The wax burns.

André: The wax doesn't burn. It just becomes liquid.

Michel: But when the candle burns, it has less and less wax.

André: Because the wax melts and runs down. If the wax burned, the whole candle would be in flames.

Michel (surprised): Oh, yes!

Teacher: What do the rest of you say? You heard what André and Michel said. What do you think?

Nicole: The wick burns. The wax melts away.

Teacher: What does that mean?

André: The wax holds the wick. Otherwise the wick would fall over.

Michel: But then one could also make a stand to hold the wick.

André: There are pine torches.

The class was perplexed.

I am always amazed when in situations like this no one asks much sooner whether we could try it out. Also here, the suggestion had to come from me. I took a piece of wick and was about to ignite it. The students were afraid that the wick would burst into flames and I would burn my fingers. I knew, of course, that I was safe but I followed André's advice ("I would use tongs") and held the wick with tweezers. In order to be able to follow such suggestions, you need to have the various materials and equipment on hand. I held the wick up and ignited it as the wick of the candle had been ignited. It burned with a small flame for a short while and then went out. It continued to glow and smolder and was thereby used up fairly quickly. The students suggested soaking the wick in wax. We did that and indeed, the wick burned like a candle flame.

Michel: The wick burns, and the wax.

I was not yet satisfied and asked: "Is it correct what André said, that wax by itself will not burn?" We held a piece of wax in the flame and it melted. We were in a difficult place and not getting anywhere. For that reason, I performed the following experiment. We put a piece of wax into a porcelain bowl and heated the bowl with a burner. The wax melted. I tried to ignite it, but the liquid wax did not catch fire. I continued to heat the bowl until white smoke rose from the wax. Perhaps this smoke could be ignited? Yes, after igniting the smoke a lively flame burned above the whole bowl even when I took the burner away. The students were surprised.

Michel: That burns just like at the Olympics.

I extinguished the flames by using a lid. The experiment went pretty fast, so we described it in detail, worked out the concepts, and wrote onto the blackboard: solid wax, liquid wax, gaseous wax. The white smoke can be ignited.

André: Does red wax produce red smoke? I doubt it actually.

We decided to leave this question for later.

The lesson began with drawing, and we had spent more than half an hour in concentrated observation, contemplation, and discussion. It was high time for a change. Therefore, I suggested that we learn to sing a song related to our topic. I had slightly revised Mani Matter's song, "D's Zündhölzli" ["The match"], by replacing 'lit cigarette' with 'candle.' The students were delighted

when I unpacked my guitar. I sang the first verse for them, and then we hummed it together. Because many of them knew the song, it went well and I could hand out the text of the song. Swiss-German is not at all easy to read. Manuela read the first verse aloud, almost without stumbling, and we sang it. We also learned the second verse and ended by singing both verses.

Afterward, we went out to the schoolyard. I wanted to show the students why I had extinguished the flames by using a lid and not water. I heated wax in the porcelain bowl again—this time it was red wax. We were curious about what color the smoke would be. As André had suspected, the smoke was white. I ignited the smoke, asked the students to move back several steps, and poured water out of a test tube that I had fastened for my own safety to a wooden slat onto the fire. A jet of flame shot up into the air about half a meter high. The students were impressed and astonished as I explained to them that burning oil behaves in the same way. This is why we must never try to put out burning oil with water, but must smother the flames.

The afternoon closed with a final experiment. I carefully heated some white wax in a test tube. As it melted, it became a clear liquid. When all wax had melted I marked the level of the liquid wax on the glass and placed the test tube in a stand for the wax to cool. My intention was to look at it in our next lesson and find out whether solid wax takes up more or less space than liquid wax.

SECOND AFTERNOON: Wax vapor from a burning candle

What about the wax in the test tube that we melted at the end of the last lesson? The now solid wax touched the glass at almost the same level as before but in the center there was a funnel. We could see this more clearly in a larger water glass in which I had melted wax and then let it cool.

Why does a depression form? We could not find an answer to this question, so I asked the students: What would happen if I filled a glass with water and placed it in a freezer? I was astonished when no one volunteered that the glass would burst. When I told them, some students reported about glasses bursting because of hot water. I had to explain that this was quite a different matter and that a glass full of water bursts in the freezer because of the ice needing more space than water. How is it with wax? The hole formed in the center of the wax because wax in the fluid state needs more space than in the solid state. Michel realized that wax “dries” in layers toward the inside. He had grasped how the hole came about. For most of the students, however, the fact that solid wax needs less space than fluid wax did not sink in deeply enough for them to remember.

I reminded them of what we had learned about wax vapor and that we knew it can be ignited. Yet, where is wax vapor in the candle?

Michel: When we blow out a candle, it smokes. The smoke rises where the wick smolders and glows.

André: Try it!

We blew out the candle and observed exactly what Michel knew would happen.

Teacher: Can this white smoke be ignited?

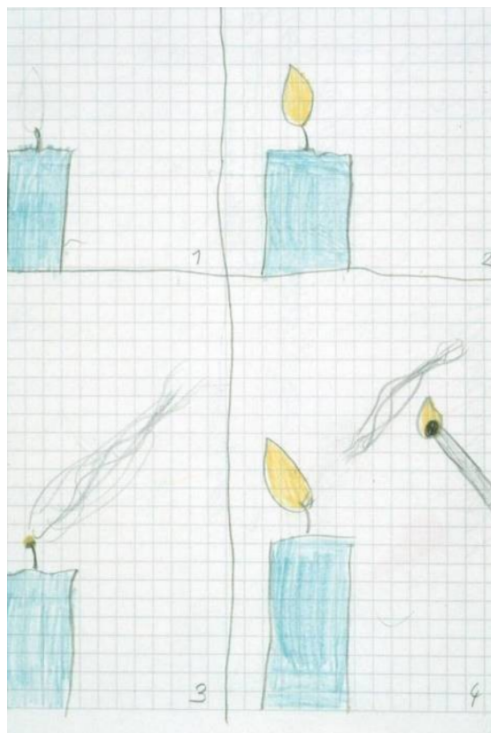
The students were skeptical, but suggested at once that we should try it. They expressed great amazement and joy when the flame of the match jumped to the candle.

André: That is like an electric current. When you aim and shoot a water pistol at an electric wire, it is the water that guides the current to you.

The students wanted to know how far a flame could jump. We tried it several times and got it to jump about ten centimeters or four inches.

Michel: It's as quick as a flash. Can we try it ourselves, or is it too dangerous?

Of course, each student should be able to try it. While some students experimented on their own, others wrote into their notebooks. What should the title for this entry be? Michel suggested, "Fire Ladder." My suggestion was, "Jump of the Flame."



*Wir haben eine Kerze aus gepustet.
Es entwickelte sich Rauch.
Wir zündeten den Rauch
an und die Flamme sprang
auf den Docht zurück.*

"Jump of the Flame"

We blew out a candle.

Smoke developed.

*We lit the smoke
and the flame sprang*

back to the wick.

(Text by Sabine)

(Drawing by André)

When we sat in a circle again, I brought out my guitar and we learned the last two verses of the song. Then we continued our conversation with my question: "Where is the smoke while the candle is burning? Does it even exist when the candle is burning?" Michel suspected that the smoke is within the flame itself. The other students did not pick up on this idea and the conversation digressed from the topic. I had to bring them back on track by asking: "How can we test Michel's idea?"

André: The flame is like a cage all around the smoke.

Teacher: But then there would be more and more smoke within the flame.

Michel: Then the flame would have to become bigger and bigger.

Ronny: The flame chases the smoke away.

Again we were stuck. I had to help by saying: "The smoke burns." "Aha!" could be heard from

many. I held a glass tube at an angle in the flame with one opening just above the wick. The students watched spellbound as smoke climbed up through the tube and escaped at the far end.

Michel: We have freed the smoke.

The students were amazed when I lit the smoke that came out of the far end of the tube and a small flame kept burning.

I now performed another experiment in which wax vapor is directed from the candle flame into a glass flask through a U-shaped glass tube: White wax vapor streamed like a fluid into the vessel.

Dani: It looks like milk!

I showed the students how the vapor hung like fog in the bottom half of the flask.

André: Can one light it?

Demian: Can one touch it?

Teacher: Yes, you may touch the wax vapor; it is not hot. However, you should not inhale it.

The vapor is heavier than air. I poured it out of the flask and ignited it. The jet of flame impressed the students.

Angelo: Will the vapor become hard again?



We wanted to find this out and, for this purpose, let wax vapor again flow into the glass flask. I closed the flask and let it stand.

THIRD AFTERNOON: Why does a candle need a wick?

I began this lesson by telling the story of Prometheus who brought fire to human beings. The students were familiar with some of the Greek gods. Michel knew that they lived on Mount Olympus and told us that he was already in Greece during vacation and visited the Acropolis. I told them that Prometheus created the human beings and gave them the following characteristics: from the lion, courage; from the fox, cleverness; from the horse, loyalty; and from the bull, strength.

André: But I am not as strong as a bull!

Prometheus taught human beings how to write and count. Zeus demanded that human beings bring an offering to the gods. The people slew a bull, and Prometheus advised them to make two piles: one large one with the bones, and a smaller one with the meat. Both piles were covered up, and Zeus should choose which pile he wanted. Naturally, he chose the larger pile. When he saw that he had been tricked, he decided to withhold fire from human beings. In spite of this, Prometheus brought fire to the earth by igniting a dried plant with the sun. To punish him, Prometheus was chained to a boulder and every day an eagle would come and eat from his liver. Finally Hercules rescued Prometheus by shooting the eagle with an arrow.

As a continuation of the candle theme, I had planned to come back to the glass with the wax vapor in it. I knew that there would be no vapor to be seen and that a thin brown deposit would be on the bottom of the glass. My intention was to heat the glass with a burner in order to show that the brown layer would again turn into vapor. But things happened differently. The students had in the meantime picked up the glass again and again to see if wax vapor was still there until the glass fell to the floor and broke. However, the many fingerprints on the wax told me that they had found for themselves that the wax vapor had not simply disappeared, but changed back to solid wax.

The class now knew a number of things about a candle. But they had difficulties when I asked: "Why does a candle need a wick?"

Michel: The wick burns along with the candle. They are always the same length.

Teacher: But we still do not know why a wick is needed.

Sabine: It makes the candle burn.

Teacher: We must consider this more thoroughly.

Sabine: The wick must consist of a material that burns.

We were not making any progress. I took a piece of wick and held it into the fluid wax of a burning candle. We saw that the wick absorbed wax. When we lit the wax-soaked wick, it burned like a candle with a quiet flame. I asked the students to observe closely what happens when I bring a lit match near the wick of a candle that is not burning.



Marianne: The wick is black above and white below.

Michel: The wick begins to glisten.

Ronny: It is becoming somewhat fluid.

André: Candle wax.

Teacher: When it is hot enough, wax will vaporize, and then the flame of the match jumps over to the wick.

Nicole: And then the wick absorbs new wax.

Since it had been difficult for the students to fully grasp the function of the wick, I asked Dani, and then Angelo, to describe the whole process in their own words. I had to help both of them with this.

Before we proceeded to making notebook entries, we sang the song about the match. André had discovered that the song has six verses.

Teacher: I left two verses out, because they are too difficult.

André: Yes, I read them, and they are devilishly difficult.

In a few days it will be Christmas. Therefore, I close the lesson by telling the story, "The Little Match-Seller," by Hans Christian Anderson.

FOURTH AFTERNOON: The two gas burners

Standing on the small laboratory table were two camping burners. I lit them both. The one burned with a large yellow flame, and the other with an almost invisible flame. This surprised the students. What was going on? The following ideas were expressed:

“The gas valve of the first burner is not turned as high.”

“They are each burning with a different kind of gas.”

“The gas tank of the one has less in it.”

“The gas in one of them is older.”

André maintained that the blue flame was hotter than the other one. We tested this by holding a glass rod in the flames. First I held it in the yellow flame, and the rod turned black with soot. Then I held it in the blue flame. The students observed that the black coating disappeared and the rod began to glow. After a while, it began to soften and bend. André remembered watching a glassblower at work. We concluded from our observation that the blue flame actually was hotter.

Michel: Why?

Teacher: We must think about that.

Michel: Aha, that is not an easy question.

Teacher: Wouldn't it be boring if everything was always easy? We will find an answer.

André: Can we regulate the burners?

Michel: The burner with the blue flame has two holes. Maybe something comes out of them.

Teacher: Do you all see these holes?

André: Can we close the holes?

Teacher: What would happen then?

Gül: The flame should be yellow.

I covered the holes with my fingers and ignited the burner. The flame was yellow. The students were impressed when, as I quickly uncovered the holes, the bright yellow flame escaped upwards and the burner continued to burn with a blue flame. So, the burner can be regulated by the holes, but why?

Nicole: The gas can escape through the holes. That is why the blue flame cannot burn properly.

Teacher: Then we should be able to light the gas at the holes.

I held a burning match near a hole. The students noticed that the flame of the match was drawn into the hole and that at the same time the burner flame turned yellow. Thus, nothing comes out of the holes, but rather something enters them.

Michel: There is only air in the room, so it must be air that goes in.

Teacher: What would happen if I put a glass over the flame?

Demian: It would be smothered.

André: No more air could reach it.

Teacher: Yes, the flame needs air for it to burn. Which flame is therefore burning more?

Suba: It is the flame where the hole is open.

Teacher: Which flame is that?

Gladys: The blue flame.

Demian: It was the hotter one too!

We observed that the blue flame burned above the whole opening of the burner, whereas the yellow flame burned only at its outer edges where the air reached it. It had a dark area inside, exactly like a candle flame.

André had already discovered the long glass tube (of about 30 centimeters) that I had brought with me. He suggested that we hold it in the flame so that the gas would travel through the tube and could be ignited at the other end. It amazed me how well he could observe and see the connections, as I had indeed brought the tube for this very purpose. I set up the experiment, putting the end of the tube into the middle of the yellow flame where the gas was not burnt. With some patience, I succeeded in igniting the gas at the other end of the tube.

Teacher: Why doesn't the gas burn inside the tube?

Dani: Because it doesn't have any air.

By holding a match into the yellow flame I then showed them that on the inside the flame is cold: The head of the match inside the flame remained unchanged while the wood at the edge of the flame was charred.

FIFTH AFTERNOON: Why does the candle flame emit light?

This was the last time I sat together in a circle with the students. Expressions of expectation were on their faces: What will he ask today? I began the conversation by asking: "Why is the flame bright?"

Demian: Because of the air.

Teacher: Yes, last time we could bring about the blue and the yellow flames by regulating the air vent. But why?

Michel: Because of the heat.

Teacher: Which flame casts light, the hot one or the cooler one?

Michel: The cooler one.

Teacher: Isn't that amazing? Wouldn't one expect that the hotter one is brighter?

André: The sun is bright, and it too is hot.

Teacher: Exactly!

Michel: When you heat an iron rod, it begins to glow.

Teacher (after a long pause): What other difference between the blue and the yellow flame did we discover?

André: The one flame makes soot.

Michel: A candle makes soot too.

Teacher: Does that mean that those flames, which emit light, make soot?

Demian: Why is there no soot in light bulbs?

Teacher: There is no fire in light bulbs either. But is brightness of a flame related to soot?

The students were at a loss.

Teacher: Look closely at the wick of a burning candle. Is it all black?

Nicole: It is red at the top. (The tip of the wick was glowing).

André: Further down the wick is white.

Michel: Further down it does not burn.

Teacher: What did we want to find out?

André: Why is the flame luminous?

Teacher: What did we achieve so far?

André: Nothing.

Michel: The flame creates soot.

Sabine: The wick glows at the top.

Demian: The flame is bright because of the glow.

In order to make this clear, I heated some soot on a tin lid. When it was hot enough, it smoldered with a yellow color and went out. The idea that the flame emits light because soot smolders, appeared to be correct. I carried out one more experiment, which confirmed this in an impressive way: I blew soot into the blue flame and many yellow sparks lit up in the flame.

Michel: Why is there soot?

Teacher: That we don't know yet. Isn't it amazing that black soot comes from a white candle? Well, we saw the soot, and for the moment we must leave it at that.

Obviously, the theme of the candle was far from being exhausted.

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