Let´s Explore the Power of Candles

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There are many different phenomena that students come across every day. Depending on their interest they may observe them in detail or may not. Candle burning is an example of a phenomenon that everybody has already seen and watched. This common but rather complex phenomenon that involves a set of processes can be used as a good opportunity to develop skills to observe, formulate a problem, develop a hypothesis and plan investigations and hence can be built up to an inquiry activity to be carried out by students. The designed activity consists of three parts: Let´s explore the candle flame, Thermal power of the candle, Combustion heat of candle. Each part is completed with materials for teachers as well as worksheets for students' independent work. The materials are developed on the basis of the ESTABLISH project guide for developing teaching and learning units (ESTABLISH, 2014). The emphasise is laid on the active students´ approach during measuring and collecting data, peer discussion, gained results analysis with regard to students predictions and drawing conclusions. The materials are complemented with the pre-test aimed at gaining information about students' primal conceptual knowledge about the topic. The authors present experience and results of the implementation of the inquiry-based candle activity in the classroom at lower secondary school. Within the workshop the participants carry out the activity in parallel groups in a role of a student and discuss the inquiry skills development, its evaluation and implementation in different European school environment.

INTRODUCTION

Since 2006 we have been involved in preparing students for the Young Physicists Tournament (YPT). The problems that students are expected to solve are clear examples of higher level inquiry activities (Establish, 2010). Students are given a problem while the way how to solve it is completely up to them or the problems can be so open that even the concrete problem that is supposed to be investigated is up to the students to formulate. This aspect of the tournament requires mastering a set of inquiry skills of students who decide to take part at such a competition. That´s why it is very important to design methods how to conduct the students´ preparation and how to decide about the learning sequence where students go step by step in order to achieve the goal.

While preparing high school students for the Physics contest we regularly involve also University students – future physics teachers into this process. We use selected YPT problems as assignments for future physics teachers. The goal is to take the problem and based on it to design an activity to be implemented in the class. Students are expected to elaborate the outline of the learning sequence as if it was conducted during the lesson. One of the examples students have been working on is the problem of burning candle. Their approach to this problem and lesson design was mainly focused on the content knowledge (what does the candle consist of, how long does it

burn, what is the temperature of the flame, how much heat is produced, how long does it burn, what is the combustion heat). Concerning methods students propose mainly traditional methods based on the transmission of knowledge from teacher to students when teacher explains the key concepts of the problem within a presentation. However, what students gain and learn from that is mainly content knowledge and skills connected with listening. Such students´ approach is a natural reflection of the way how they were and are being taught during their own lessons.

Different approach that we are trying to implement is to choose methods and strategies when students conducting the activity play a key role and there are directly involved in the process in order to develop not only content knowledge but also inquiry and reasoning skills. The learning sequence goes from observation through experimental design, formulating hypothesis, data collection and their interpretation, peer discussion, drawing conclusions based on evidence and sharing and defending the results. Our goal is to influence and persuade students about the benefits of IBSE to become their strategy of teaching in the future.

IDENTIFICATION OF PRIOR KNOWLEDGE

When conducting an inquiry activity, it seems to be very useful to get information about pre-existing knowledge that students have when they come to the classroom. Using a pre-test about the concepts of the activity gives information about the preconcepts that teacher can build on as well as it can draw students´ interest towards the subject of study. In case of candle burning activity we have developed several conceptual questions that students answer explaining also reasons for their response (Table 1).

Table 1: Items of pre-test on candle burning activity.

1. You have obviously seen how candle burns. What do you think the flame is created from? Describe your idea in your own words.
2. You have obviously seen how candle burns. What do you think the flame is created from? Describe your idea in your own words.
3. Imagine a candle flame. Think first and then answer: a. What is the flame temperature? Write down the temperature and describe how you have decided about this value. b. Is the candle flame temperature equal all over of the flame? Explain your answer.
4. Besides the burning candle you have certainly seen how wood or alcohol burner burns. Is there any difference between the burning of different materials? If so, what it is different? Explain your answer.
5. Mankind has been using flames to produce heat and light. Logically, bigger flame produces more heat than smaller flame. However, does the same-sized flame from different sources (e.g. alcohol burner and candle) produce the same amount of heat? Choose one of the following answers: a. Candle flame produces more heat than the alcohol burner flame of the same size. b. The alcohol burner flame produces more heat than the candle flame of the same size. c. Both same-sized flames from different sources produces same amount of heat. Give reasons for your answer.
6. When buying candles, you can usually find information about the length of burning on the label. The producers claim that their candle will be burning for 8, 12 or even more hours. What do you think the time of burning depends on? Choose one of the following answers: a. Time of burning depends on the size of the candle. Bigger candle will be burning longer. b. Time of burning depends on the size of the flame. Candle with smaller flame will be burning longer. c. All candles have more or less equal-sized flames. Time of burning depends on the quality of candle material. Give reasons for your answer.

The pre-test have been used at lower secondary class of 28 students aged 13-14 who answered the test about a week before the lesson. Here are the most frequent answers:

- The flame consists of fire, flammable gases, oxygen and wax.
- Estimated flame temperature is about 100°C.
- The flame temperature distribution along the flame is different; however students do not give reasons why.
- Different sources produce different flames; however there are no arguments for the answer presented.

- Alcohol burner produces more heat than that of the candle; however students do not give reasons why.
- Time of burning depends only on the amount of wax that the candle is made of.

The responses on the pre-test has shown that except from obvious lack of students´ knowledge in the field of burning there is also low level of argumentation skills of students. That made us think to put more emphasize on development of these skills, in particular.

INQUIRY ACTIVITY ON CANDLE BURNING

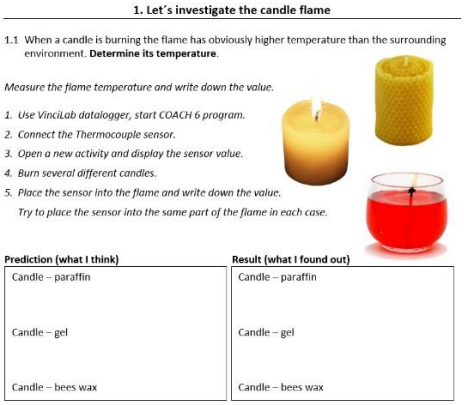
We have designed the candle burning activity as a guided inquiry activity when students investigate a teacher-presented question through a prescribed procedure. Students working in small groups of three are given a worksheet with step by step instructions that they follow. When measuring physical quantities, they use data logging tools (thermocouple and temperature sensor) and scales connected to the computer equipped with measuring and processing software (e.g. Coach). The activity is designed for 90 minutes (two school lessons).

Nevertheless, students before starting investigation can begin with observation of the phenomenon and formulating problems connected with it. They observe the flame, draw the picture of the flame, and describe what they noticed about the flame. We expect that they discuss the flame shape, different colours of different parts, candlewick burning, and hot air trembling around the flame, etc. Based on our experience from the classroom students mainly discuss why the flame shakes, what about its temperatures, how long the candle will be burning. Raising questions about candle burning can be supported by teacher-student dialogue when teacher help students to ask additional questions, e.g. How does candle start to burn?, What does the flame consist of, Is the temperature equal in different parts of the flame?, What is the difference between the flames produced by different sources?, What does the amount of heat produced by the flame (and time of burning) depend on?, Why do most candles produce some soot while cake candles do not leave any residue and burn cleanly with minimal soot?, etc.

Based on students´ formulated questions there can be the investigation plan designed. However, taking into account the time limitation and the current state curriculum in physics and availability of tools needed for experimentation we have developed three inquiry activities, i.e. Let´s investigate the candle flame, Thermal power of candle, Heat of combustion of candle.

Let´s investigate the candle flame

This part is aimed at formulating prediction about the flame temperature and verifying the prediction by taking data with the help of thermocouple connected to the computer.



1. Let´s investigate the candle flame

1.1 When a candle is burning the flame has obviously higher temperature than the surrounding environment. **Determine its temperature**.

Measure the flame temperature and write down the value.

1. *Use VinciLab datalogger, start COACH 6 program.*
2. *Connect the Thermocouple sensor.*
3. *Open a new activity and display the sensor value.*
4. *Burn several different candles.*
5. *Place the sensor into the flame and write down the value.*
   Try to place the sensor into the same part of the flame in each case.

Prediction (what I think)	Result (what I found out)
Candle – paraffin	Candle – paraffin
Candle – gel	Candle – gel
Candle – bees wax	Candle – bees wax

Figure 1: Example of students´ worksheet.

Thermal power of a candle

This part involves students into the discussion about the thermal power of a heat source. They are asked to search for information about thermal power of appliances that they use. Based on this information students are expected to estimate the value of heat produced by candle and give proposals how the thermal power could be measured using simple equipment. After discussing the measuring procedure students using temperature sensor connected to the computer measure the temperature change of the known amount of water heated by the candle, calculate the required value and compare it with their prediction.

$$P_{candle} = \frac{Q_{water}}{t_{heating}}$$

$$P_{candle} = \frac{c_{water}.m_{water}(t_2 - t_1)}{t_{heating}}$$

$$P_{candle} = \frac{4180J.kg^{-1}.K^{-1}.0{,}4\ kg.(29{,}6°C - 20{,}6°C)}{900s}$$

$$P_{candle} = \frac{15048J}{900s}$$

$$P_{candle} = 16{,}72\frac{J}{s} = 16{,}72\ W$$

Figure 2: Students measuring thermal power of a candle (left) and example of students´ calculations on thermal power of a candle (right).

Heat of combustion of a candle

The last part of the activity is aimed at determining the amount of heat of combustion, i.e. the amount of heat gained by burning one gram of paraffin. Firstly, they try to predict the value. In order to find out the value students investigate how quickly candle burns. Measuring the mass of a candle situated on the scales connected to the computer students find out how mass changes with time. Students are expected to use their skills to work with graph in order to gain the speed of burning. Knowing the

thermal power as well as the speed of burning they can determine the amount of heat gained from burning one gram of paraffin.

$$Q_{combustion} = \frac{Q_{water}}{\Delta m_{candle}}$$

$$Q_{combustion} = \frac{c_{water} . m_{water} (t_2 - t_1)}{(m_1 - m_2)}$$

$$Q_{combustion} = \frac{4180 J.kg^{-1}.K^{-1} .0{,}4\ kg.(29{,}6°C - 20{,}6°C)}{(9{,}11g - 8{,}67g)}$$

$$Q_{combustion} = \frac{15048 J}{0{,}44g} = 34{,}2 \frac{kJ}{g}$$

Figure 3: Students measuring heat of combustion of a candle (left) and example of students´ calculations on heat of combustion (right).

EXPERIENCE FROM THE CLASSROOM

The activity was carried out by lower secondary class of 28 students aged 13-14. The classroom implementation has brought interesting information about the level of competencies and skills of students in conducting such activities. Based on direct experience from the classroom we can conclude:

- Searching for information skills are not sufficient, information provided by students are often very superficial
- Peer discussion must be strongly supported and encouraged by teacher, students cannot ask relevant questions, they have lack of communication skills in this field
- Students have problems in formulating predictions, they are used to write down what they are asked to do by teacher not what is the result of their own opinion
- Computer-aided measurement does not cause any major problems, students can handle the equipment easily
- Students are interested in presenting their ideas or group opinions in front of the class
- It is very important to revise what has been done during the lesson by the teacher and draw conclusions together with the whole class pointing to the most important facts

CONCLUSION

The design of inquiry activity on candle burning requires the active use of several inquiry skills, e.g. raising questions, conducting investigation, collecting, processing, analysing and interpreting data and drawing conclusions supported by peer discussion. Students proved to carry out the activity under the strong guidance from the teacher.

We have identified a lack of skills mainly in the field of argumentation and peer discussion. Following from that teacher should put more emphasize on developing these skills of students while carrying out similar activities. With regular use of them students can surely improve towards more independent active learning.

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