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Lesson Plan

Module:	**Cooling of water**	
Teaching Time:	45-90 min	
Grade Level/Age Range:	Grade 7-9 (13-15 years old)	
Short description:	Students predict, verify, create, and analyse graphs of temperature changes in time by performing experiments.	
Design Principles:	**Inquiry**	
	Situatedness	
	Digital tools	
	Embodiment	
Functional Thinking:	**Input – Output**	
	Covariation	
	Correspondence	
	Object	
Learning Goals:	The student: - takes measurements of water temperature at regular intervals, - enters the values of measurements into a table, - presents the values of measurements on a graph in the form of points, - combines different representations of the concept of function: description and analysis of a real situation, an ordered pair of numbers (data), a table, a graph, - intuitively discovers that the analysed function is continuous, because at each point in time, the water was of a particular temperature between measurements, - intuitively discovers the monotonicity of the function (non-increasing or constant function on intervals), - intuitively discovers what an asymptote is, - learns about functions other than linear, - learns what interpolation (approximation of function values) is about, - discovers the shape of the graph of a function describing the theoretical model of water cooling. The lesson can be implemented as a propaedeutic of the concept of functions, before introducing the concept of a function.	

This material is provided by the FunThink Team, responsible institution: Pedagogical University of Krakow.

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Activities

Engage

Activity 1. Brainstorm: What do you associate the word "cooling" with?

The teacher asks the students open-ended questions:

- What do they associate the word "cooling" with? (He writes the students' suggestions on the board).

To cool down, to change the temperature, to cool something (e.g. tea, dinner), (answers of several students)

- What can cool down?

- And what do you think, at what rate does water cool down?

Slowly, first slowly then quickly / Or maybe it should be the other way around, that is, first quickly, then slowly

- The opinions are split, so let's conduct an experiment to find the answer to this question.

Explore

Activity 2. Measuring the temperature of water while cooling it – an experiment in class

Suggested tools/materials/:

- *Pyrometer (or any digital thermometer),*

Figure 1. Pyrometer

- *Computer, tablet or phone with any spreadsheet,*
- *Projector,*
- *Several (4-5) dishes of different sizes, shapes and made of different materials (e.g. glass, metal pot, plastic bowl, porcelain dish),*
- *Kettle,*
- *Stopwatch (e.g., on a phone),*
- *Work sheets.*

We heat the water in the kettle before the lesson, so that during the lesson the water is not boiling (in order for it to be relevant to the lesson, but also for safety reasons) and reaches, for example, about 70 degrees Celsius.

We divide the students into as many groups as we have different utensils - for example, into 4 groups (a glass, a metal pot, a plastic bowl, a porcelain dish). We pour hot water into the dishes for each group.

We start the experiment. The students:

- measure the temperature of the water in their given vessel (with a pyrometer or other digital thermometer) at regular intervals, e.g. every 1-2 minutes, depending on the number of students and the number of groups (see Figure 1), marking the time of measurement with a stopwatch,
- they record the results of the measurements in the prepared tables on the work sheets,

Figure 2. Temperature measurements by students

- simultaneously annotate the results in the coordinate system on the worksheets (this section can be omitted when implementing the lesson in younger grades),
- enter the results of the measurements into a spreadsheet. This task can be implemented in different ways, such as:

    1. on a shared file in the cloud if each group has a tablet, laptop, or uses a phone for this purpose,

    2. sequentially approaching the teacher's computer or otherwise providing data to the teacher,

    3. by appointing one person from the class to systematically enter the results obtained by all groups one by one.

The student assignment (identical with the one in the student handout).

Group No. 1

Metal bowl

Time [min.]	0	1	2	3	4	5	6	7	8	9	10
Temperature [°C]											

Group No. 1 Metal bowl

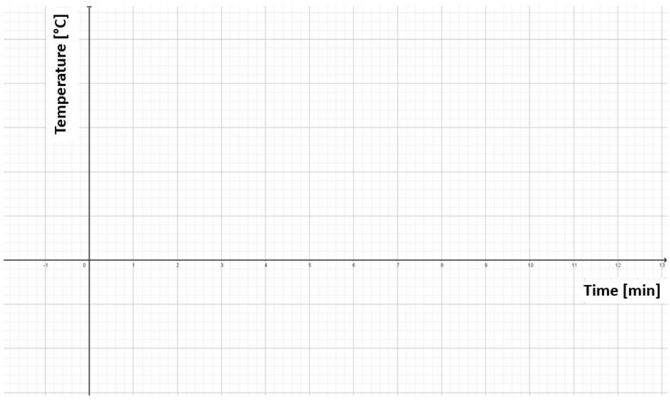


Figure 3. Worksheets for one group (analogous for other groups)

Explore / Explain

Activity 3. Analysis of data recorded during measurement

After completing the experiment, we display the data of each group on the monitor, in one spreadsheet, in a summary table, for example, like this:

Time [min]	0	2	4	6	8	10	12
Glass	76,2	72,1	67,2	65,1	63	59,9	57,5
Metal pot	74,9	65,2	57	53,1	50,2	47,8	44,2
Plastic bowl	75	67,6	60	54,9	51,5	49,4	47,3
Porcelain dish	76,2	68,8	63,8	58,5	54,6	49,9	47,9

Figure 4. Measurement data obtained by students

We then display these points in the coordinate system.

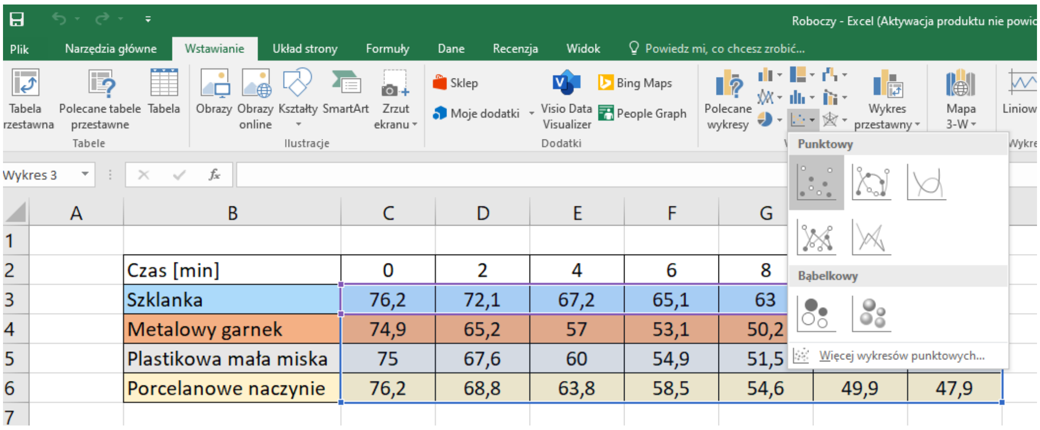


Figure 5. Example implementation of table in spreadsheet

We get the following graph:

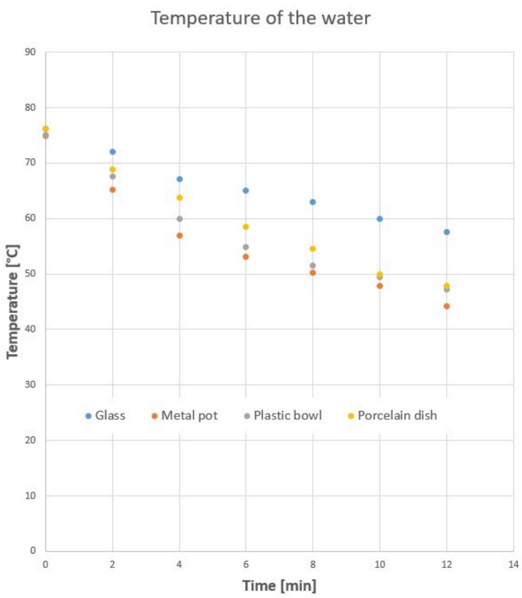


Figure 6. Point chart

We analyse the results of the experiment. The teacher asks open-ended questions and moderates the discussion with the students:

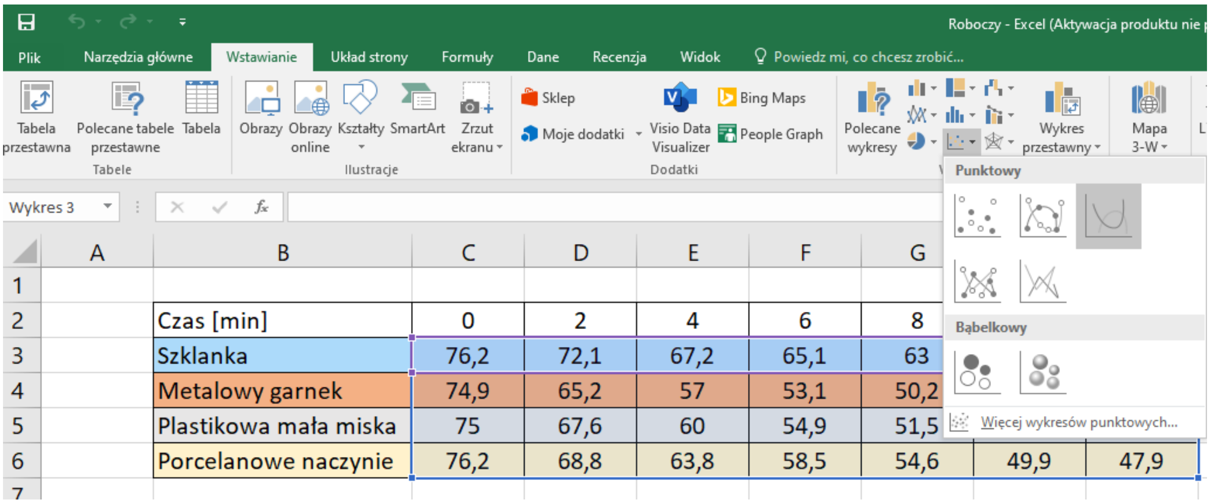
- How did the water cool in each vessel?
- What causes the differences?
- How often could we measure the water temperature?
- Is it possible to determine the temperature value at any point in time?
    - (Comment: In theory, yes, but other tools are needed to measure the temperature continuously, such as a traditional thermometer.)
- Can the recorded points describing the temperature during the cooling of water for each vessel be connected by using a line? Why? (Students justify that it is possible to connect the points with a line, since water has a particular temperature at any given point in time.)
- Could the temperature rise under our conditions?
    - (No. However, it is possible to discuss a change in conditions: What could happen to make this temperature rise?)
- How can the points be connected? (Discussion of various proposals – Fig. 7.)

Figure 7. How can you connect the points?

As a result of this discussion, students discover that different ways of connecting the points can be correct, as we do not have enough experimental data.

- How does the temperature change with time? (It decreases.)

We choose a different kind of graph - to show the general trend of temperature changes (Fig. 8).



	A	B	C	D	E	F	G		
1									
2		Czas [min]	0	2	4	6	8		
3		Szklanka	76,2	72,1	67,2	65,1	63		
4		Metalowy garnek	74,9	65,2	57	53,1	50,2		
5		Plastikowa mała miska	75	67,6	60	54,9	51,5		
6		Porcelanowe naczynie	76,2	68,8	63,8	58,5	54,6	49,9	47,9

Figure 8. General trend of temperature changes in spreadsheet

In our case, the graph is shown in Figure 9.

We emphasize that we do not have precise enough data to draw an exact graph. It only gives us an approximation of what the graph of water cooling in each vessel looks like in the context of the 12 minute duration of our experiment

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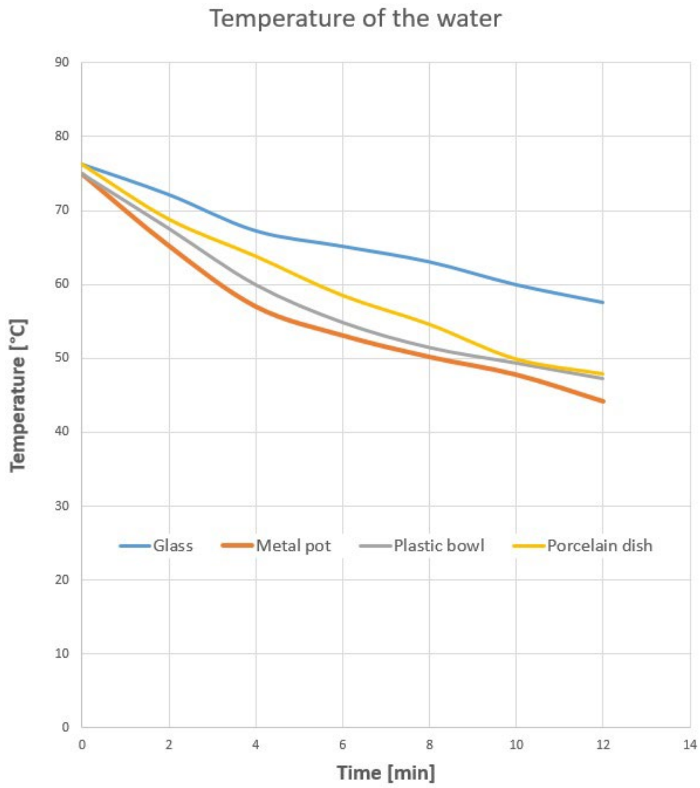

Figure 9. Graph with smoothed lines based on measured data

We continue the discussion to analyse these graphs and summarize. The teacher asks an open-ended question:

- What else do you notice? What can you tell about the temperature change in each dish?
- We suggest the following supporting questions:
    - How does the temperature change in each vessel?
    - *The temperature decreases with time.*
    - And is it the same in each vessel?
    - What can the rate of temperature decrease in a vessel depend on?
    - *On the size and material, vessel, amount of water, ambient temperature, initial temperature, etc.*
    - Are the lines on the graphs straight lines?
    - *No*

Pose a hypothesis / Explore

Activity 4. Pose a hypothesis

The students work individually in this part of the lesson. They plot their own proposed answer in the form of a sketch graph on the provided worksheets, to the following command:

Sketch how you think the water in the pot left in our classroom will cool from boiling for 5 hours.

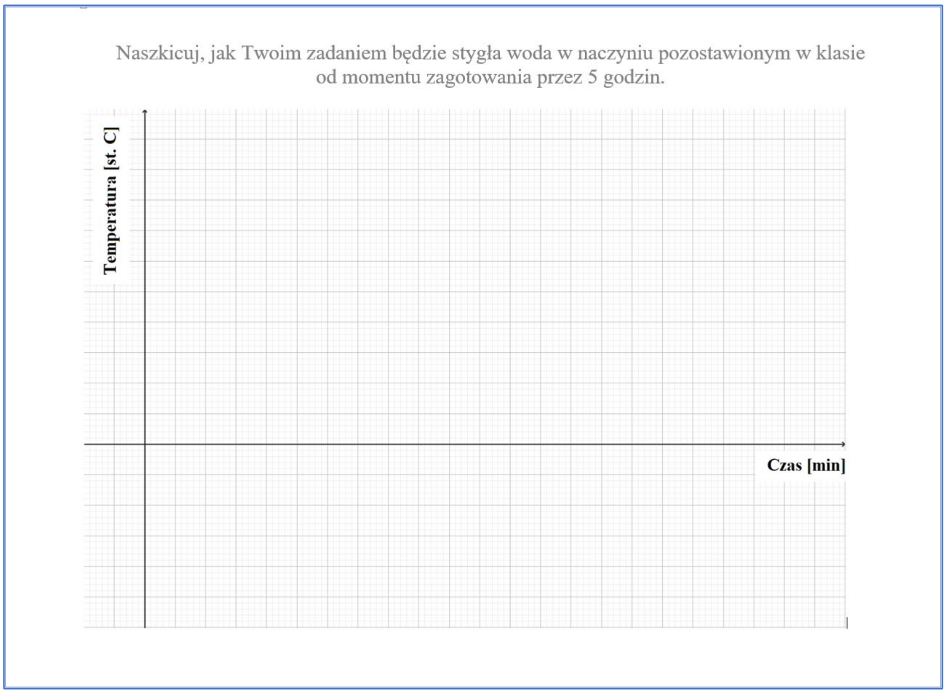

Figure 10. Worksheet - predicting cooling process of water

While doing this activity, the teacher observes the students' individual work. He selects the most interesting diagrams (in such a way that they are different).

Evaluate / Extend

Activity 5. Activity 5 Verifying hypotheses - discussion (possibly with the second part of the experiment)

The teacher asks the authors of the selected works to draw their proposals on the board or redraws them themself on the board and moderates the discussion on their correctness.

- Can the water temperature reach negative values under our classroom conditions? What about the value of 0?
- What is the lowest temperature the water will reach after 5 hours under our conditions? *Room temperature*
- Is the cooling rate the same all the time?

If a correct graph appears spontaneously - we analyse it at the end.

Then, if there is enough time (we have 2 lesson hours allotted), the teacher boils the water and, for safety reasons, repeats the experiment themself in one selected vessel - for example, a tin bowl, measuring the temperature of the water every minute since boiling. A selected student enters the data into a spreadsheet table, while another measures the time.

If there is no time for such activities - you can display data from a similar experiment conducted earlier in a table and graph - for example:

Time [min]	0	1	2	3	4	5
Kettle water temperature [degrees Celsius]	93,6	80,1	75,4	71,5	69,7	67,3

Analysing the graph, the students find that, at first, the water cools at a faster rate, which then gets progressively slower (if the students do not notice - you can calculate the subsequent differences in temperature values). The rate of the cooling of water does not remain the same. At the end, together, we create a sketch of the shape of the graph, which represents the curve of water cooling (if it has not appeared before).

The teacher tells the students that a well-known physicist and mathematician called Isaac Newton came to similar conclusions, and, based on observations similar to ours, theoretically described the cooling process named after him, Newton's law of cooling.

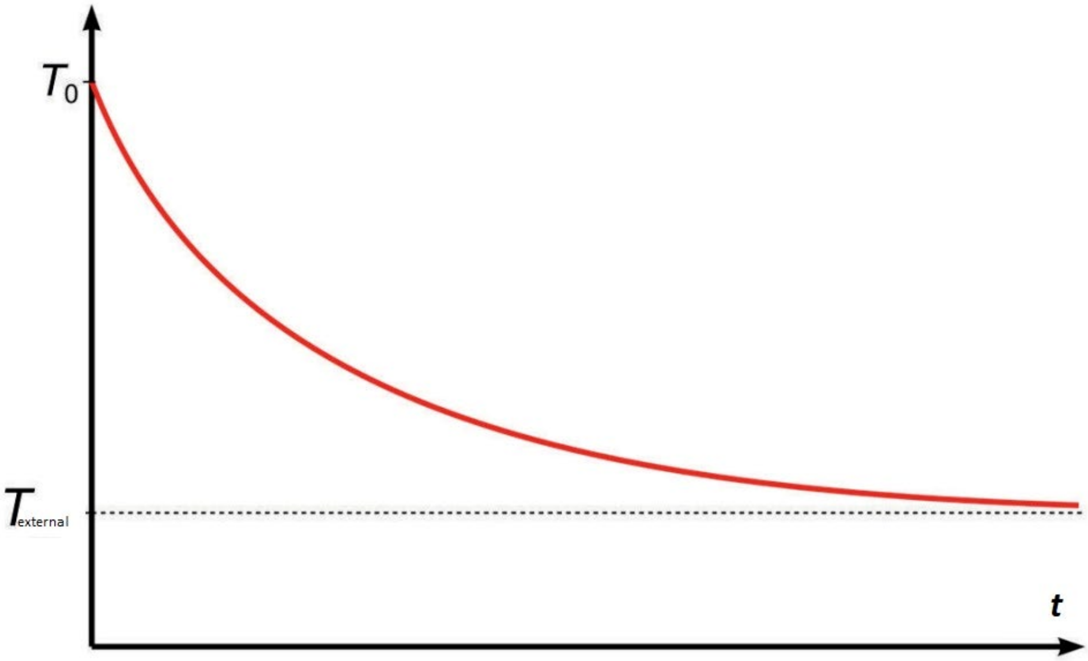

Figure 11. Water cooling graph as model of Newton's law of cooling

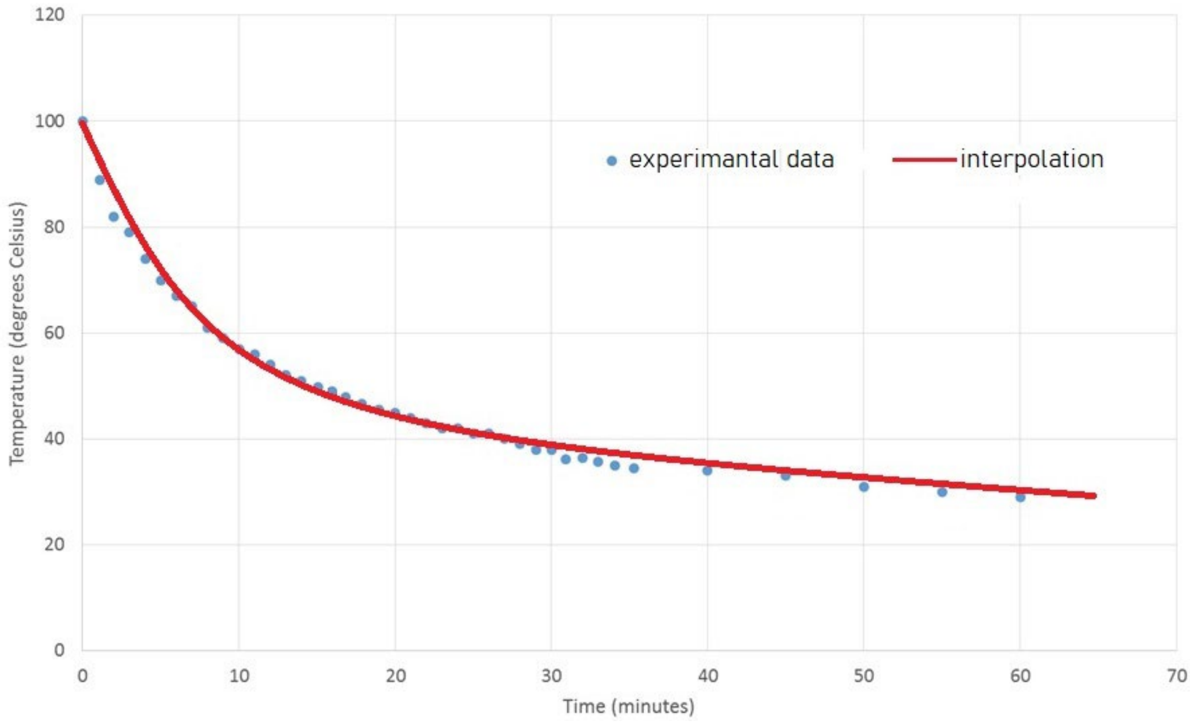

Figure 12. Experimental data versus their interpolation

Summary:

- What conclusions can be drawn from today's lesson?
- The temperature of the water in our vessel changes continuously over time - that's why we can represent it as a line (curve) on the graph.
- The temperature in each vessel decreases initially, then reaches a constant value.
- The rate at which water cools is not the same for different vessels, which is why the curves we obtained differ but have similar shapes. They depend on various factors, e.g.: type of vessel, amount and type of liquid contained, ambient temperature, initial temperature.