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Using project-based education to develop pre-service biology teachers' knowledge of the cooling effect of vegetation.

Ryplova Renata[1], Pokorny Jan[2]

Abstract

Vegetation has a significant cooling effect on local climate and contributes to the retention of water in the landscape. Surprisingly, this significant environmental topic is completely omitted from the Czech science curriculum. To introduce this topic into the curriculum it is necessary to first educate the future science teachers. Our paper presents results of a pilot study that introduced pre-service teachers to the cooling effect of vegetation via a hands-on project and assessed the improvement of their understanding of the key concepts using a pre and post-test.

Key words

Environment, Initial Teacher Education, Project based Learning, Science Education

INTRODUCTION

Why is it important to teach about the cooling effect of vegetation?

Everybody knows that during the heat of the summer it is much more pleasant to spend a hot day in the forest rather than in the city. The cooling effect of vegetation (Fig.1) is widely known, but it is taken for granted and not well understood. People mostly do not care about the reasons why the climate is cooler in the forest. This is one of the consequences of human indifference and ignorance of the roles plants have in their environment; this indifference has been referred to as "plant blindness" (Wandersee & Schussler, 1999).

Considering the recent changes in the global climate, it is very important to understand the physiological role of vegetation in cooling climate at local scales. Global temperature has been steadily increasing, the continents have become significantly dryer, and the experts warn of an impending global water crisis (IPCC, 2014, 2018). One of the possible ways to mitigate this dire situation is proposed by the "new water paradigm", (Kravčík et al.,2007). It calls for better landscape management to retain water in the landscape and recover the cooling function of ecosystems. Although the positive role of vegetation in cooling of local climate and in increasing water availability in the landscape has been demonstrated in numerous studies (for the review see Ellison et al., 2017), general public pays less attention to this topic. Deforestation and incompetent management of the landscape, caused by ignorance of the role of plant physiology in dissipation of solar energy and in the hydrologic cycle, contribute to the warming of climate at local scale, and lead to a decrease in the availability of water in the landscape (Ellison et al., 2017, Huryna & Pokorny, 2016).

Therefore it is necessary to raise awareness of the general public about the physiological „cooling“ function of the vegetation and to teach the subject, at an appropriate level, in elementary schools. According to the curricular documents of the Czech Ministry of Education, this topic falls into the category of environmental education. To educate future science teachers, a project-based lesson on the cooling effect of vegetation was developed and implemented into the education of pre-service biology teachers at Department of Biology, University of South Bohemia in Ceske Budejovice. A pilot study was carried out to answer the following research question: Can an expert-developed project-based lesson improve students' knowledge of the cooling effect of vegetation?

The "air-conditioning" effect of evapotranspiration

Transpiration is a necessity by which a plant maintains its internal temperature within it's optimal thermal limits. Using elementary physics, it can be shown that at the level of a landscape, evapotranspiration is the most efficient air conditioning system developed by nature. In addition to optimizing temperature, plants use evapotranspiration to control the water balance in their root zone. Water is able to redistribute much of the solar heat energy received by the Earth through the water cycle, thanks to its high latent heat of evaporation and condensation. Water has a unique feature. It exists in three aggregate states in our living environment: solid, liquid and vapour. Phase transition from liquid into vapour is associated with changes of volume (18 ml of liquid forms 22,400 ml of vapour) and consumption or release of energy (0.68 kWh kg^{-1}, 2.45 MJ kg^{-1} at 20 °C). The consumption of heat through evaporation in places that are currently hot and the release of heat through condensation in places that are currently cold (e.g. via formation of fog or dew equalizes temperature differences in time (between day and night) and in space (between different spaces).

Let us imagine a tree with a crown 5m in diameter covering an area of approximately 20 m^2. On a single sunny day, the crown will receive in the excess of 150 kWh of solar energy. What happens with this energy? About 1 % is used for photosynthesis, 10 - 15 % is reflected back into space, 5 – 10 % is released into the atmosphere as sensible heat and the same percentage is transferred as ground heat flux into soil. The largest percentage enters the process of transpiration, whereby water vapour is released from the tree. If a tree has a sufficient water supply, it can evaporate more than 100 litres of water a day and use approximately 70 kWh (250 MJ) of solar energy in the process. This energy is hidden in water vapour as latent heat and is released again during the process of condensation to liquid water.

The tree transpired around 100 litres of water, thus cooling its environment by approximately 70 kWh. The tree transpired water only during the daylight hours when it's stomata were open, and much of the evaporation happened during peak solar radiation, thus during a ten-hour period the tree cooled its environment with a 7 kWh power output. The energy of 70 kWh did not appear as sensible heat, it stayed in form of water vapour, and was released in cool places or during a night. Such a tree has a cooling capacity comparable with several technological air-conditioning and heating system used in households, hotels, offices. Transpiring tree has a double air-conditioning effect: it cools when water evaporates and water vapour passes energy to cool places where latent heat is released when water vapour condensates back to water liquid (Pokorny, 2019).

From thermodynamic point of view, trees reduce gradients of energy between the sun and outer space, they degrade incoming solar radiation through life processes (Schneider & Sagan, 2005).

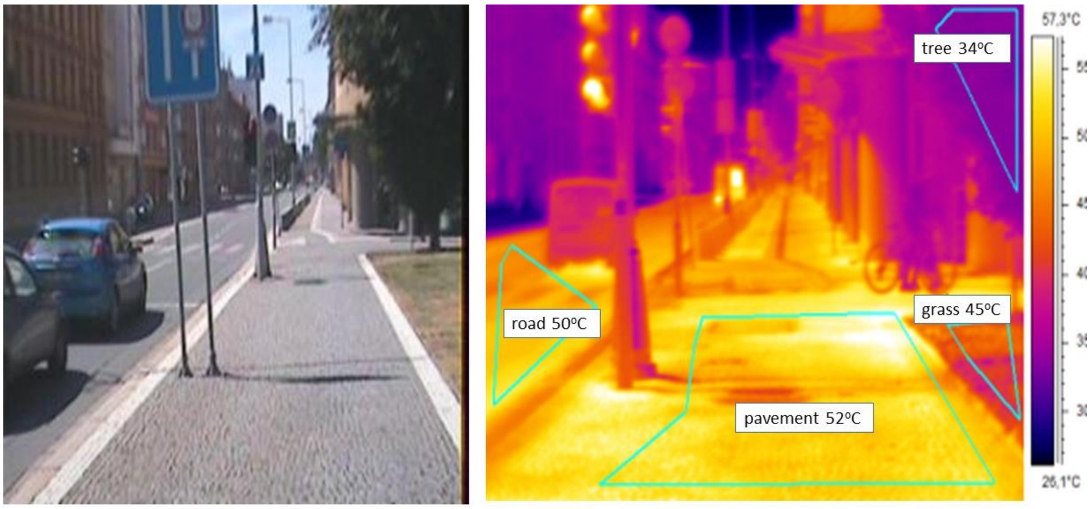


Fig.1. Street without trees on a summer day. Surface temperature of pavement 52°C, a tree on a side 34°C. (Pokorny et al., 2018)

METHODOLOGY

Project- based education on the topic of the cooling effect of vegetation

To educate future biology teachers, we developed a project-based lesson named "Using vegetation cover to cool down the main square in our town", focusing on the topic „solar energy – vegetation – water in the landscape." The lesson was implemented into the education of fourth grade pre-service biology teachers at the Faculty of Education, University of South Bohemia. The lesson was based on hands-on field experiments, using a thermo-camera, a solar radiation meter, and an IR thermometer. For the purposes of the lessons scientific measuring methods were adopted and simplified. An impact of this teaching method on students' knowledge was investigated by the didactic survey described below.

Design of the project based learning:

1. **Theoretical introduction** - **Transpiration and solar energy distribution in the landscape.** One hour lesson was delivered in the classroom on the distribution of transpiration and solar energy in the landscape, motivated via the following inquiry question: "Why is the shadow under the tree cooler than the shadow under the umbrella? "

2. **Outdoor hands-on part - three groups working on different inquiry based tasks during a sunny day**:

Group A: How much solar energy reaches the surface of the grass under a tree compared to open treeless space? What is the surface temperature of the grass in the open and under the tree? The pre-service teachers we asked to consider the cooling power of the tree given a transpiration rate of 20 litres per hour.

Group B: Is there any difference between the surface temperature of the lawn with tall uncut grass and cut grass? The pre-service teachers were asked to make observations using the thermocamera (or IR thermometer) and to explain any differences.

Group C: Using the IR thermometer, find the coolest surface in the courtyard of the faculty building, including the lawn, the pavement, the tree and the building. Explain the differences among the various surface temperatures

3. Presentation of the results and discussion among the groups.

4. A proposal for the vegetation cover of the main square. All groups work together on the proposal, based on their experience from the hands-on field exercises (A-C).

The pre-service teachers were given the following directions: Imagine, that the average amount of solar energy reaching the surface of the main square in our town (Ceske Budejovice, 1 hectare area) is 900 W/m$^{2.}$ Create a proposal of a new vegetation cover (how many trees, how many m^2 of uncut lawn) to cool the square by the average of 200 kW/ hour. Draw the trees and lawns into the map of the square (source - Google maps).

(Consider transpiration rate of a tree as 20 l / hour, transpiration rate of 1 m^2 uncut lawn as 0, 3 l/ hour)

Design of the didactic survey

To investigate the impact of this project-based lesson on the students' knowledge of the cooling effect of vegetation a pre – test/ post- test experimental design was used. The respondents underwent a pre–test a day before and a post–test a day after the project. The students' understanding of the cooling effect of vegetation was assessed using the short questionnaire consisting of 5 questions:

1) Tropical rain forests and deserts occur on the Earth at approximately the same altitudes. How is it possible, that there are big differences between the day and night temperature in the desert, while there are nearly no differences in the tropical rain forests? Explain: *(2 points)*

2) If we cut down the forest, the local climate: a) will warm up, because…b) will cool down, because… *(correct answer (a) with correct explanation 2 points, correct answer with wrong or no explanation 1 point, false answer (b) 0 point*

3) Is it possible that some deserts have recently enlarged due to the wrong human management?

   a) Yes, because…. b) No, because…. *(Correct answer (a) with correct explanation 2 points, correct answer with wrong or no explanation 1 point, false answer (b) 0 point)*

4) Which physiological process in plant utilizes the biggest amount of solar energy reaching the plant surface? *(transpiration 1 point)*

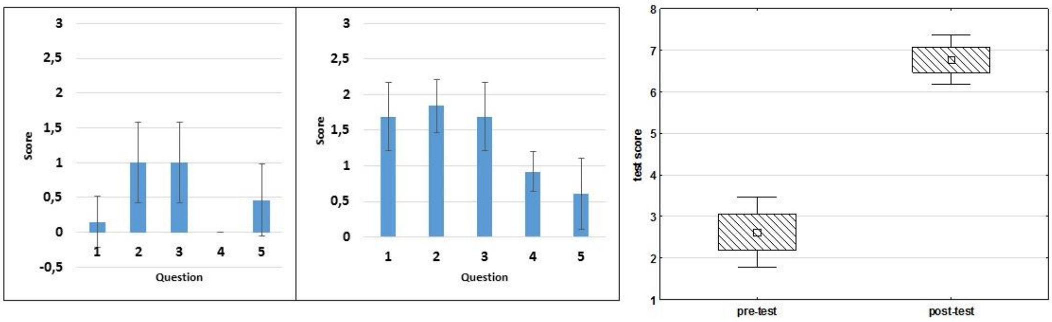
5) The morning dew condensing on a leaves a) warms up, or b) cools down the plant? *(a=1 point)*

In a total 13 pre-service teachers in the first year of their master studies took part in this survey (1 male, 12 females). The results of the tests were statistically evaluated by using STATISTICA 12 PC package (StatSoft Inc.) and the differences between the pre and post-test were compared by using Student t-test.

RESULTS AND DISCUSSION

Pre-test results

According to the results of the pre-test, the level of the pre-service teachers' knowledge of the cooling effect of vegetation was very low before the lesson (Fig.2). In a pre-test the students achieved quite a low mean score of 2.61 ± 1.55 Std. Dev. (out of 8 possible points). The most difficult question was question number 4, which asked the pre-service teachers to name the physiological process that consumes the largest amount of solar energy. None of the respondents gave the correct answer; all pre-service teachers considered photosynthesis instead of transpiration as the correct answer. The respondents either did not fully understand the process of transpiration or they did not have a correct conception about the solar energy distribution across the landscape. They understood photosynthesis to be the main solar energy-consuming process in the plant. The overestimation of the role of photosynthesis and underestimation of the role of transpiration follows also from the incorrect answers on the questions Nr.1 and 2. In question Nr.1 the respondents explained the differences between the diurnal course of temperatures in a desert and a tropical rain forest by the differences in photosynthesis, consuming significantly more solar energy in a tropical rain forest and therefore decreasing the day temperatures. Similarly, on the question Nr. 2 they mostly answered that if we cut down the forest, the local climate warms up, because the lowered photosynthesis in the cut forest causes more solar energy to be radiated as a heat. Thereby we can assume that the respondents did not understand the thermoregulatory function of evapotranspiration in the local climate and did not consider transpiration as the process that transfers solar energy and prevents the plant from overheating. Further problems were found in interdisciplinary relations: The respondents did not understand the heat transfer via evaporation of water (questions Nr.5, Nr.1 and Nr.2). These results correspond to the results of previous studies aimed on the basic or high school students' knowledge of water regime of the plant (Ryplova & Bezpalcova, 2016) or plant role in environment (Ryplova, 2017), which also revealed low level of understanding of the cooling function of the vegetation via evapotranspiration. To our knowledge, no studies on the pre-service teachers' knowledge of the cooling effect of vegetation exist in the recent international literature, but according to the personal experience of the authors the knowledge of the cooling effect of vegetation is also low in other countries (this remains to be shown by future research). Several previous studies point to transpiration as a difficult subject in science education (Vitharana, 2015; Wang, 2004).



A B C

Fig.2. The detail results of pre – test (A) and post-test (B). The values represent mean score ± std. dev. C - comparison of the general results of pre- and post –test (small squares represent mean values, boxes mean value± std. dev., line segments mean value± 1,96*std. dev. t = -7,8767, p=4,15*10^{-8}, N =13.

An impact of project-based learning on the knowledge of the cooling effect of vegetation

The project-based lesson with elements of inquiry improved significantly the level of pre-service teacher' knowledge of the cooling function of vegetation. The differences between the pre and post – test (the general score) were statistically significant according to the Student t-test ($t = -7,8767$, $p=4,15*10^{-8}$).

Drought and global warming are serious problems of recent times and thus the pre-service teachers were fully interested in taking part in this project. The project-based learning was advantageous for this interdisciplinary topic. According to the Bilek and Machkova, (2014), project-oriented instruction is a method of motivating students to actively problem-solve and search for meaningful "products"/solutions. One such „product" was a possible plan of cooling the square in their own city by using vegetation. Positive impact of interdisciplinary projects in the pre – service teachers' preparation was also found by previous studies (Lindner, 2013, Machkova et al., 2015). According to the results of this pilot study, we can assume, that project-based education seems to be suitable for the topic of cooling function in the pre – service teachers' preparation. These results are to be corroborated by future research, because of the low number of respondents taking part in this pilot-study survey.

CONCLUSIONS

- The project-based lesson improved the pre-service teachers' knowledge of the cooling function of vegetation
- Education on this topic should be focused on the following critical points, based on the results of our pre-test: a) evapotranspiration b) solar energy distribution in the landscape (especially over estimated role of photosynthesis, underestimated role of transpiration) c) interdisciplinary relations - the use of laws of physics (heat conversion, evaporation, condensation) as drivers for biology (transpiration).

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Contact address:

RNDr. Renata Ryplová, Ph.D. [1]
Katedra biologie, Pedagogická fakulta,
Jihočeská univerzita v Českých Budějovicích
Jeronýmova 10
371 15 České Budějovice
e-mail: ryplova@pf.jcu.cz

doc. RNDr. Jan Pokorný, CSc. [2]
ENKI,o.p.s.
Dukelská 145
e-mail: pokorny@enki.cz