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Education for Sustainability: Innovative Teaching on Photosynthesis of Aquatic Plants in Ecological Context

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Abstract
Eutrophication due to high load of nutrients from the catchment is significant worldwide problem causing impairment of water ecosystems and water quality. The reason is tight connection of eutrophication with photosynthetic biomass production of blue green algae resulting in extreme changes of oxygen level, anoxia at the bottom and release of toxic substances in water. Acceleration and extension of eutrophication due to human activities together with insufficient human understanding of the ecological role of photosynthesis of aquatic plants leads to inappropriate water and landscape management resulting in further loss of clear water. To save enough clear water supplies for future generation it is necessary to improve human understanding of these processes starting already from school education. This contribution brings results of a survey aimed on the impact of developed innovative teaching activity on photosynthetic biomass production of aquatic plants in ecological context and using digital technologies which was implemented into the education at Czech upper secondary schools. Significant improvement of student understanding of ecological function of photosynthetic biomass production in water and increase of attractiveness of plant education for students were proved. The contribution of innovative teaching on photosynthetic biomass production in ecological context for sustainable education is discussed.

Keywords: Plant blindness, Aquatic plants, Eutrophication, Sustainable Education, Water.

1. Introduction

Eutrophication due to excessive nutrient enrichment has been a major problem in European freshwaters for the several last decades (EEA, 2012; EEA, 2015). Eutrophication has many negative consequences such as the proliferation of toxic algal bloom (Chislock et al., 2013; Ibisch et al., 2016), tainted drinking water supplies, degradation of recreational opportunities (Chislock et al., 2013), the loss of aquatic biodiversity (Ibisch et al., 2016) or hypoxia causing sometimes mass fish kills (Chislock et al., 2013).The cause of these consequences is the tight connection among eutrophication and photosynthetic production of aquatic plants. High nutrients load causes an accelerated growth of algae and plants due to the higher rate of photosynthesis, resulting in a wide range of impacts on aquatic ecosystems.(Barznji, 2014)
Besides internal causes like nutrient loading from sediment (Søndergaard et al. 1999), eutrophications is caused primarily by nutrient discharges from human activities (Withers

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et al., 2014). To ensure sustainable water management, it is consequently necessary to improve general awareness and understanding of the interconnection among the plant biomass production and eutrophication and the role of plants for aquatic ecosystems in general.
Unfortunately, there are significant barriers for the enhancement of human awareness of these processes. The first one is an overall spread phenomenon of "plant blindness" described by Wandersee and Schussler (1999) explaining the inability of people to notice plants in the surrounding environment or even recognize their importance. One of the symptoms of this dire phenomenon, persisting for decades in our society, is the low level of knowledge (Amprazis & Papadopoulou, 2020; Ryplova & Pokorny, 2020; Pany et al., 2022). Understanding of the role of plants in aquatic systems requires an understanding of their photosynthetic biomass production with all its circumstances. However, photosynthesis itself is known to be one of the most difficult topics in science education at all school levels (Carlsson, 2002; Keleş & Kefeli, 2010).

2. Theoretical framework

2.1.The role of aquatic plants in in oligotrophic and eutrophic waters

Aquatic plants i.e. microscopic algae, blue greens (phytoplankton) and macroscopic mosses, filamentous algae, higher plants (macrophytes) are an inseparable part of aquatic ecosystems (Pokorny & Kvet, 2004). They fulfil a wide range of ecological roles, and contribute substantially to the structure, function and service provision of aquatic ecosystems (O'Hare et al., 2018).
Photosynthetic autotrophic organisms evolved first in water, the first of which, cyanobacteria, began to supply oxygen to the atmosphere until later plants moved onto land and gradually evolved into vascular plants and massive trees which are able to regulate climate by evapotranspiration in their stands. (Pokorny & Kvet, 2004).
Photosynthesis of aquatic plants (production of plant biomass) is a fundamental process that determines oxygen concentration in water, pH changes and food supply for other organisms. Plant biomass that serves as a source of food/energy for other consumers or else it is not consumed but deposited on the bottom where it undergoes decomposition with oxygen consumption, carbon dioxide release and a decrease in pH, whereby nutrients are released back. In this way, biomass determines the environmental conditions at the bottom. (Pokorny & Bjork 2010)
In oligotrophic waters, biomass of water plants is low, limited by a lack of nutrients. Therefore, macrophytes develop which are able to take nutrients via their roots from sediment. Examples include oligotrophic glacial and alpine lakes, some quarries, sand pits and forested reservoirs with a low nutrient external load from catchment. (Pokorny & Bjork 2010)
Increasing the amount of nutrients from agriculture fields, waste waters and direct fertilization results in the development of plants which take nutrients directly from water via their leaves or whole body (phytoplankton). Under the impact of higher nutrients, both biodiversity and total biomass of plants increases. Nutrients accumulate in plant bodies. Macrophytes provide shelter and substrate for spawning fish, for insects as well as for nesting birds. Plant biomass is a source of energy and nutrients for further steps of the

food chain, phytoplankton for zooplankton, macrophytes for birds, insects etc. A functioning food chain, i.e. transfer of energy and nutrients from plant biomass via zooplankton to fish and birds occurs under the condition of good water quality. (Pokorny et al., 2008, Hesslerova et al., 2012)
Fish very often consume zooplankton (small crustaceans), and subsequently the organisms that feed on phytoplankton are missing and therefore phytoplankton are not consumed but accumulate in the water column so water transparency decreases. The dead phytoplankton gradually accumulate on the bottom and in this manner the absorbed nutrients consequently accumulate on the bottom as well. The sediments on the bottom are then a source of nutrients in summer when they warm up and the intense bacterial activity reduces the oxygen content and releases phosphorus and ammonia into water (Baxa et al. 2019).
The limiting condition in oligotrophic waters is nutrient , while in eutrophic waters plants compete for light and carbon dioxide. Fast growing plant biomass due to the high nutrient load in eutrophic waters prevent light from reaching the bottom. The high rate of photosynthesis is accompanied by the release of oxygen and the photosynthetic uptake of carbon dioxide is accompanied by an increase in pH. The pH values influence forms of carbon dioxide available for the photosynthesis in water. At pH value 8.3, only the ionic forms of carbon dioxide, i.e. bicarbonate and carbonate, are present but free carbon dioxide is absent. Macrophytes use mainly dissolved CO_2 for photosynthesis and mostly fail to use the ionic forms so they give way to phytoplankton or are overgrown by algae (periphyton) and then die. Dead plant biomass is deposited on the bottom where it undergoes decomposition with oxygen consumption while nutrients are released back and periods of oxygen deficiency occur, leading to anaerobiosis and the release of toxic substances (sulphate, ammonia, methane). Nevertheless, algae and cyanobacteria in particular are able to photosynthesize even at a pH around 10 (Ondok & Pokorny 1987, a, b)
The effect of aquatic plants on the aquatic environment is relatively easy to observe as changes in the oxygen concentration and pH which reflects CO_2 concentration. Even in water, the photosynthetic quotient is valid - for every molecule of carbon dioxide taken up, one molecule of oxygen is eliminated; the uptake of carbon dioxide is accompanied by a rise in pH, because carbon dioxide is an acid-forming substance. If bicarbonate is used, hydroxyl (OH^-) is excreted and calcium carbonate may coagulate on the leaf surface. (Pokorny et al., 1989)
The body of aquatic plants contains over 90 % water. The dry biomass contains about 95% organic matter and the rest are minerals calcium, magnesium, potassium, nitrogen, phosphorus etc. Thus, aquatic plants bind minerals and nutrients in themselves and reduce the trophic (nutrient) value of water (Pokorny et al., 1989). This ability of plants to remove accumulates and decomposition in waters is used also in phytoremediation for removing toxic substances or pollutants (Barznji 2014; Najila & Anila, 2022). The rate of biomass formation can be measured as oxygen production, because according to the photosynthetic equation, an oxygen production of 192 grams corresponds to 180 grams of sugar, the basic component of cellulose and starch, formed. pH increase is proportional to CO_2 uptake and can be calculated on basis of carbonate equilibria. (Pokorny & Ondok, 1991)

Photosynthesis of aquatic plants is relatively easy to determine because oxygen is not very soluble in water, the amount of oxygen in a unit volume of water is 30 times lower than in the same volume of air. Photosynthesis in aquatic plants is therefore manifested by changes in oxygen concentration that normally exceed 100% saturation in air. For example, at 20° C, air-saturated water contains approximately 9 mg of oxygen in 1 litre; however, photosynthesis of aquatic plants can double the oxygen concentration to 18 mg/l. Conversely, very low oxygen concentrations, at most a few mg/l, are found near the bottom even in shallow water around 1 m, because in eutrophic water, when there are high levels of phytoplankton (algae, cyanobacteria) or macrophytes, it is dark near the bottom. Light penetrates at most to a depth of a few dm. (Pokorny & Kvet, 2004).

2.2. Photsynthesis of aquatic plants - important topic of sustainable education

Plant blindness and related insufficient knowledge of plant physiological processes are significant barriers for human effort to reach the Sustainable Development Goals (SDG). Among others, the SDG No 6 (clean water and sanitation) cannot be analyzed and implemented without taking plants into proper consideration (Amprazis & Papadopoulou, 2020). Eutrophication causing water quality degradation associated with nutrient enrichment poses a serious threat to potable drinking water sources (Chislock et al., 2013). Cyanobacterial blooms as a consequence of eutrophication prevails in surface waters all over the world (Smith & Schindler, 2009). Human population growth together with the climate change are supposed to contribute to an even further degradation of water quality and quantity (Paerl & Paul 2012). Hence, there is an immediate need to minimize those human activities causing the so-called "cultural eutrophication" of waters. This requires among other things the improvement of a general understanding of the aforementioned relations between eutrophication and plant physiological processes. This must be accomplished via the improvement of science education in schools. Therefore, enhancing awareness regarding the role of plants in waters and improving the understanding of photosynthesis of water plants in relation to eutrophication is a crucial task for science educators and an inseparable part of education regarding sustainability.

Photosynthesis is internationally considered one of the most difficult topics of science education. Among other issues, students have difficulties understanding connections between plant nutrition, photosynthesis, and plant growth (Carlson, 2002; Hershey, 2005; Marmaroti & Galanopoulou, 2006) as well as the energy transfer from solar energy into the biomass (Eldridge, 2004; Marmaroti & Galanopoulou, 2006). A barrier for the students' understanding of photosynthesis seems to include the overall abstraction of the photosynthetic process (Hershey, 2005) and low interest of students in plants generally which is intimately related to the phenomenon of plant blindness (Amprazis & Papadopoulou, 2020). Innovative educational approaches are therefore necessary which will attract and motivate students to the study of photosynthesis of aquatic plants and help visualize these processes. To enhance attractiveness of science education, inquiry education is widely recommended and used (Rocard et al., 2007). For the visualization of complex phenomena in science education, the use of digital technologies was found to be effective (Keleş & Kefeli, 2010; Tran et all. 2017).

Despite the high importance of the plant's role in eutrophic waters, quite little attention is paid to this topic in science education or didactic research. The level of students' knowledge on the role of aquatic plants in waters and the role of their photosynthetic production in correlation to eutrophication are inadequately conveyed in international scientific publications. There are just few studies for primary school level (Feio et al., 2022). On the other hand, aquatic plants are frequently used in students experiments on photosynthesis, but these experiments are mostly carrying on under laboratory conditions. Experiments on photosynthesis of aquatic plants are highly illustrative (Eldridge, 2004), because after the exposition to light, they release bubbles of oxygen. Counting bubbles upon the light has been a traditional method for quantifying photosynthesis since its development from the 18th century until now (Bowes, 1989).

3. Methodology

3.1. Innovative teaching/learning activity for upper secondary school

An innovative teaching/learning activity was developed and implemented into the education in the region of South Bohemia. This area is known for the multitude of wetlands and many ponds, among other complex systems of artificial fishponds, for instance the Třeboňské rybníky, Ramsar site and the UNESCO Biosphere reserve. In recent times, a lot of these fishponds have suffered from eutrophication.
In the creation of this educational activity, a dynamic collaboration unfolded, uniting science educators from the Faculty of Education, University of South Bohemia in České Budejovice with scholars from the scientific institution ENKI, o.p.s., who lent their knowledge in the field of hydrobiology and ensured the inclusion of robust scientific content specifically relating to these fishponds. Together, they crafted a pedagogical methodology, seamlessly merging their expertise. This novel teaching activity underwent development and testing as part of a project supported by the Technology Agency of the Czech Republic (TACR). The activity employs the inquiry approach supported by the use of digital interactive textbook on the topic of photosynthesis of aquatic plants. Within the activity, the common light and dark bottle method, which is frequently used for the determination of photosynthesis in the classroom (Eldridge, 2004, Ray & Beardsley, 2008) is applied in an out-door activity for the measurement in eutrophic pond. The method is based on the two bottles with water from eutrophic pond, one of them in a dark condition (inside of a dark box), another under the sunlight. Aquatic plants under light conditions produce oxygen, therefore bubbles of oxygen appeared in the light bottle and measurable oxygen concentration increases. Due to recent technological developments, besides the traditional bubble counting experiments, a more sophisticated method for the school experiments has become available in recent years using optical sensors for the measurement of dissolved oxygen in water which was used in hands-on activities within the structure of this teaching activity.
One-day inquiry-based outdoor teaching activity was developed based on the 5E model of inquiry (Engagement, Exploration, Explanation, Elaboration and Evaluation; Carin et al., 2005).

Engagement was accomplished via two bottles of water, one of them containing aquatic plants (algae), and both exposed to sunlight. Students were asked where the bubbles in the bottle with algae come from?

Exploration: During this phase, students made their own discoveries by using a pilot version of the interactive workbook on photosynthesis which was developed by the authors of this contribution. The interactive workbook is available in their tablets or mobile phones. Drawing from this information, students are encouraged to exercise their creativity by crafting their own hypothesis, which will be reviewed and guided by the teacher. Their hypothesis centers around the notion that aquatic plants produce oxygen when exposed to light. To put this idea to the test, a captivating and hands-on outdoor experiment is proposed, utilizing dark and light bottles as the testing grounds. The experiment employs the optical oxygen sensor described earlier to measure the oxygen levels and verify the validity of their hypothesis. Through this engaging process, students embark on a journey of discovery, gaining valuable insights into the remarkable world of aquatic plants and their vital role in the production of life-giving oxygen.

In the phase of **Explanation** which follows after this experiment, the students in groups reach conclusions of their results and introduce them during the discussion with their peers and teacher. Finally, the teacher summarizes the findings supported by the use of interactive workbook in the tablets and mobile phones of the students.

In the phase of **Elaboration**, students apply the dark-light bottles method with a water sample from a specific eutrophic pond to calculate the primary biomass production from the measured oxygen production using the photosynthesis equation. The simultaneous pH measurements will show to the students how high the pH reaches and as a consequence what this means for calcium carbonate, the form of ammonia nitrogen, and competition between aquatic plants for carbon. An illustrative and relatively easy method is to measure the oxygen concentration, pH and temperature of the water throughout the day in a vertical profile of the water column. On a sunny day, students observe an increase in oxygen concentration and pH, as well as a temperature stratification from a uniform distribution in the morning to a marked temperature stratification, oxygen supersaturation and higher pH in the euphoric zone and low oxygen concentration and pH below the euphotic zone. Likewise, on a sunny day, the upper layer of water, which is lighter, warms up and cooler/heavier water remains near the bottom. Then overnight, the temperature profile mixes to about 2m depths. Students will realize that each day, nutrients from the bottom sediments enter the water column while this mixing does not occur in deep water, so there is less primary production. In shallow water, we are in epilimnion. The light conditions in the water are easily described using a Secchi Plate, employed to determine the transparency of the water. Students also measure incoming solar energy using a relatively inexpensive instrument to assess the relationship between incoming solar energy and the rate of photosynthesis.

From the measured oxygen concentrations, students calculate the oxygen production per unit area of the tank and use the photosynthetic equation to calculate the amount of biomass produced (the amount of bound energy in this biomass) and discuss the future fate of this biomass in the food chain. Students then roughly determine the size of the zooplankton and assess how the food chain works. Knowledge of the fish assemblage is an advantage. Students work with three possible food chain alternatives and discuss how

to optimize the flow of substances and energy from primary production to fish, thus exploiting natural primary production in eutrophic conditions.
The phase of **Evaluation** is supported by interactive tasks of interactive workbook again, which allows the students to prove repeat their knowledge and the teacher to receive feedback. The interactive tasks of the workbook include animations simulating different nutritional conditions in water as well as different light conditions. These animations simulate the invisible life under the water and enables its visualization.

3.2. An impact of novel teaching activity on students' knowledge and plant awareness

The new teaching activity was implemented into the education at 5 South Bohemian upper-secondary schools. A didactic pre/post-test survey was conducted with an aim to find an answer on the main research question: Can this innovative teaching activity improve students understanding of plant role in water ecosystem and increase students' awareness of aquatic plants?
In a total 244 upper-secondary school students of 1st grade, (15 - 16 years old) took part in this study. The students in each school were randomly divided into two groups. Focus group was then taught by using the new teaching activity including inquiry approach, interactive workbook with animations and digital measuring devices in student outdoor experiments. The control group was taught by traditional teacher- centered transmissive education without interactive workbook and without any experimental activity. Prior to accessing the learning activity, the students were required to complete a pre-test using a questionnaire consisting of 12 questions focusing on 3 areas:

1) Understanding of photosynthesis: example questions:
   a) Select the true statement
      1) During the day, there is more oxygen and less carbon dioxide in the water of a pond with aquatic plants than at night
      2) At night, there is more oxygen and more carbon dioxide in the water of a pond with aquatic plants than during the day
      (3) The amount of oxygen and carbon dioxide in the water of a pond with aquatic plants is equal during the day and at night
   b) Can the oxygen concentration in a pond be higher than it is when the water is 100% saturated with air? Justify your answer
2) Understanding plant role for water ecosystem, example questions:
   a) Why are aquatic plants important ?
   b) During summer, the pH of the pond water decreases or increases? Justify your answer.
   c) Plants affect the coagulation of calcium carbonate in the water. Explain how.
3) Understanding correlation between photosynthesis and eutrophication, example questions:
   a) What organisms make up an aquatic bloom ?
   b) Why does a water bloom form?
   c) In water with high nutrient content, some plants may lack one mineral and therefore die. What is this mineral and how is it possible?

The total possible amount was 12 points, 4 points in each particular area, each correct answer was awarded by 1 point. The last question of the questionnaire was the Likert 5 grade scale, asking the students to assess the importance of aquatic plants for water ecosystem.

The post-test replicated the items of pre-test and was carry out immediately after the education. Upon the conclusion of the post-test, the students were invited to reflect on their educational journey, posing the question of whether they had enjoined education or not and why (open type question). The differences in the results among pre-test and post-test and among the groups were analyzed using two-way analysis of variance (ANOVA) and Tukey HSD post hoc test, the differences in students‘ assessment of the importance of aquatic plants for water ecosystem were analyzed by using Wilcoxon test (The STATISTICA 12 PC package, StatSoft Inc.).

4. Results and discussion

From the pretest's findings follows, that the Czech students from upper secondary schools, partaking in our survey, had not fully embraced the significance of aquatic plants within water ecosystems and did not understand properly the processes by which aquatic plants influence the water bodies. They also do not consider aquatic plants as important, students of both groups assessed in pre-tests the importance of aquatic plants on the 5 grade Likert-scale as middle important (Median=3, Fig. 1). The participants from both groups also reached very low pre-tests' results in all tested areas (Fig.2): In the area of understanding of photosynthesis the focus group taught by inquiry approach supported by digital interactive workbook (marked as "IBSE" in graphs) reached 0.95 ± 0.79 Std. Dev. control group (marked as "C" in graphs) 1.02 ± 0.80 Std. Dev out of 4 possible points, in the area of understanding plant role for water ecosystem the focus group reached 0.52 ± 0.33 Std. Dev. control group 0.5 ± 0.32 Std. Dev out of 4 possible points, in the area of understanding correlation between photosynthesis and eutrophication the focus group reached 0.92 ± 0.58 Std. Dev. control group 0.85 ± 0.7 Std. Dev out of 4 possible points. No significant differences were found between pre-test results of both groups in all areas.

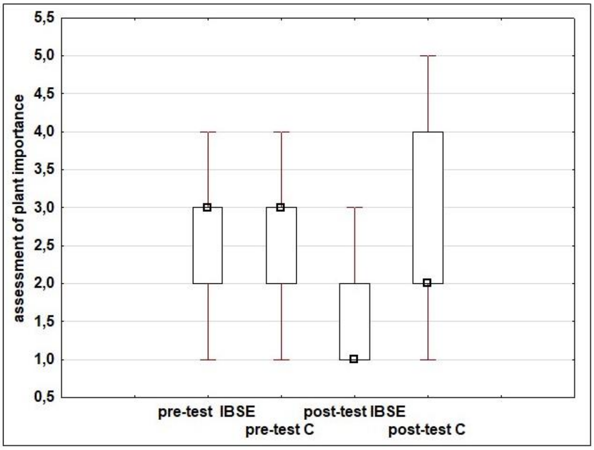

Fig.1: Students' assessment of the importance of aquatic plants for water ecosystem. 5 -grade Likert scale, 1= plants are very important, 5= plants are unimportant for the water ecosystem. Small squares represent median values, Small squares represent median values, boxes quantiles 25 – 75 %, line segments min-max values, N=244.

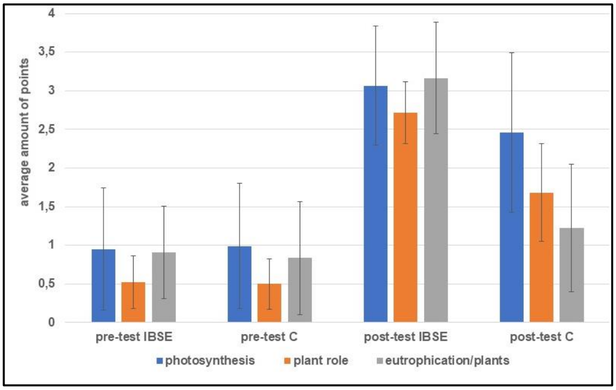

Fig.2: Comparison of students' understanding of focused areas (1. photosynthesis, 2. plant role for aquatic ecosystem, 3. correlation between photosynthesis and eutrophication) among both groups before (pre-test) and after (post-test) education. IBSE= focus group taught by new teaching activity, C= control group taught by traditional transmissive education. Line segments represent std. deviation, N=244.

Our results of pre-tests are consistent with previous research demonstrating students' difficulties in understanding photosynthesis. Among our respondents also previously known photosynthesis – respiration misconception was detected (Keleş & Kefeli, 2010), 15 % of our respondents did not believe that plants respire the whole day, they believed that plants respire during night only. The students did not know that aquatic plants can take up different forms of carbon and that carbon in an adequate form is a limiting condition for some of them. There was very little knowledge of the role of plants in the aquatic ecosystem. Surprisingly, most students saw the importance of plants only in the production of plant biomass as food for other consumers in the food chain. Particularly striking was the fact that the vast majority of students did not mention the importance of plants as oxygen producers for the aquatic ecosystem. Photosynthetic oxygen production by aquatic plants was mentioned by only 12 % of respondents in the pre-test. Only 2 respondents (1 %) knew that plants affect the pH in water through the process of photosynthesis and correctly answered that the pH in the pond increases during summer. No one knew how plants affect the coagulation of calcium carbonate in the water. Only 30 % of the respondents knew that water bloom is formed by cyanobacteria, but none were able to explain why water bloom is formed.

Positive impact of tested activity on student knowledge was proved by post-tests (Tab.1). The respondents of IBSE groups reached significantly higher average amount of points compared to pre-test results in all particular focused areas. On the other hand, the control group reached significantly higher average amount of points in post-test compared to pre-test just in case of understanding plant role for water ecosystem.

Tab.1: Comparison of students' understanding of focused areas – statistic evaluation of the differences among both groups before (pre-test) and after (post-test) education. IBSE= focus group taught by new teaching activity, C= control group taught by traditional transmissive education. Two-way ANOVA and Tukey HSD post hoc test, different letters mean statistically significant differences ($P \leq 0{,}01$), N=244.

		Understanding photosynthesis			**Understanding plant role for water ecosystem**			**Understanding correlation photosynthesis - eutrophication**		
	Group	Mean	SD	HSD	Mean	SD	HSD	Mean	SD	HSD
Pre-test	IBSE	0.9508	0.7909	a	0.5227	0.3376	a	0.9166	0.5800	a
	Control	1.0254	0.8002	a	0.5000	0.3269	a	0.8484	0.7042	a
Post-test	IBSE	3.0655	0.7685	b	2.7196	0.4016	b	3.1515	0.6933	b
	Control	2.4576	1.0348	ab	1.6818	0.6308	c	1.2803	0.8225	a

The most significant effect of absolved teaching activity was detected in case of the students' assessment of plant importance for water ecosystem. The median value in case of focus IBSE group increased significantly from 3 in pre-test to 1 in post-test (Wilcoxon test, $Z=10.14$, $p=3.47*10^{-24}$). It means, the teaching activity helped the students to realize plant importance in their environment. On the other hand, the median value in case of control group increase from 3 to 2 only, but the increase was not statistically significant according to the Wilcoxon test ($Z=1.3189$, $p=0.1871$).

The adoption of the new teaching activity was met with success, with over 80 % of the pupils enjoying this approach to education. Students' responses describing their motivation were categorized into four groups: For 62 % of the students, the allure of real-life examples in education proved to be a draw. A significant 55 % of respondents expressed their enthusiasm for interactive workbooks. Animations in the workbook received a resounding endorsement from 42 % of students, they indicated animations in workbook like "amazing" or "cool". Additionally, 41 % of pupils cherished the joys of outdoor education, relishing the chance to step outside the traditional classroom setting. In relation to students' preferences for outdoor education there is also a possible limitation of this study, because outdoor education itself is considered as motivating for students by previous studies (James & Williams, 2017).

Based on the results of our survey, we may credibly conclude, that the students' awareness of aquatic plants before the teaching was very poor. This fact is even more alarming, considering the fact, that these students come from area with many ponds and therefore they meet aquatic plants frequently as important part of their environment. We can speculate about the phenomenon of plant blindness which could be in case of aquatic plants even deeper than in case of terrestrial plants. Submersed aquatic plants, algae or cyanobacteria in ponds are more invisible for the students than terrestrial plants. From this reason it could be hard for the students to experience the processes by which aquatic plants influence their environment. Stagg and Dillon (2022) concluded in their study that plant blindness (renamed recently also as plant awareness disparity), could be related to a decline in relevant experience with plants.

In Europe ponds form a significant part of the continental freshwater resource (Oertli et al., 2009) and as mentioned above, aquatic plants influence significantly the water quality of these ponds. From this reason, it is crucial to improve understanding of the role of plants in water ecosystem based on their photosynthesis via the innovative sustainable education. The use of digital technologies is considered as a possible innovative way in science education increasing student motivation and engagement (Alt, 2018; Taber, 2017) According to Tran et all. (2017) modern digital technologies, enables to visualize complex or microscopic phenomena in nature and by this way help students to understand them. In this teaching activity digital animations and interactive workbook were used to visualize processes of photosynthetic biomass production in relation to eutrophication. Positive impact of our novel activity on student knowledge of photosynthesis agrees with previous research of Taber (2017) who concluded, that the use of digital technologies together with constructivist approach in education (in our case inquiry-based learning) can improve understanding of photosynthesis. Majority of students (62 %) appreciated the embedding of the experiments into real life via the measurement of photosynthesis in real eutrophic pond. Also, previous study of Carlson, (2002) highlights the necessity of so called „ecological understanding" as effective way of teaching photosynthesis. In our activity we show how photosynthesis of aquatic plants affects the aquatic environment. From measured photosynthesis rates in the laboratory using the light and dark bottle method, we go into the real pond and explain the relationships in water quality changes (oxygen content, pH change, calcium carbonate precipitation), calculate the amount of plant biomass produced by photosynthesis from measured oxygen production based on the photosynthesis equation. The students learn, that the amount of plant biomass created by photosynthesis (primary production) is then used in the next steps of the food chain (zooplankton or macrophyte grazing) and the species composition and size of the fish then determines whether phytoplankton dominate (carp and small fish consume zooplankton) or whether zooplankton consume algae (predation by predatory fish) and macrophytes dominate at high water clarity.

Differences in oxygen concentrations in the light and dark bottles indicate differences in oxygen concentrations between day and night in water bodies and a possible lack of oxygen at night at high respiration rates. Increased pH in the light bottle indicates diurnal dynamics of pH values in eutrophic water and possible precipitation of calcium carbonate on the leaf surface. Here we highlight the function of the most abundant buffer of the seas and most fresh surface waters and blood, i.e. carbonate equilibrium. The students are faced also to the problem of well-buffered calcareous waters and the problem of acidic waters that need to be hardened.

5. Conclusions and implications

Aquatic plants play deciding role in water ecosystems and under eutrophication this role is increased. However, according to the results of our didactic survey, students' pre-instructional understanding of plant role in water bodies is poor. The signs of plant blindness (plant awareness disparity) were detected. The tested innovative teaching activity, carried out in real conditions of eutrophic pond and using modern digital technologies like interactive workbook and digital animations for better visualization of the processes under water, improved significantly students' understanding of photosynthesis of water plants as well as role of plants in water ecosystem and helped the students to understand the correlation among the photosynthetic biomass production and eutrophication.

The problem of plant blindness (plant awareness disparity) seems to be very important in case of aquatic plants. This study shows possible way of improvement of plant awareness via innovative teaching of photosynthesis.

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