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DISCOVERING PHOTOSYNTHESIS BY EXPERIMENTS

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Abstract. By photosynthesis, plants are converting light energy into chemical energy. Photosynthesis is studied in physics and biology classes starting from the middle school, but it is not so easily understood by the students. An alternative solution to study photosynthesis is the project-based design approach, using specific experimental activities. In this paper, we will present, in an elementary way, some methods and physical means used in the study of photosynthesis by the middle school students.

Key words: photosynthesis, project-based design, middle school.

1. INTRODUCTION

Nowadays in schools, new experiments and new pedagogical approaches for teaching life processes, like photosynthesis, have been developed [1]. Photosynthesis is one of the issues that can be approached by teachers of natural sciences, both in the middle school and in high school. Therefore, the study of photosynthesis must be addressed in an interdisciplinary manner. The teacher must be able to integrate knowledge and models of thinking drawn from two or more disciplines, to produce a cognitive advancement, for example, explaining a phenomenon, solving a problem, creating a product or raising new questions [2–3]. At curricular level, the integration involving the establishment of clear relationships between competent attitudes and knowledge belongs to different disciplines.

In classical education, the competences and methods used by the teacher to assimilate knowledge are too numerous for the students to understand the phenomena. School curricula and textbooks must be subjected to a number of changes, so that students can correctly understand the phenomena. At high school, the students can understand this natural process more easily because they have some knowledge of quantum mechanics, spectral analysis, emission/absorption spectra or molecular energy levels.

Teaching and learning are two phases of an interactive process. Learning is the product of the effective teaching. The way of teaching requires that the teacher

understand profoundly the material being taught, the best strategies to teach the material, and how students learn [4].

The study of photosynthesis is based on two types of methods: traditional methods, that are expositive, and modern interactive experiments.

In the traditional teaching, the lecture content is well organized and presented. Teachers mainly focus on how to deliver knowledge and students attend the lecture, listening and taking notes. At the end of the lecture, the students review their notes and recall the information. In this way of teaching, the students are passive partners and they being only centered on passing the examination. Therefore the teacher must combine this way of teaching with modern teaching techniques, like multimedia materials, PowerPoint slides or computer simulations, to actively capture the attention of students and to make the lecture more interesting [4].

A considerable interest must be paid to experimental and new pedagogical approaches for teaching complex phenomena like photosynthesis. In the experimental approach, which is a project-based teaching, the students are encouraged to work together, inside a team, to discover the importance of principles and processes of the photosynthesis. There are advantages of project-based teaching, but disadvantages, too. One of the advantages of this type of teaching is the effective participation of students that learn to work as researchers, using various tools and materials. An interesting student's project was presented by Govindjee [5] who, based on analogies, used students volunteer acting as specific molecules in order to explain the phases of the photosynthesis. In the project-based teaching, the students have, also the possibility to solve interdisciplinary problems, to collaborate and to present their work [6]. On the other hand, a disadvantage of this approach is the difficulty of teachers to evaluate the work of each member of the team.

2. OBJECTIVES

This article aims to investigate some important tasks regarding the study of photosynthesis in middle school: to what extent do middle school students understand important concepts of photosynthesis: the role of chlorophyll in photosynthesis, of the light as the energy source, and of CO_2 as the carbon source for plants. The study of photosynthesis by students implies setting the objectives in a clear manner. Thus, based on these goals, students will be able to track and fulfill the tasks they are given and correctly perform the experiments.

In the study of photosynthesis, the students must be oriented to:

a) identify the cell parts involved in the process of photosynthesis;

b) explain the functions of cell structures in the photosynthetic process;

c) be able to assemble the equipment needed to measure the rate of photosynthesis of a chosen plant *e.g.*, *Elodea canadensis,* a common water plant native to North America;

d) identify the products of photosynthesis (e.g. oxygen);

e) analyze the effect of light on the rate of photosynthesis by:

i. counting bubbles of oxygen given off by *Elodea canadensis* their number being proportional with the rate of photosynthesis,

ii. changing the conditions of photosynthesis by altering both the light intensity and light colour (white, red, blue, and green), and comparing the rates of photosynthesis in different light conditions.

3. MATERIALS AND METHODS

The materials required for this experiment for each group of the students are: lamps with different colours of light: white, red, blue, and green, tubes, sodium bicarbonate, *Elodea canadensis* branches, and a ruler.

The teacher will divide the students in groups each group measuring the number of bubbles released by *Elodea canadensis* using coloured light.

Elodea canadensis is frequently used in aquaria to help the oxygen balance, as it produces oxygen when it is exposed to light. Actually, one can observe, by counting the oxygen bubbles given off by the plant. In order to follow the influence of temperature on the water dissolved oxygen, a Voltcraft DO-100 oxymeter was used.

4. THE WAY OF TEACHING AND THE EXPERIMENTAL PROCEDURE

Photosynthesis is an essential concept in understanding energy transformations both in the case of middle school students and high school students. An important factor in student learning is how well the teacher perceives the students' misconceptions and conceptual understanding. The new vocabulary words are the most difficult part of learning about photosynthesis for middle school students. They are no longer learning the simple parts of the plants (stem, leaf, roots), but they are finding out chloroplast and chlorophyll, and how the plants uses sunlight and water to produce their own food. The students will need practice with this vocabulary in order to recognize it and learn the meaning of the terms. The teacher must be able to predict the students' responses at the end of class, relative to the student real gain.

The teacher has to apply appropriate teaching strategies to help students to give up or modify their commonsense ways of thinking in favour of the true

concept of photosynthesis. The teacher may use the following general strategies [7]:

1. getting students by asking questions that will encourage them to think on the plant world; making connections between their knowledge on plants and the concept of photosynthesis;
2. diagnosing student difficulties and proving corrective feedback;
3. changing the native ways of thinking, because many students have difficulty to change conceptions they have previously acquired and to accept a scientific explanation of photosynthesis;
4. providing opportunities for practice and applications; students need to see how difficulties or not to change conceptions they have previously acquired and to accept a scientific explanation of photosynthesis. Teachers have to conduct the activities in a way that allow to the students to practice and apply new concepts.

The experiment presented in this paper allows students to demonstrate their first acquired knowledge on plants and photosynthesis. The students are stimulating to begin this activity by brainstorming concepts about plants. Students are advised to write the new words or concepts on their papers and to draw lines to show the relationship between all of the words including also connecting words (e.g., requires, produces, absorbs, reflects etc.) to clarify the connections.

The teacher will ask students two questions in order to determine if they are be able to identify that photosynthesis occurs in any cell that contains chlorophyll. The first question will be: In which part of the plant does photosynthesis takes place? Chose from the next points: a. Photosynthesis takes place in the roots; b. Photosynthesis takes place in the leaves; c. Photosynthesis takes place in all green parts of the plant; d. Photosynthesis takes place in the whole plant body [8]. The next question will be: Which part of the plant contains chlorophyll pigment? Chose from the next points: a. the roots; b. the leaves; c. the green parts of the plant; d. the whole body plant [8]. The teacher will comment with students their responses in order to establish proper scientific bases on photosynthesis. The steps proposed to students for the development of the knowledge and for the achievement of experiment are:

a) cutting few bottom leaves from the plant stem;
b) cutting diagonally the stem with a blade;
c) placing the plant into the test tube with cut side up and filling with water;
d) placing the test tube to different distances from the light source;
e) observing the effect of light on the rate of photosynthesis by counting the number of released oxygen bubbles;
b) determining the total amount of oxygen evolved in photosynthesis as a function of light intensity modifying the distance (i.e., plant-light source) and light quality (*i.e.*, colour).

5. RESULTS AND DISCUSSIONS

5.1. THE EFFECT OF LIGHT COLOUR ON THE PHOTOSYNTHESIS RATE

When the students reach middle school, they have previous ideas about photosynthesis from early age and some of them still hold on to their ideas and demonstrate their lack in understanding this phenomenon. Teachers must know that their students have misconceptions on this phenomenon and also must to address their students' misconceptions. A common way to focus on student thinking and to incorporate current ideas to them building correct concepts is the experiment.

Very simple experiments allow students to observe both the effect of light intensity and of light quality (*i.e.*, its colour) on the rate of photosynthesis on *Elodea canadensis*. The rate of photosynthesis is defined by the rate of oxygen production per unit mass (or area) of green plant tissues. Light, carbon dioxide, temperature, water supply and availability to minerals are the most important factors that directly affect the rate of photosynthesis. The rate of photosynthesis may be determined by the number of bubbles given off by the *Elodea* branches. This experiment tests the influence both of the light colour (red, blue, green, and white) and of the light intensity on the photosynthesis rate.

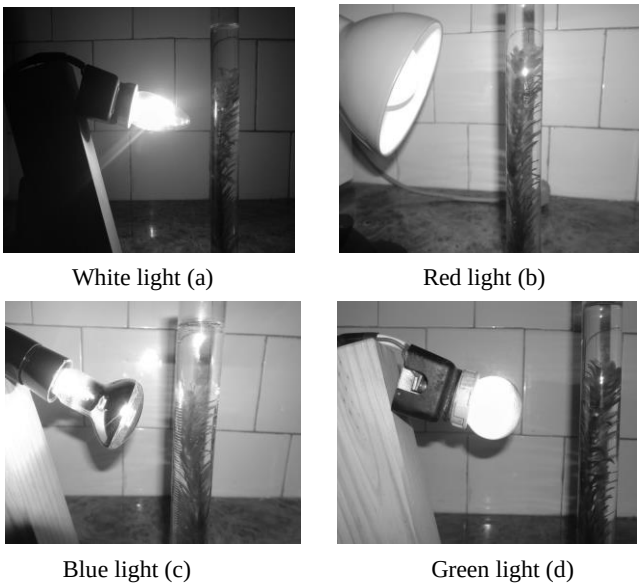

Fig. 1 – The experimental setup used to study the effect of the colours of light on the rate of photosynthesis. The water plant *Elodea canadensis* is exposed to the action of light emitted by bulbs of different colours (white: a, red: b, blue: c, and green: d).

Table 1

Variation of the oxygen amount (number of bubbles) given off by Elodea canadensis with light colour and intensity after 20 s of light exposure. Light intensity is indirectly appreciated by the distance between plant and the light source

Distance between the plant and light source (cm)	White light	Red light	Blue light	Green light
5	45.6	41.6	36.4	27.4
10	34.4	30.2	25.0	18.8
15	24.4	21.2	17.2	12.2
20	14.2	11.8	10.0	7.2
25	8.2	6.6	5.4	3.6
30	4.6	3.6	2.6	0.8

Because white light consists of a spectrum of colours and because chlorophyll is green, different colours of light (*i.e*., different wavelengths) affect the rate of photosynthesis in their specific ways. Plants photosynthesize at higher rates when exposed to light wavelengths strongly absorbed by chlorophyll and at lower rates when it is exposed to wavelengths weakly absorbed by the chlorophyll (Table 1).

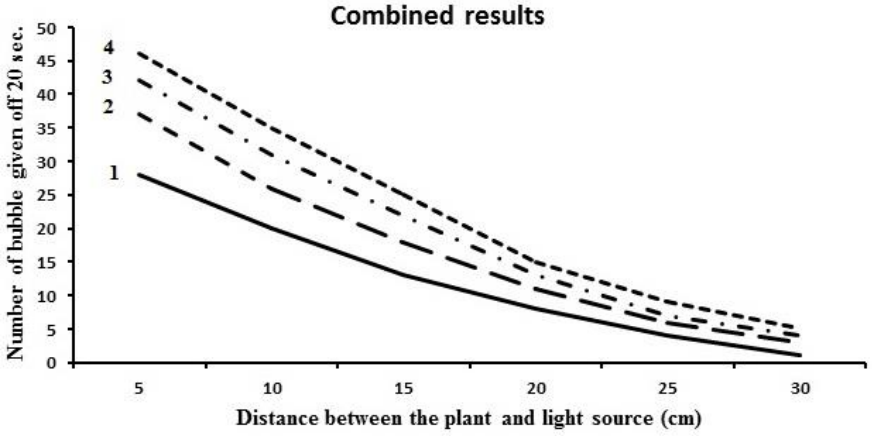

Fig. 2 – Comparison between the numbers of bubbles released by *Elodea canadensis* illuminated with different colours (1: green light; 2: blue light; 3: red light; d: white light) and bulbs positioned at different distances from the test tube.

Photosynthesis rate is directly influenced by the type of light to which the plant is exposed. The photosynthesis rate is maximal in white light and gradually decreases in the red and blue light, with the lowest values in green light, as one can see from Table 1. In order to minimize the measuring errors, the students will be

advised to observe five times the effect of the light colours on the rate of photosynthesis. The students have noted every experiment with A, B, C, D, E and the data shown Table 1 are the averages on five experiments (A–E).

Based on the above results, the students have reached the conclusion: the largest number of oxygen bubbles (given off in photosynthesis) is obtained in white light and the smallest distance (*i.e.* the higher light intensity) between the light source and the plant, as one can see in Fig. 2. As the light source is moved away from the plant, the number of bubbles decreases. As the *Elodea canadensis* plant get further away from the lamp, the rate of photosynthesis declines as one can see in Fig. 2. The students have observed that the rate of photosynthesis declines as the light intensity is decreased in the case of all four colours. This explains the fact the light energy is directly used when the plant is giving off oxygen, therefore the more intense is the light, the higher is the photosynthesis rate. By this conclusion, students must understand that both the light colour and intensity are principal factors affecting the rate of photosynthesis.

5.2. TEMPERATURE DEPENDENCE OF THE DISSOLVED OXYGEN CONCENTRATION

Water dissolved oxygen level influences the development of aquatic plants and animals. Therefore, oxygen concentration could be an indicator of the degree of water pollution. High levels of dissolved oxygen indicate a better water quality. A large part of the dissolved oxygen is derived from oxygen in the atmosphere or is the result of the photosynthesis of the aquatic plants.

Table 2

The concentration of dissolved oxygen (DO) in the aquarium with fresh water, salt water, and plants *versus* temperature increase

Temperature (˚C)	DO in fresh water (mg/L)	DO in salt water (mg/L)	DO in water with plant (mg/L)
0	14.8	11.9	13.5
5	12.7	10.6	12.1
10	11.2	9.6	11.0
15	10.1	8.4	9.8
20	9.3	7.9	8.4
25	8.2	7.2	7.6
30	7.4	6.4	6.7

In the next stage of the experiment the teacher explains to students that the rate of photosynthesis is influenced by the temperature. This is because in photosynthesis are involved many biochemical reactions whose rates increase with temperature. So, the students are asked to observe the role of temperature on the photosynthesis rate. The students must make a comparison between aquarium normal water, aquarium salt water and aquarium plant accommodating water.

They must also measure the amount of oxygen dissolved in aquarium illuminated with different coloured radiations at different values of temperature.

Using the oxymeter (Voltcraft DO-100), the students are measuring the concentration (mg/L) of the dissolved oxygen (DO) in water. This parameter is depending on different factors, such as water temperature, salinity, and atmospheric pressure. Thus, cold water has more oxygen than warm water and contains less oxygen at higher altitudes (due to a lower partial oxygen pressure).

In these experiments, the students have compared the concentration of oxygen present in the aquarium with and without plants in it (Table 2). They also are lighting the aquarium with different coloured lights. The students have observed that the largest amount of DO is found in the aquarium with fresh water, then in the aquarium with plant (Fig. 3). They also have noticed that the amount of DO decreases with temperature. These results are presented in Fig. 3.

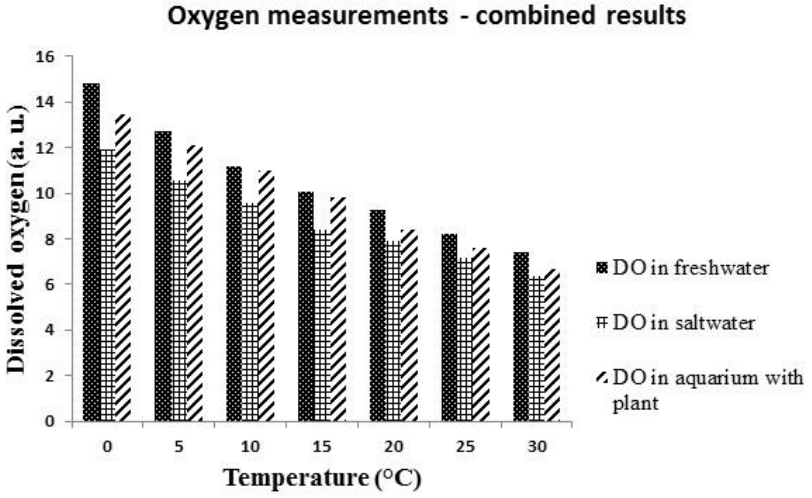

Fig. 3 – Comparison between the amount of oxygen dissolved in a fresh water, salt water and aquarium water in the presence of the plants.

Each laboratory activity must have questions at the end to aid the students to understand the new key concepts. At the end of this experiment, the teacher will test the knowledge acquired by students, by some pointed questions. For instance, the students will be asked:

Q1: Which factor is more important to photosynthesis?
Q2: Where does photosynthesis occur in plants?
Q3: Is the light energy important to photosynthesis?
Q4: How does light is influencing photosynthesis?
Q5: Which colour of light determined more oxygen release?
Q6: How important is photosynthesis for animals and people?

This questionnaire was applied to students from middle school. The research experimental group was made up of a total of 68 students, divided into three groups (classes): V A – 16 students, V B – 24 students, V C – 28 students. They were obtained the results presented in Fig. 4.

First question, Q1, refers to the knowledge of students of which factors influencing photosynthesis. As it is shown in the Table 3, about 80 % of students who responded correctly to the answer, identifying light as the main factor in photosynthesis. On Q2 and Q3, most students answered correctly, identifying where photosynthesis occurs and the type of energy used in developing photosynthesis.

At Q4 about 75 % of students answered correctly. Although most of the students know how light influences photosynthesis, there are difficulties in understanding chemical reaction that occur in photosynthesis (conversion of solar energy into chemical energy).

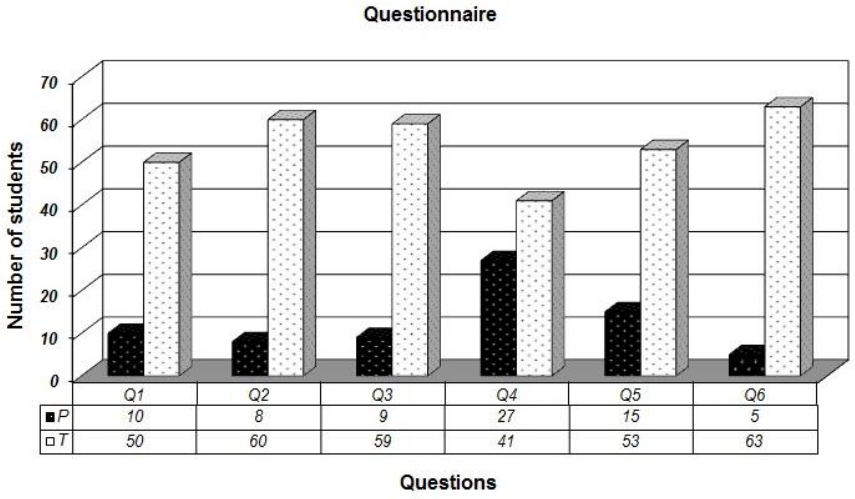

Fig. 4 – The results of the questionnaire applied to students after teaching the photosynthesis lesson. P represents partial response and T represents total response at questions Q1–Q6.

At the Q5 about 90 % of students answered correctly. They understood the mechanism of photosynthesis and have learned and acquired practical skills.

Students have had difficulty on Q6, in knowing the importance of photosynthesis for plants and animals. They know that through photosynthesis, plants synthesize their own food but cannot explain from which is made (minerals, water, carbon dioxide, etc.). This ensures the growth and development of plants. They also understood that plants are the only organism able to synthesize their own food, but they do not understand that plants, animals and people take food from the environment. Students understand that plants are important because they produce

oxygen for humans and animals and also they are the food source for them (but not the only source).

6. CONCLUSION

The integrated approach of the curriculum brings the school closer to real life. The environment in which solving concrete problems involves calling onto knowledge and competences no longer restrained to a limited context of a single discipline. In the interdisciplinary approach the strict limits of disciplines are ignored, seeking themes common to the different study objects. This approach are stimulating the abilities of method and competence transfer between disciplines.

The photosynthesis activity of plants can be demonstrated in an interdisciplinary way, by a simple experiment following the evolved or dissolved oxygen in water.

The students have noticed that when an aquatic plant is placed close to a light source, the plant will increase its photosynthesis rate and produce bubbles of oxygen, their number indicating the rate of photosynthesisis strongly dependent of the light intensity.

The students have observed that plants given off the most oxygen bubbles in white light and their number decreases in the order: red, blue, and green light. Thus. the rate of the photosynthesis is dependent also of the light quality (i.e. colour).

The water dissolved oxygen is dependent of the temperature and also of the presence of aquatic plants.

By these simple experiments, the students are expected to understand several basic concepts about photosynthesis. At the end of the class, students have to realise the importance of plants in the environment and the vital role of the cycle of gases in the atmosphere by generating oxygen and capturing the carbon dioxide from the air.

Activities such as group discussions, laboratory experiment, and concept mapping may be effective methods for teaching difficult concepts like photosynthesis.

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