Education and Culture

Socrates

IT for US

Information Technology for Understanding Science

Socrates Comenius programme

Action 2.1 - Training of School Education Staff

119001-CP-1-2004-1-PL-COMENIUS-C21

Photosynthesis and Respiration

All life on Earth is driven by the power of green, as in green chlorophyll. The process at the heart of Nature's most efficient engine is photosynthesis. Most of the difficult work occurs in trillionths of a second. Many researchers are teasing out the details of life's most important chemical reaction.

It takes eight minutes for a photon of light to travel nearly 150 million kilometres from the sun to the Earth's surface. A green plant needs only a few seconds to capture the energy in that light, process it, and store it in the form of a chemical bond. The amazing process for converting light energy to stored energy is called photosynthesis.

Photosynthesis as a process includes some of the fastest known chemical reactions. The most important events in a photosynthetic reaction occur in trillionths of a second. Measuring such short-lived events, and understanding the chains that link them together, demand some of the most precise experiments and exact measurements technology currently allows.

The stakes are high. Ultimately, almost all life on our planet is fuelled by the power of green—green chlorophyll, that is.

Based on "The Power of Green" by John Svetlik

drawing by Michael Hagelberg

Arizona State University's Center for the Study of Early Events in Photosynthesis

http://photoscience.la.asu.edu/photosyn/default.html

A. Introduction

The theme of this module is photosynthesis. Photosynthesis is the most important biochemical process on earth and is very important for a basic understanding of how the world functions.

With only a few exceptions, all of the energy for all life and human technology comes from the SUN. Energy moves through the food chain from life form to life form. The first step is always photosynthesis in which the sun's radiant energy is turned into carbohydrate molecules. These carbohydrates are used by all living things as fuel for energy, and as building blocks. Even fossil fuels like petrol, coal, fuel oil or natural gas, are hydrocarbons, primarily formed from the remains of dead plants and animals. Therefore the origin of their energy is also photosynthesis.

It is a relatively difficult phenomenon for students to understand because it is a complex process that involves many counter-intuitive and abstract concepts, but the basics are very simple.

The activities in this module exploit the use of ICT to develop deeper understanding of processes connected to photosynthesis and respiration. The following activities are available:

1. **Data logging:** Three laboratory experiments:
   - To investigate plant respiration.
   - To investigate relationship between the photosynthesis and the intensity and colour of light.
   - To observe photosynthesis of different plant types in long time measurement (day and night rhythm).
2. **Modelling:** To simulate use of oxygen in water by plants and animals in a pond.

All student activities are offered as Coach 6 Activities in the project Photosynthesis.

1. Background theory

1. Introduction

In the process of photosynthesis plants, some bacteria, and some protistans (so called autotrophs) use light energy to produce sugar molecules from carbon dioxide and water. The oxygen is released during this process. The following chemical equation shows the net input and output of photosynthesis.

$$6CO_2 + 6H_2O + \textbf{Light Energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

Most plants make more sugar than they need and store it. These stored sugars are a major source of food for many animals. On a global scale, photosynthesis by plant chloroplasts creates billion of tons of organic matter each year. It makes photosynthesis the most important chemical process to life on Earth. This process provides the food supply for other organisms and the oxygen for those organisms that require oxygen for respiration.

Photosynthesis takes place in green parts of a plant, in chloroplast where the solar energy is absorbed by the green pigment chlorophyll. Chlorophyll serves also as catalyst for reactions of hydrocarbonates synthesis. *Chloroplasts* have complicated structure. Chlorophyll is contained in *thylakoid membranes* forming chloroplast *grana*.

2. History

Knowledge about photosynthesis has accumulated rapidly in recent years, although the process was not well defined until twentieth century.
A few important historical facts are as follows:

The ancient Greeks believed that the soil satisfied all plants' needs, and this idea was generally accepted.

In the mid-seventeenth century Belgian physician Jan Baptista van Helmont (1577 - 1644) performed an experiment with a small willow tree in a pot, adding nothing to the soil except water as the tree grew. He concluded correctly that a plant does not gain most of its substance from the soil and incorrectly that his willow tree gained most of its substance from the water he gave it.

In the 1700s Joseph Priestley (1733 - 1804) discovered that, although a candle burned out in a closed container, when he added a living sprig of mint to the container, the candle would continue to burn. At that time, Priestley did not know of O2, but he correctly concluded that the mint sprig “restored” the air that the burning candle had depleted.

Dutch doctor and plant physiologist Jan Ingenhousz (1730 - 1799), inspired by Priestley's research, later learned that only the green parts of plants can revitalize stale air - that is, take in carbon dioxide and release oxygen - and that they do so only in the presence of sunlight. This was the first indication of light's role in the photosynthetic process. Ingenhousz also discovered that only the light of the Sun - and not the heat it generates - is necessary for photosynthesis.

In the late 1800s, German botanist Julius von Sachs (1832 - 1897) suggested that starch is a product of carbon dioxide. He also argued in 1865 that, in the presence of light, chlorophyll catalyzes photosynthetic reactions, and he discovered the chlorophyll-containing chloroplasts.

In the 1880s, German physiologist Theodor Wilhelm Engelmann (1843 - 1909) showed that the light reactions, which capture solar energy and convert it into chemical energy, occur within the chloroplasts and respond only to the red and blue hues of natural light.

It was not until the twentieth century that scientists began to understand the complex biochemistry of photosynthesis. In 1940, the discovery of carbon-14, a radioactive isotope of carbon isolated by Kamen, allowed for more detailed studies of photosynthesis. Using carbon-14, Melvin Calvin was able to trace carbon's path through the entire photosynthetic process. During the 1950s and 1960s, he confirmed that the light reactions involving chlorophyll instantly capture the Sun's energy. Then he studied the subsequent dark reactions. Working with green algal cells, Calvin interrupted the photosynthetic process at different stages and plunged the cells into an alcohol solution. Then, using the laboratory technique called paper chromatography; he analyzed the cells and the chemicals that had been produced, identifying at least ten intermediate products that had been created within a few seconds. This series of reactions is now called the Calvin Benson Cycle.

In 1998, scientists at Arizona State University announced that they had created an artificial photosynthetic energy system. The cell-like machine used light to power the synthesis of ATP, a carrier of chemical energy in all organisms. The new technology could eventually lead to biological computers and new drugs. (McGrath, 1999, p. 600)

(Source: http://www.geocities.com /barefeetchild/history.html).

3. O2 GAS IS PRODUCED BY SPLITTING WATER

Plants produce O_2 gas by extracting it from water **not** from CO_2. This was tested by scientists in 1950s by using an isotope of oxygen, ^{18}O, to follow the fate of oxygen atoms during photosynthesis. In Experiment 1, a plant given carbon dioxide containing ^{18}O gave off no labelled (^{18}O-containing) oxygen gas. In Experiment 2 a plant given water containing ^{18}O did produced labelled O2 gas.

Experiment 1: $6\ CO_2 + 12\ H_20 \Rightarrow C_6H_{12}O_6 + 6H_20 + 6O_2$ (not labelled)

Experiment 2: $6\ CO_2 + 12\ H_2O \Rightarrow C_6H_{12}O_6 + 6H_20 + 6O_2$ (labelled)

4. Photosynthesis and cellular respiration are reverse redox processes

The photosynthesis and cellular respiration are reverse redox (oxidation – reduction) processes. When water molecules are split apart, yielding O_2 they are actually oxidized; that is they lose electrons, along with hydrogen ions (H^+). Meanwhile CO_2 is reduced to sugar as electrons and H^+ ions are added to it. The cellular respiration harvests energy stored in a glucose molecule by oxidizing the sugar and reducing O_2 to H_2O.

Reduction	**Oxidation**
$\mathbf{6\ CO_2 + 12\ H_20 \Rightarrow C_6H_{12}O_6 + 6H_20 + 6O_2}$	$\mathbf{C_6H_{12}O_6 + 6H_20 + 6\ O_2 \Rightarrow 6\ CO_2 + 12\ H_20}$
Oxidation	**Reduction**

Photosynthesis uses light energy to produce glucose

Cellular respiration releases chemical energy

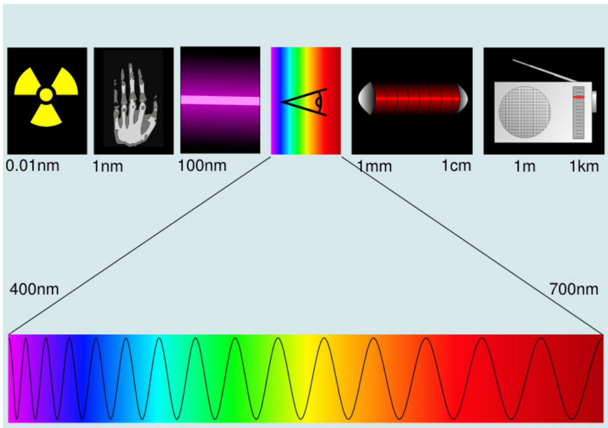
5. Visible radiation drives the light reactions

Sun emits most of their electro-magnetic radiation in the range of visible light which is only a small fraction of the electromagnetic spectrum. Visible light consists of different wavelengths that our eyes see as different colours.

The light reactions of photosynthesis use only certain wavelengths of visible light.

Light absorbing molecules called pigments in the membranes of a granum absorb mainly blue-violet and red-orange wavelengths (for instance *chlorophyll a* absorbs mainly blue-violet and red light, *chlorophyll b* absorbs mainly blue and orange light and reflects yellow-green).

We do not see these absorbed wavelengths. What we see when we look at a leaf are the green wavelengths that the pigments transmit and reflect.



The electromagnetic spectrum; visible light consists of wavelengths from 400 to 700 nm.

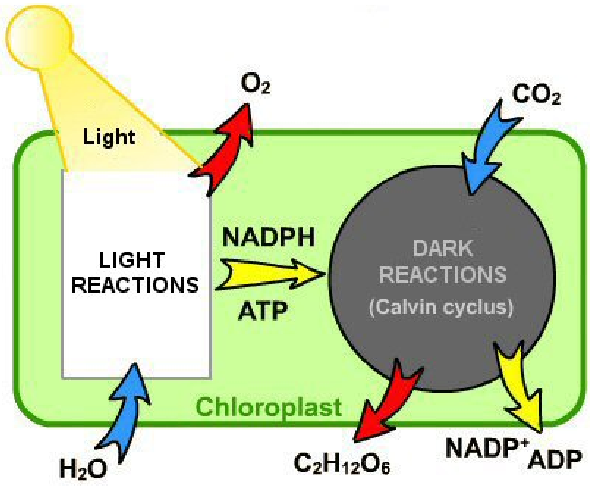
6. PHOTOSYNTHESIS OCCURS IN TWO STAGES

Photosynthesis is not a simple process, but occurs in two stages, each with multiple steps. The steps of the first stage are known as light reactions and the steps of the second stage as dark reactions.

The light reactions are the reactions that absorb light energy and convert it to chemical energy stored in ATP and NADPH. As a by product O2 gas is produced.

The dark reactions are known as the Calvin cycle. This is a cyclic series of reactions that assemble sugar molecules using CO2 and the energy-containing products (ATP and NADPH) of the light reactions.

The two-stage mechanism of photosynthesis makes possible fixation of carbon dioxide independently of time. It may be important in hot and dry conditions when plants close their stomata to prevent loss of water. CO2 is admitted only at night, and then glucose production occurs in a light-independent process. (However, in most plants, the Calvin cycle runs during daytime, when the light reactions power the cycle's sugar assembly line by supplying it with NADPH and ATP.)

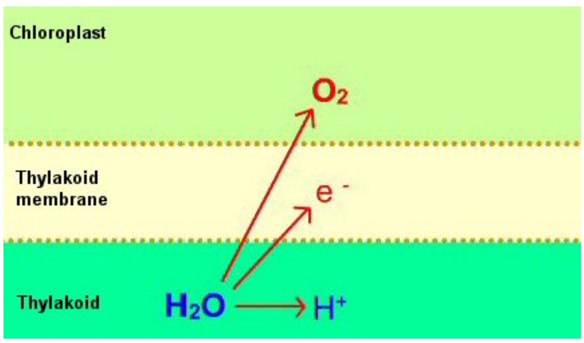


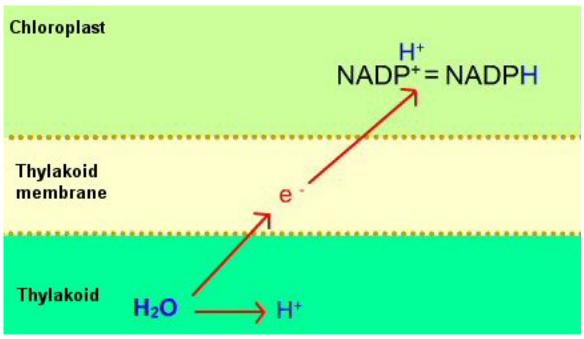
7. THE LIGHT REACTIONS (ADVANCED INFORMATION)

The light reactions occur in thylakoid membranes of the chloroplast's grana. The thylakoid membranes contain chlorophyll, the green pigment that absorbs the light energy.

The O2 gas liberated by the photosynthesis is made from the oxygen atoms in water. Water molecules H20 are split apart, and electrons and hydrogen ions H+ are removed leaving O2 gas.

Two photosystems in the thylakoid membranes absorb the light energy and use it to energize electrons. The photosystems transfer energized electrons to electron transport chains. When NADP+ gains two high-energy electrons (the reduction) and an H+

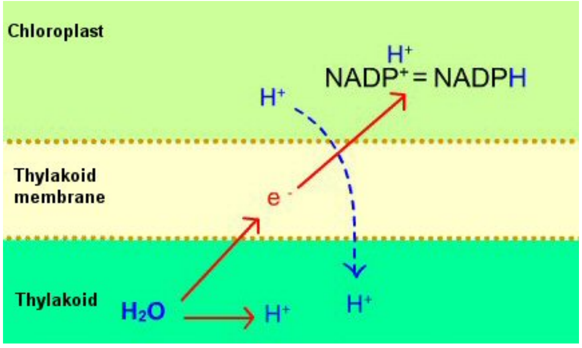


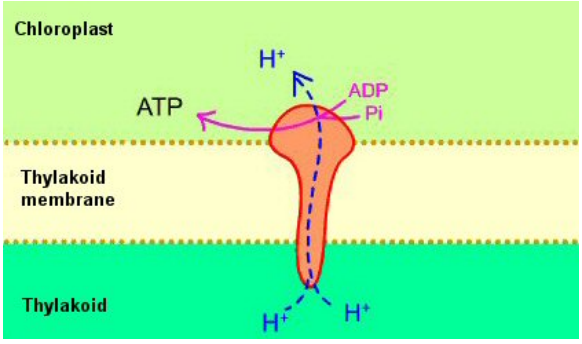


icon then it forms NADPH, an energy carrier needed in the dark reactions.

High energy NADPH and the waste product O2 both result directly from redox reactions. The synthesis of ATP is different, it is driven by chemiosmosis. Some of the electron carriers use energy released from the electrons to actively transport hydrogen ions H+ from one side of the membrane to the other. This generates the concentration gradient of H+ across the membrane.

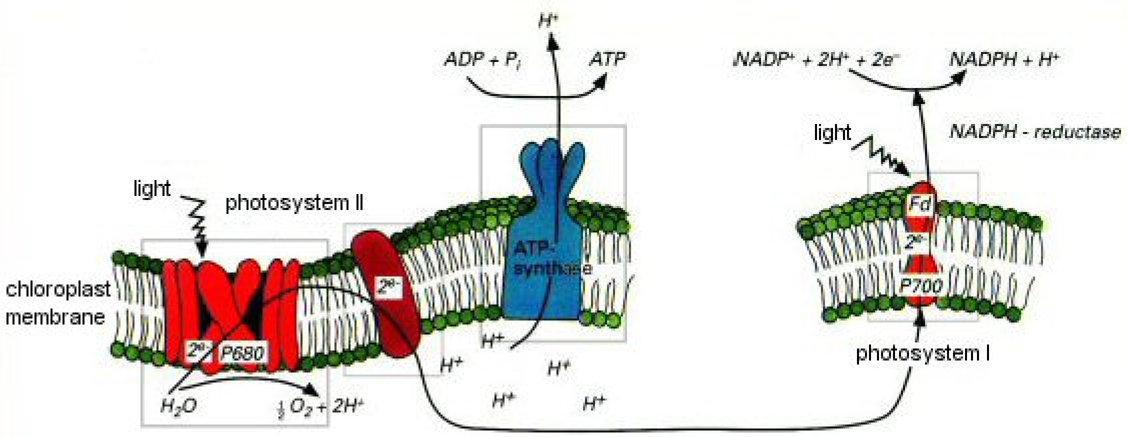
The protein complex ATP synthase provides a port through which H+ can diffuse back into the stroma from the thylakoid compartment. The energy of the H+ gradient drives H+ back across, and energy is released in the process. ATP synthase uses some of this energy to phosphorylate ADP, making ATP.





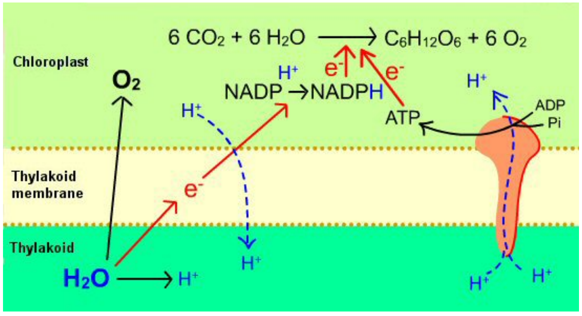
In the light reactions there is no sugar production.

The processes which take place during light reactions of the photosynthesis are shown below.



8. DARK REACTIONS (ADVANCED INFORMATION)

The dark reactions - Calvin Cycle[1]- occur in the stroma of the chloroplast. The incorporation of carbon from CO2 into organic compounds is called carbon fixation. After carbon fixation, enzymes of the cycle make sugars by further reducing the fixed carbon – by adding high-energy electrons to it, along with H+.



NADPH produced by light reactions provides the high energy electrons for reduction in the Calvin cycle, and ATP from the light reactions provides the chemical energy that powers several of the steps of the Calvin cycle. The Calvin cycle does not require the light directly. However, in most plants, the Calvin cycle runs during daytime, when the light reactions power the cycle's sugar assembly line by supplying it with NADPH and ATP.

9. PHOTOSYNTHESIS VARIATIONS

Plants in which the Calvin cycle use CO2 directly from the air are called C3 plants (common and widely distributed) because the first organic compound produced is three carbon compound 3-PGA. One of the problems of C3 plants is that in hot and dry conditions C3 plants close their stomata to prevent loss of water. Under these conditions, oxygen gas, produced by the light reactions of photosynthesis, will concentrate in the leaves causing photorespiration to occur.

In contrast to C3 plants, so-called C4 plants have special adaptations. When the weather is hot and dry, a C4 plant keeps its stomata closed most of the time, thus conserving water. At the same time it continues making sugars by photosynthesis. A C4 plant has an enzyme that fixes carbon into a four-carbon (4-C) compound instead if into 3-PGA. The four-carbon compound acts as a carbon shuttle; it donates the CO2 to Calvin cycle in a nearby cell, which therefore keeps on making sugars even though the plant's stomata are closed most of the time. Many important crop plants are C4 plants including maize, sorghum, sugarcane, and millet.

Cacti and most succulents (CAM plants) have developed a third mode of carbon fixation. A CAM plant conserves water by opening its stomata and admitting CO2 only at night. The CO2 is released to the Calvin cycle during the day. This keeps photosynthesis operating during the day even though the leaf admits no more CO2.

---

[1]This complicated process was discovered by American biochemist Melvin Calvin. This accomplishment brought him the Nobel Prize in Chemistry in 1961.

2. Pre-requisite knowledge required

- Plant respiration
- Photosynthesis – light and dark reactions
- Cellular respiration

3. Science concepts developed in the module

- Plant respiration
- Photosynthesis

4. Other useful information

Arizona State University Center for the Study of Early Events in Photosynthesis
http://photoscience.la.asu.edu/photosyn/
This site gives a lot of research and educational resources on photosynthesis.

Illuminating photosynthesis
http://www.pbs.org/wgbh/nova/methuselah/photosynthesis.html

Why Leaves Change Colour
http://www.esf.edu/pubprog/brochure/leaves/leaves.htm

B. Didactical approach

1. Pedagogical context

The proposed module can be used as an application module. Students use concepts that were already introduced and apply them to explain results of measurements. The goal is to have students generalize the application of their knowledge. This application of the principles leads to further understanding of the theories and models.

2. Common student difficulties

Photosynthesis is rated by teachers as the most important and the most difficult concept for students (Stavy et al., 1987). Its difficulty lies mainly in the fact that it is a complex biological topic, with a number of conceptual aspects (ecological, physiological, biochemical, energetic, autotrophic feeding) whose connection cannot be easily understood by the students (Waheed & Lucas, 1992). The common student difficulties concerning photosynthesis are:

- Difficulty in understanding the autotrophic feeding of plants; a commonly held idea is that plants obtain their food from the soil.
- Difficulty concerning the process of respiration as well as its relationship to photosynthesis, and confusion of photosynthesis with respiration (some students understand respiration as synonymous with breathing, while others understand plant respiration as an inverse gaseous exchange compared with that of animals).
- Difficulty with the concept of energy and energy exchange during photosynthesis.
- Difficulty in recognising and understanding of the concept of chemical change.

  Examples of misconceptions concerning photosynthesis and respiration in plants are:

  - Carbon dioxide is used in respiration which only occurs in green plants when there is no light energy to photosynthesize
  - Respiration in plants takes place in the cells of the leaves only
  - Respiration is the exchange of carbon dioxide and oxygen gasses through plant stomata
  - Green plants take in carbon dioxide and give off oxygen when they respire
  - Green plants respire only at night when there is no light energy
  - Green plants do not respire they only photosynthesize

- Photosynthesis provides energy for plant growth
- Plants respire when they cannot obtain enough energy from photosynthesis and animals respire continuously because they cannot photosynthesize

- Difficulty in conceiving gas a substance.
- Difficulty in combining chemical and biological concepts (e.g. they cannot treat the human body as a chemical system).

REFERENCES:

1. Amir, R., Tamir, P. (1994) "In-depth analysis of misconceptions as a basis for developing research-based remedial instruction: The case of photosynthesis" *The American Biology Teacher, 56,* 94–100.
2. Barker, M., Carr, M. (1989) "Teaching and learning about photosynthesis. Part 1: An assessment in terms of students' prior knowledge" *International Journal of Science Education, 11,* 49–56.
3. Canal, P. (1999) "Photosynthesis and "inverse respiration" in plants: An inevitable misconception?" *International Journal of Science Education, 21,* 363–371.
4. F. Haslam, D. F.Treagust, (1987) "Diagnosing secondary students' misconceptions of photosynthesis and respiration in plants using a two-tier multiple choice instrument" *Journal of Biological Education* **21,** 203–211.
5. Marmaroti P., Galanopoulou D., (2006) "Pupils' Understanding of Photosynthesis: A questionnaire for the simultaneous assessment of all aspect", *International Journal of Science Education* Vol. 28, No. 4, 383–403.
6. Stavy, R., Eisen, Y., Yaakobi, D. (1987) "How students aged 13-15 understand photosynthesis" *International Journal of Science Education, 9,* 105–115.
7. Waheed, T., Lucas, A. (1992) "Understanding interrelated topics: Photosynthesis at age 14+. *Journal of Biological Education, 26,* 193–199.

3. Evaluation of ICT

The specific qualities of ICT which benefit student learning are specified below per a type of activity.

DATA LOGGING

Using data logging in the Biology lab extends the ability to observe complicated phenomena. The measurements can exceed normal class periods and data may be collected over a whole day or weekend. The use of sensors like O_2 or CO_2 gas sensors allows experiencing "unseen" variables such as oxygen and carbon dioxide concentrations.

Data logging graphs better show how measured quantities change and offer unique discussion opportunities. This encourages students to ask and answer questions.

Activity 1. Plant respiration

In this experiment the gas sensors are used to measure the oxygen and/or carbon dioxide gas concentration changes in the bottle with a green plant. In this activity students realise that plants respire in the same way as animals, by using oxygen and producing carbon dioxide.

Activity 2. Processes in dark and light

In this experiment the CO_2 gas sensor is used to observe the process of photosynthesis in artificial light. The CO_2 gas is produced by plants in dark and used for photosynthesis in light. Students investigate relationship between the rate of photosynthesis (the rate of consuming) and the intensity and colour of used light.

The setup presented in this activity is somewhat simpler and easier to prepare and perform than in activity 1 or 3. The CO2 changes can be observed in much shorter time period.

Activity 3. Monitoring photosynthesis

This experiment is performed over a longer period of time (72 hours). Here many different sensors like O_2, CO_2, light, temperature, and humidity sensors can be used to monitor the photosynthesis process and to get data for further class discussion of the concepts involved. The measurements done for different type of plants e.g. C_3 and CAM plants can be compared.

Modelling

In the Modelling activities of this module students concentrate on relations between important factors in respiration and photosynthesis. The variables represented in graphical form need to be identified and associated with the phenomena they represent.

By using a model students have possibility to experiment with different parameters to simulate different conditions.

Activity 4. Life in a pond

The model which calculates the oxygen concentration in the water stream is presented to students. In the model two processes for production and consumption of oxygen are taken into account. These are photosynthesis by plants and respiration by plants and animals in a pond (closed water system). Students use the model to investigate the influence of plants, animals and light on the oxygen concentration in the water.

In the model the following simple assumptions are taken:

1. Photosynthesis depends on light, the higher the light intensity, the higher the photosynthesis rate.
2. Respiration is influenced by the oxygen concentration and the number of plants and animals.
3. Light depends on the light intensity value. If the light intensity value:
    - is equal to 0 then there is no light (dark),
    - lies between 0 and 100 then the light of constant intensity is generated (value 100 means the maximum constant light intensity),
    - is higher then 100 then the periodic changing light is generated. This simulates a day and night rhythm.

4. Teaching approaches

The four activities presented here offer distinctive but complementary insights into the science involved in this topic. The first activity concentrates mostly on a plant respiration process. The second activity adds the photosynthesis process and analyzes the influence of light intensity and light colour. The third activity analyses the process of photosynthesis and respiration in a long time period (few days). The fourth activity analyses the process of changing the oxygen concentration in a pond. The oxygen is produced by plants photosynthesis and used by plants and animals respiration.

For the activities to be effective for teaching and learning, it is helpful for teachers to consider two types of skills in using the software tools:

- ***Operational skills*** which concern the manipulation of the computer hardware and knowledge of the features in the software.
- ***Procedural skills*** which concern the manner in which the software tools are employed in the lesson context for the purpose of achieving learning benefits. A dominant aspect of these skills is the development of an inquiring approach to the analysis and interpretation of data and to making links with previous knowledge.

Such skills are important for the preparation of pupils for the activities, and the activity sheets below each contain indications of the skills needed for the particular activity.

For the teacher, there are further *pedagogical skills* which contribute to the effectiveness of the activities:

1. Clarity of learning objectives for each activity.
2. Understanding of the special value of the ICT method and exploiting its full potential in purposeful ways.
3. To manage the activity in a way which promotes 'appropriate' rather than 'indiscriminate' use of ICT.
4. To integrate the learning from each activity to develop pupils' understanding of the topic.

The development of the last of these is a particular aim of the IT for US Project, and the activities presented have been specially selected to illustrate how integration might be achieved. Comparisons of the observations and results of each activity form a central role in this integration process. For example:

- Use the results from the data-logging activities and model activities to contribute to a discussion about the factors which influence photosynthesis and plant respiration;
- Compare results from data-logging activities (activity 1 and 2) with the results of the data logging activity 3.

In these, the graph is a key tool in facilitating comparisons and interpretations and skills with graphs generally provide a common thread in exploiting IT for US activities.

The management of the classroom setting also has an important influence on the successful integration of activities. When access to computer equipment is scarce it is likely that the teacher will wish to present the activity as a demonstration in a didactic manner. In this mode, the teacher can give strong guidance to pupils' thinking about the comparisons between the activities. Alternatively, pupils could perform the activities in small groups of three or four pupils, each group engaged on a different activity. Integration might be achieved by each group making a presentation of their results to the whole class. In chairing these presentations the teacher can prompt discussion of the significant findings of each group.

It is worth considering that all the activities may be used in a variety of learning contexts.

Although the activities have been designed to provide complementary experiences, it is not essential to use all of them; two or three activities might be chosen according to how well they suit the needs of teachers and pupils in a particular context. In varying conditions between schools and within schools at different times of the year or different stages in the curriculum, needs and appropriateness are likely to change; for example, data-logging equipment might not be available at the time of need, an individual pupil might need a revision or extension activity, an enrichment activity might be required to occupy some spare time, a quick activity might be needed if time is scarce. The overlapping features, such as graphical presentation, between the activities allows them to be used to a certain extent as alternatives, but their distinctive features also allow them to be used as complements to each other. The table below summarises the distinctive potential learning benefits of each. It is a useful guide to the special value of each ICT activity.

Activity	Potential learning benefits, 'ICT value'
Data logging	Graph of CO_2 (and/or O_2) is displayed during the experiment. Graph of light intensity is displayed during the experiment. and light intensity Graph analysis tools facilitate detailed investigation of data. Long duration experiments are recorded.
Modelling	The model calculates the change of the oxygen in water in a pond. The model is used to simulate different situations.

5. Resources for Student Activities

Using Coach 6 software

Activity	Software program	Files available in Coach 6 Project Photosynthesis and Respiration
1. Data-logging	Coach 6	1.Plant respiration.cma (activity file) 1.Plant respiration.cmr (result file with exemplary data)
2. Data-logging	Coach 6	2.Processes in dark and light.cma (activity file) 2.Processes in dark and light.cmr (result file with exemplary data)
3. Data-logging	Coach 6	3.Monitoring photosynthesis.cma (activity file) 3.Monitoring photosynthesis.cmr (result file with exemplary data)
4. Modeling	Coach 6	4.Life in a pond.cma (activity file)

Equipment and materials for Activity 1 and Activity 2 (Data-logging)

- Computer
- Software – *See table above*
- Interface (CoachLab II/II$^+$ interface or ULAB data-logger)
- CO_2 gas sensor with a 250-ml sampling bottle and rubber stopper delivered with the sensor
- Light sensor, Temperature sensor, O_2 Gas sensor, Humidity sensor (optional)

For Activity 1

- Seeds for example cuckoo-flower or peas, a paper towel or cotton
- Large, transparent plastic bottle or big glass jar

For Activity 2

- Lamp (bright)
- Large glass container filled with water (heat sink)
- Fresh green leaves
- Aluminium foil
- Different colour filters

For Activity 3

- Green plant with large leaves
- Large transparent plastic bottle

C. Student Activities

ACTIVITY 1. PLANT RESPIRATION

Learning Objectives:

1. Measure changes in oxygen gas concentration resulting from plant respiration (germinating seeds)
2. Measure changes in carbon dioxide gas concentration resulting from plant respiration (germinating seeds)
3. Understand that plants respire as well during the night as during the day

APPLIED ICT TECHNOLOGY: DATA LOGGING

STUDENT LEVEL: AGE 14 - 17

RECOMMENDED SETTINGS: TEACHER LED STUDENT ACTIVITY

Operational Skills:

- Connecting sensors and interfaces
- Connecting sensors and interfaces
- Collecting data in the time-based measurement mode

Procedural Skills:

- Analysing data using graph
- Reading values/slopes
- Evaluating measurement quality
- Using time bonus

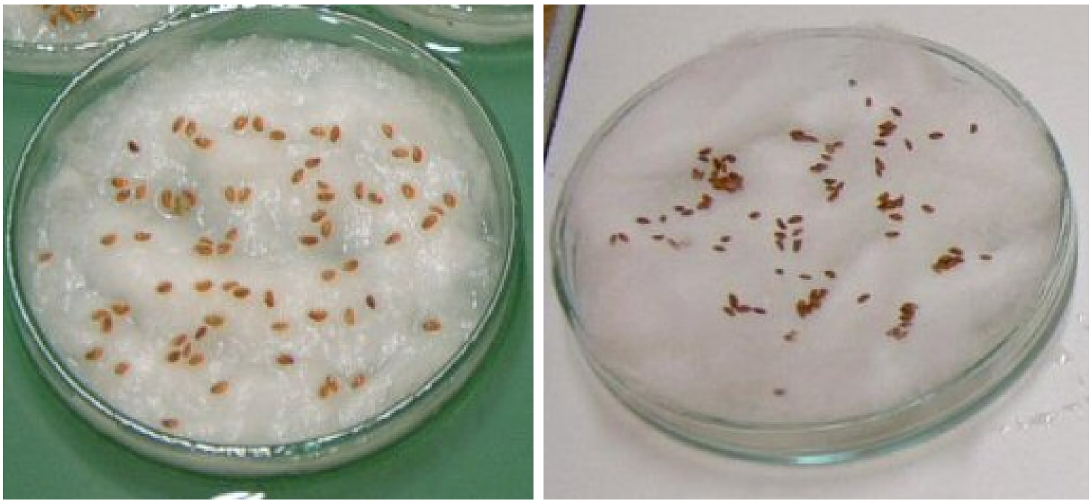
Materials:

- Interface (CoachLab II/II^{+})
- CO2 gas sensor (and/or O2 gas sensor)
- Light sensor
- Temperature sensor (optional)
- Seeds for example cuckoo-flower or peas, a paper towel or cotton
- Large, transparent plastic bottle or big glass jar

Activity method:

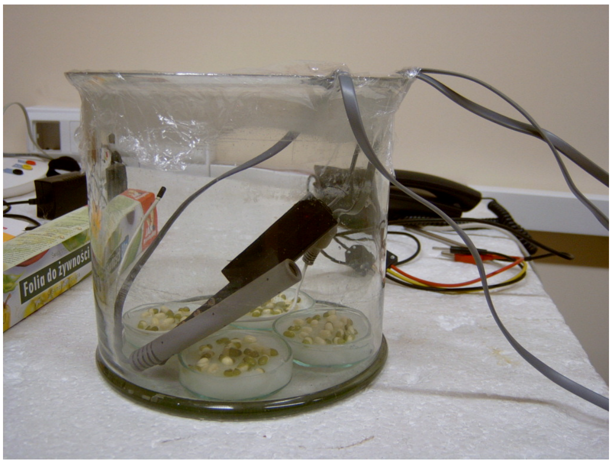
In this activity germinating seeds are used to demonstrate plant respiration.

1. Germinating seeds.
   - Place the paper towel or cotton on the little boards (of 8 - 10 cm diameter). Spread seeds on the boards and add 20-25 ml mineral water to each board.
   - Let the seeds germinate in temperature 20 – 22 °C in a laboratory room for two days. An adequate, continuous supply of moisture is important to ensure germination.
   - For a control experiment you can use non-germinating seeds. These seeds are kept in the same conditions as germinating seeds but are not supplied with water. Such control measurement should be performed before the main experiment.



Germinating (left) and non-germinating (right) cuckoo-flower seeds.

2. Connect the CO_2 (or O_2) gas sensor to input 1. Before you start the measurement calibrate the CO_2 sensor in fresh air.
3. Place the boards with germinating seeds into a jar.
4. Place the CO_2 (or O_2) and light sensor inside the jar.
5. Seal the jar with the plastic foil.
6. Place the bottle with the sensor in the dark.



7. Start the measurement and record for few hours (for example 2 h).

8. Determine the rate of respiration (by using the *Slope* option).

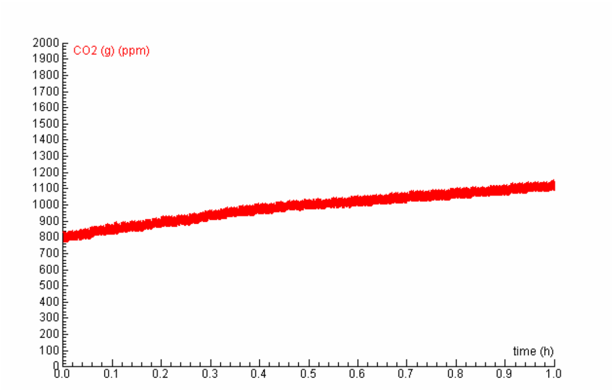
9. Repeat your experiment in ambient light (circa 700 Lux).

Questions:

- Explain how the CO_2 (O_2) gas concentration changes during the measurement in the dark.
- What kind of process is responsible for producing the CO_2 (or consuming O_2) gas in the jar?
- Is this process similar to another process which you know? Which one.
- Are the CO_2 (or O_2) gas concentration changes similar during the measurement in ambient light?
- Do plants respire during the day?
- If you have made measurements simultaneously with CO_2 and O_2 gas sensors, compare the change of O2 to the change of CO_2. What is the ratio of these changes? Can you explain what it means? (only if measurement done with the CO_2gas sensor)
- Is there any relationship between temperature and the respiration rate of germinating seeds?

Analysing activities:

By analysing the graph students can conclude that germinating seeds (plants) respire by using oxygen and producing the carbon dioxide, so in the similar way to animals.



An exemplary measurement performed with germinating cuckoo-flower seeds (3 boards with 50 germinating seeds in the closed jar) is shown in the right graph. The measurement was performed in a day light.

The measurement data shows that germinating seeds produce the CO_2 gas. In the course of the experiment the rate of CO_2 production becomes lower, the respiration rate of germinating seeds decreases because there is not enough of O_2 gas in the closed jar.

The result of the experiment performed in ambient light is similar; the resulting graph is a little bit more flat. Such experiment shows students that plants respire not only during a night but also during a day.

Additionally by using the temperature sensor the influence of temperature on the speed of respiration can be investigated.

Hints and tips:

The change in oxygen concentration is very small, about 0.5%. Measuring in parts per million (ppm) yields more differentiated data. However, the percentage measurement shows a difference as well.

Coach 6 Activity:

1. Plant respiration

ACTIVITY 2. PROCESSES IN LIGHT AND DARK

Learning Objectives:

1. Measure changes in CO2 gas concentration resulting from photosynthesis and respiration
2. To investigate the relationship between the rate of photosynthesis and intensity of light
3. To determine the rate of photosynthesis and respiration
4. To investigate the relationship between the rate of photosynthesis and the colour of light

APPLIED ICT TECHNOLOGY:
DATA LOGGING

STUDENT LEVEL:
AGE 17

RECOMMENDED SETTINGS:
STUDENT ACTIVITY IF ENOUGH EQUIPMENT AVAILABLE OTHERWISE TEACHER LED STUDENT ACTIVITY

Operational Skills:

- Connecting sensors and interfaces
- Choosing logging parameters
- Collecting data in the manual measurement mode

Procedural Skills:

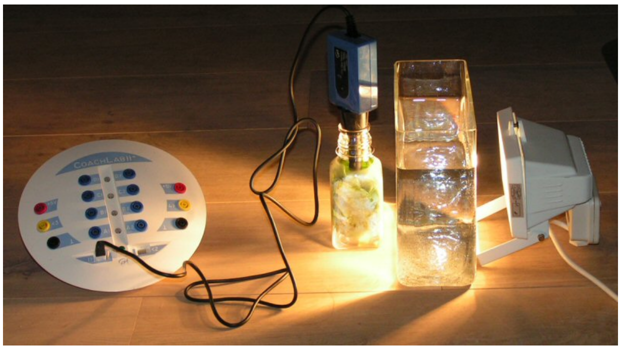
- Active observation during real-time logging
- Evaluating measurement quality
- Analysing data using graph
- Reading values/slopes
- Using time bonus

Materials:

- Interface (CoachLab II/II$^+$)
- CO_2 gas sensor with a 250-ml sampling bottle and rubber stopper delivered with the sensor
- Light sensor (optional)
- Lamp (bright)
- Large glass container filled with water (heat sink)
- Fresh green leaves
- Aluminium foil
- Different colour filters

Activity method:

1. Place a glass tank between the light and sampling bottle. This tank acts as a heat shield.
2. Connect the CO_2 sensor to input 1
3. Let the sensor warm up.
4. Calibrate the CO_2 sensor in fresh air.
5. Place fresh green leaves in the bottle and leave it for a while.
6. Wrap the bottle in aluminium foil so that no light reaches the leaves.
7. Refresh the air inside the bottle by shaking the bottle and catching the fresh air.
8. Place the CO_2 sensor in the bottle. Gently push the sensor down into the bottle until it stops. The sensor is designed to seal the bottle.
9. Start the measurement.
10. After 10 minutes remove the foil and measure in the day light.
11. After the next 10 minutes turn the lamp on.
12. Determine the rate of photosynthesis/respiration in three situations.



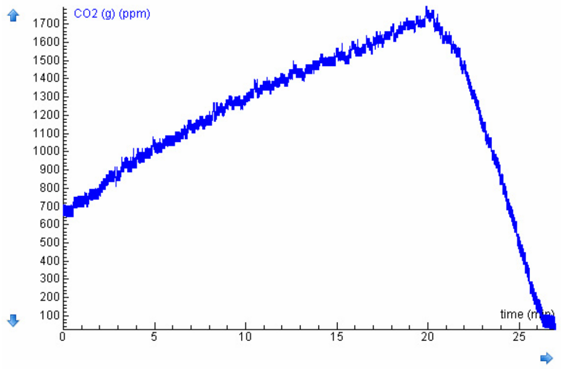
13. Rearrange your experiment to investigate the effect of different light colours by placing different colour filters in front of the light source.

Questions:

- How the CO_2 gas concentration changes when the light is turned off?
- What process is responsible for such behaviour? Write down the reaction equation which plays a main role when leafs remain longer in dark.
- What is the effect of light on the CO_2 gas concentration?
- What process is responsible for such behaviour? Write down the reaction equation which plays a main role when leaves remain longer in strong light.
- How the light intensity influences the rate of photosynthesis?

- How the light colour influences the rate of photosynthesis/respiration?
- List other factors that might influence the rate of carbon dioxide production?

Analysing activities:



The exemplary data are shown on the graph. In the experiment spinach leaves were used.

First 10 minutes of the measurement the bottle with leaves was wrapped in the aluminium foil. During this period the CO_2 gas concentration increases; the rate of CO2 production is 77 ppm/min (determined by using the Slope option).

In this part of the experiment only the respiration process takes place. Green leaves harvest energy stored in glucose molecule by oxidizing the glucose, the CO_2 gas is produces.

For the second ten minutes of the measurement (10 to 20 min), the aluminium foil is removed and the bottle is placed in ambient light (circa 700 Lux). The CO_2 gas concentration still increases but more slowly, with the rate of 44 ppm/min. More carbon dioxide is produced in respiration then used by photosynthesis.

For the last 7 minutes of the measurement the lamp producing bright light is turned on. The CO2 gas concentration decreases very fast. The process of photosynthesis takes place much faster now. The CO2 gas is used in the photosynthesis process to form sugar.

Hints and tips:

Spinach leaves purchased from a grocery store work well and are available any time of the year. For best results, keep the leaves cool until they are to be used. Just before use, expose the leaves to bright light for 5 minutes.

There should be enough leaves (7- 8) in the bottle, then the CO_2 changes are faster.

Coach 6 Activity:

2. Processes in light and dark

ACTIVITY 3. MONITORING OF PHOTOSYNTHESIS

Learning Objectives:

1. Measure changes in oxygen in carbon dioxide concentration and resulting from photosynthesis and respiration during over a long period of time
2. Observing how the process of photosynthesis changes during the day-night cycles
3. Understand the light and dark reactions

APPLIED ICT TECHNOLOGY: DATA LOGGING

STUDENT LEVEL: AGE 17

RECOMMENDED SETTINGS: TEACHER LED STUDENT ACTIVITY STUDENT ACTIVITY

Operational Skills:

- Connecting sensors and interfaces
- Choosing logging parameters
- Collecting data in the time-based measurement mode

Procedural Skills:

- Evaluating measurement quality
- Analysing data using graph
- Reading values/areas under the graph
- Creating new diagrams

Materials:

- Interface (ULAB or CoachLab II/II$^+$)
- CO_2 gas sensor
- Light sensor
- O_2 gas, temperature or humidity sensor (optional)
- Green plant with large leaves
- Large transparent plastic bottle

Activity method:

1. Place your plant inside a large transparent plastic bottle (5 L) in the following way:
   - cut the bottle in the middle,
   - place the plant in the lower part of the bottle,
   - place the upper part of the bottle on its lower part and tape these two parts to each other.
2. Connect the CO_2 gas sensor to input 1 and the Light sensor to the input 2 of an interface. If you use other sensors connect these to other inputs.
3. Calibrate the CO_2 gas sensor in the fresh air.
4. Through the opening of the bottle place the sensors inside the bottle. Seal the bottle with the plastic foil as shown in the photo.
5. Place the bottle on a windowsill.
6. Start the measurement and record for 72 hours.
7. Repeat your experiment for a different type of plant.

Questions:

- Explain how the CO_2 gas concentration changes during the measurement? Is the carbon dioxide used steadily during photosynthesis?
- When (at what time) is the CO_2 gas concentration the highest and when the lowest?
- What happen with the CO_2 gas concentration when it becomes dark and when it becomes light?
- How does light affect the rate of photosynthesis?
- Explain how the O_2 gas concentration changes during the measurement? Is oxygen produced steadily during photosynthesis?
- When (at what time) is the O_2 gas concentration the highest and when the lowest?

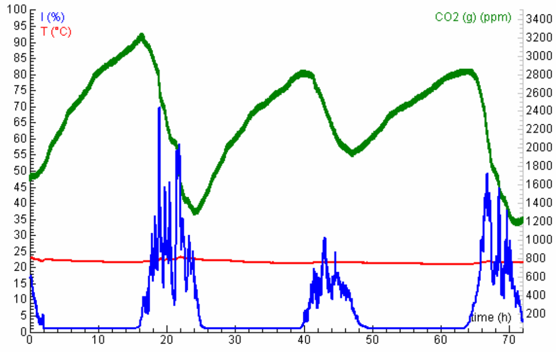
- What happen with the O_2 gas concentration when it becomes dark and when it becomes light?
- How the O_2 gas concentration peaks match with the light level peaks? Why might the oxygen level reach a peak after the light level does?
- At what time of the day does the plant produce the most oxygen (uses the most carbon dioxide)?
- Does the plant respire during photosynthesis? Can you see it?
- Discuss both the light-dependent and light-independent reactions of photosynthesis. Use this information to explain the trends you notice in the data. Does this help explain behaviour of the leaf being studied?

Analysing activities:

Run the experiment for few nights – this will allow you to discuss which processes take place durign days and which during nights.

The exemplary data measured with the CO_2 gas, light and temperature sensors are shown in the diagram.

It is convenient to display the data in the same diagram and then use the Scan option to analyse the data.



The Smoothing option can help to simplify the light signal to show the "trends" of the light changes.

During nights the carbon dioxide concentration increases, the carbon dioxide is produced by respiration. During days (light intensity larger than 2%) the carbon dioxide concentration decreases, CO_2 gas is used in the photosynthesis process.

Hints and tips:

A plant with fuzzy, as opposed to waxy, leaves, will give better data due to differences in gas exchange.

You may want to ensure the container is fully sealed by using tape to reinforce the seal.

The change in oxygen concentration is very small, about 0.5%. Measuring in parts per million (ppm) yields more differentiated data. However, the percentage measurement shows a difference as well.

Coach 6 Activity:

3. Monitoring photosynthesis

ACTIVITY 4. LIFE IN A POND

APPLIED ICT TECHNOLOGY: MODELLING - SIMULATION

STUDENT LEVEL: AGE 17

RECOMMENDED SETTINGS: STUDENT ACTIVITY

Learning Objectives:

1. To understand processes which determine the oxygen concentration in a pond
2. To interpret graphs of oxygen level concentration and light intensity.
3. To investigate the influence of plants, animals and light on the oxygen concentration in a pond

Operational Skills:

- Using the model to simulate different conditions in a pond

Procedural Skills:

- Changing parameters of the model
- Active observation during executing model

Activity method:

The model used in this activity calculates the oxygen concentration in a pond. In this simple model the processes of photosynthesis of plants and respiration of plants and animals are responsible for production and consumption of oxygen in water. In the model the following factors can be changed:

- number of plants
- number of animals
- the light intensity.

Students use the model to predict the oxygen concentration in the water and answer the main research question "What is the influence of plants, animals and light on the oxygen concentration in the water?"

Questions:

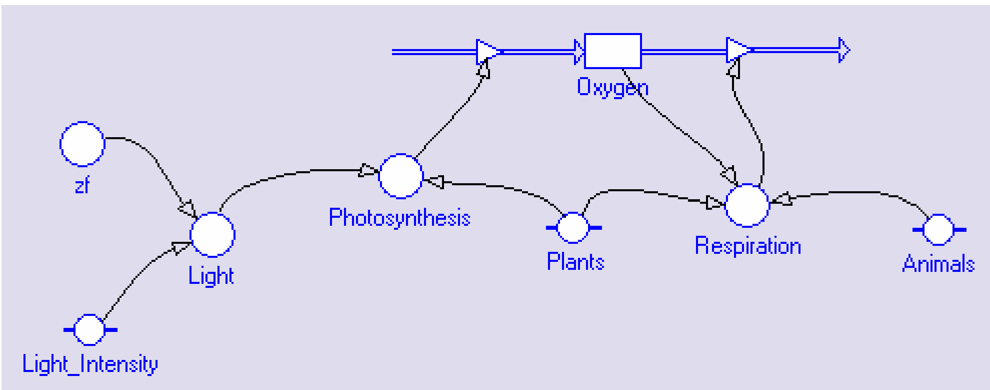
- What happens to the oxygen concentration when there are no plants and animals in the water?
- What happens to the oxygen concentration when there are no plants and only animals in the water?
- What happens to the oxygen concentration when there are more animals in the water?
- What can you say about the effect of animals on the oxygen concentration

in water?

- What happens to the oxygen concentration when there are only plants in the water?
- What happens to the oxygen concentration when there are more plants in the water?
- What can you say about the effect of animals on the oxygen concentration in water?
- Assume that in the water there are only animals, what happens to the oxygen concentration in the water when it is:
  - completely dark
  - there is a light
  - the amount of light is changing?
- Assume that in the water there are only plants, what happens to the oxygen concentration in the water when:
  - completely dark
  - there is a light
  - the amount of light is changing?
- At which moment of the day is the oxygen concentration in the water the highest; the lowest?
- How does light affect the oxygen concentration?
- How do the oxygen peaks match with the light level peaks? Why might the oxygen level reach a peak after the light level does?

Analysing activities:

Students need to explain the model and relations between the variables.



In photosynthesis plants produce oxygen. The light intensity influences photosynthesis, the higher the light intensity, the higher the photosynthesis rate.

Oxygen in water is being used in respiration process as well by plants and as by animals.

The respiration is influenced by the oxygen concentration and the number of plants and animals.

The light depends on the light intensity value. If the light intensity value:

- is equal to 0 then there is no light (dark),
- lies between 0 and 100 then the light of constant intensity is generated (value 100 means the maximum constant light intensity),
- is higher then 100 then the periodical changing light is generated. This simulates a day and night rhythm.

Students simulate a different situation by changing the number of plants, number of animals, and the light intensity and observe the oxygen concentration in the water over time. They use their investigations to answer their research question.

After the research question has been answered you can discuss with students possible ways of improving model to better describe the reality, for instance by:

- assuming the relation between the numbers of animals and the oxygen concentration, (if there is no enough oxygen animals die),
- assuming the relation between the numbers of animals and the number of plants (plants serve as food and protection for animals), or
- assuming the relation between the numbers of plants and the number of animals (plants are eaten by animals).

During a discussion concept of biological balance can be applied.

Coach 6 Activity:

4. Life in a pond