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Integrated Science through Computer-aided Experiments

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Abstract. The paper outlines curriculum development activities that have been done in science education in the Slovak Republic as a result of an international collaboration within the frame of the Leonardo da Vinci II pilot project *Computerised Laboratory in Science and Technology Teaching* – "*ComLab-SciTech*". The created teaching and learning materials include integration of science curricula in two meanings: an integration of knowledge and methodology of physics, chemistry and biology, as well as an integration of various true and virtual computerised methods of experiments. The materials contain suggestions for student investigative activities, in which life science processes are studied with the use of laboratory models.

Key words: science education, life science,integration,investigations, computer-aided experiments.

Introduction

In the Slovak Republic there has long been a tradition of science courses being taught within separate subjects – physics, chemistry and biology. Science teacher training has reflected this isolated way of teaching. An effort to encourage the application of a more integrated approach to the sciences and to provide future physics, biology and chemistry teachers a greater understanding of natural phenomena brought together researchers and teacher trainers from three Slovak universities with their partners from the United Kingdom and the Netherlands in a Tempus funded project *Science Teacher Training 2000* (1995–1998).

The most important output of this project is considered to be an introduction of a new study subject *Natural Science* into the teacher training curricula at the three Slovak universities involved in the project. The course that integrates aspects of environment, natural processes and scientific methodology, was also seen to provide a vehicle through which more active and participatory approaches to teaching and learning could be achieved. While explanatory methods have proven satisfactory and efficient in the teaching of individual science branches, the integrated approach has called for the use of more investigative methods. These investigative methods must respect the important position, which information technologies have in the development of every science discipline.

Therefore a next step in the strengthening of the ICT use in science education in Slovakia was made through a pilot project *Computerised Laboratory in Science and Technology Teaching* (*ComLab-SciTech*) within the frame of Leonardo da Vinci II programme. The aims of the *ComLab-SciTech* project have included the application of a more integrated approach to the sciences via students/pupils practical investigative activities with the use of various tools of modern ICT. This aim should be achieved through an introduction of a course *Integrated Science through Experiments* into science curricula in the Slovak Republic and in other partner countries.

1. Background to the Course *Integrated Science through Experiments*

The course *Integrated Science through Experiments* by its nature integrates the science curriculum in two meanings: it involves an integration of knowledge and methodology of physics, chemistry and biology, as well as an integration of various true and virtual computerised methods of experiments.

The course content is based on the close cross-curricular links between science subjects, which result from their common object of study – the nature, as well as from the equal methods, that physicists, chemists and biologists use in their research. The themes were chosen to illustrate the integration of natural processes and cover topics such as radiation in everyday life, thermoregulation in living organisms, environmental measurements, etc.

The second integrating aspect of the developed course means that the suggested experimental student activities comprise of:

- Real experiments supported by computers. These activities include measurements using sensors, collecting of data and their further manipulation, analyses and displaying in the form of the graph and/or the table.
- Dynamical simulations of natural phenomena and processes.
- Quantitative models of natural processes.
- Animations of selected phenomena and processes.
- Virtual laboratories that can replace the real experiments in some cases, for example if these are too costly or dangerous for students.

The student activities are supplemented with a set of questions and problem tasks. The whole course is html-based and is accessible for science teacher trainees as well as for students at other universities in Slovakia and partner countries. The course structure is shortly described in Bulla and Holec (2004).

In the next section we bring a few examples of the students' guides from the *Integrated Science through Experiments* course, that introduce suggestions of computer-aided investigations from the area of "life science".

2. What does the Fish Breathe?

Have you ever come to thing what the fish breathes? Fish blood is similar like human thus fish need oxygen for breathing too. Let's see if water contains any dissolved oxygen.

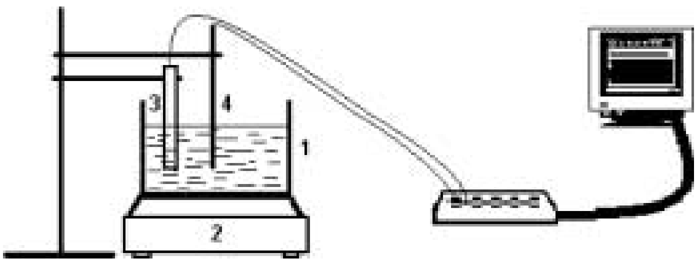
A little bit of the theory

A small amount of oxygen, up to about ten molecules of oxygen per million of water, is actually dissolved in water. This dissolved oxygen is breathed by fishes and zooplankton and is needed by them to survive. Oxygen enters the water by photosynthesis of aquatic biota and by the transfer of oxygen across the air-water interface. The amount of oxygen that can be held by the water depends on the water temperature, salinity, and pressure. Gas solubility increases with decreasing temperature (colder water holds more oxygen). Gas solubility increases with decreasing salinity (freshwater holds more oxygen than does saltwater). Both the partial pressure and the degree of saturation of oxygen will change with altitude. Finally, gas solubility decreases as pressure decreases. Thus, the amount of oxygen absorbed in water decreases as altitude increases because of the decrease in relative pressure.

What you need

1 – vessel with water,
2 – table cooker,
3 – oxygen sensor,
4 – temperature sensor.

Scheme of the experiment



What to do

- Put the oxygen and the temperature sensors into the vessel with water.
- Set up time interval between two measurements to 5 seconds.
- Switch the cooking stove up and start to measure oxygen level in water against temperature of water.
- Stop to measure when temperature reaches 35–40°C.

Look at your data

- Estimate maximum and minimum value of oxygen level and difference between them.
- Compare oxygen level of the cold and hot water.

Questions for you

- Which water contains more oxygen, cold or hot?
- Try to explain, which water is better for fish and other aquatic organisms for breathing.
- Discuss your answers with the teacher.

Science around

Oxygen is a necessary element to all forms of life. Natural stream purification processes require adequate oxygen levels in order to provide for aerobic life forms. As dissolved oxygen levels in water drop below 5.0 mg/l, aquatic life is put under stress. The lower the concentration, the greater the stress. Oxygen levels that remain below 1–2 mg/l for a few hours can result in large fish kills.

Very high concentration can be harmful to aquatic life. Fish in waters containing excessive dissolved gases may suffer from "gas bubble disease"; however, this is a very rare occurrence. The bubbles or emboli block the flow of blood through blood vessels causing death. External bubbles (*emphysema*) can also occur and be seen on fins, on skin and on other tissue. Aquatic invertebrates are also affected by gas bubble disease but at levels higher than those lethal to fish.

Rapidly moving water, such as in a mountain stream or large river, tends to contain a lot of dissolved oxygen, while stagnant water contains little. The process where bacteria in water help organic matter, such as that which comes from a sewage-treatment plant, decay consumes oxygen. Thus, excess organic material in our lakes and rivers can cause an oxygen-deficient situation to occur. Aquatic life can have a hard time in stagnant water that has a lot of rotting, organic material in it, especially in summer, when dissolved-oxygen levels are at a seasonal low.

Related experiments

- Where is the atmospheric oxygen from?
- Aquarium observation.

3. Where is the Atmospheric Oxygen from?

Oxygen is a colourless odourless reactive gaseous element. Atmospheric oxygen (21% by volume) is of vital importance for all organisms that carry out aerobic respiration. It is a reactive element; it reacts with most other elements during combustion on most occasions. So, where is the atmospheric oxygen from? Do you know any process by with oxygen is released into the atmosphere?

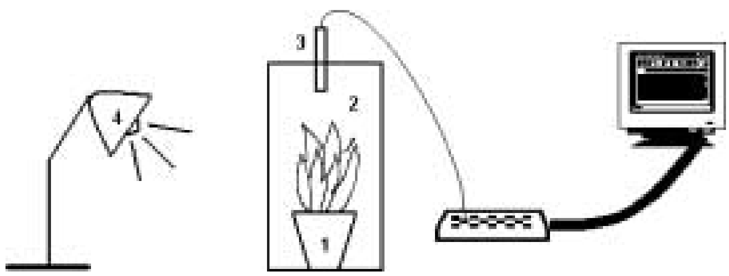
A little bit of the theory

Photosynthesis is a chemical process by which green plants synthesize organic compounds from carbon dioxide and water in the presence of sunlight. It occurs in the chloroplasts (most of which are in the leaves) and there are two principal series of reactions. In the light reactions, which require the presence of light, energy from sunlight is absorbed by photosynthetic pigments (chiefly the green pigment chlorophyll) and converted into chemical energy. In the ensuing dark reactions, which can take place either in light or darkness, this chemical energy is used in the production of simple organic compounds from carbon dioxide and water. Further chemical reactions convert these compounds into chemicals useful to the plant. Photosynthesis can be summarized by this equation:

What you need

1 – plant,
2 – plastic bag or plastic bottle which has a minimum volume of 5 dm^3,
3 – oxygen sensor,
4 – standing lamp with 100–150 W light bulb or intensive daylight.

Scheme of the experiment



What to do

- Place the plant to be studied and the oxygen sensor into the plastic bottle or plastic bag without access to the outside air. It is better to enclose a large volume of air because greater carbon dioxide resources are needed for photosynthesis.
- Start to record the oxygen and light changes for about 1 hour or one day according to the type of experiment.

Look at your data

Observe and describe the oxygen level changes during the presence of light and without light.

Questions for you

- Does the weather influence the amount of oxygen produced?
- Do different kinds of plants produce different amounts of oxygen?

Science around

Virtually all oxygen in the atmosphere is thought to have been generated through the process of photosynthesis. Obviously, all respiring organisms (including plants) utilize this oxygen and produce CO_2. Thus, photosynthesis and respiration are interlinked, with each process depending on the products of the other. The global amount of photosynthesis is in the order of a trillion kg (10^{18} kg) of dry organic matter produced per day, and respiratory processes convert about the same amount of organic matter to CO_2. A large part (probably the majority) of photosynthetic productivity occurs in open oceans, mostly by oxygenic prokaryotes. Without photosynthesis, the oxygen in the atmosphere would be depleted within several thousand years. It should be emphasized that plants respire just like any other higher organism, and that during the day this respiration is masked by a higher rate of photosynthesis.

Photosynthesis and related processes can be applied to many more areas.

Light energy is cheap, clean, and essentially inexhaustible. With limited supplies of fossil fuel and increasing concern about CO_2 emissions, further development of technologies that make use of solar energy is inevitable. Current silicon-based technologies for the harvesting of solar energy require a very energy-intensive production process and even though they have improved significantly over the years in their efficiency, further development of photosynthesis-based technologies for energy collection is certainly warranted.

There are a myriad of possible applications for artificial reaction centres and related molecules in *nanotechnology*. Many synthetic pigments also have found biomedical uses in tumor detection, as they – for unknown reasons – tend to accumulate preferentially in tumors and are highly fluorescent and thus easily detectable in a patient whom is being operated on to surgically remove a tumor.

In the *biotechnology* field, photosynthetic organisms are likely to play an increasing role in (over)production of enzymes, pharmaceuticals etc., which until now are produced primarily by genetically modified heterotrophic microorganisms such as yeast and selected bacteria. A major advantage of photosynthetic organisms is that no fixed-carbon source needs to be added for growth and, therefore, production costs are lower and the chances of contamination with other microorganisms are less.

Another potential application of photosynthetic organisms is in *bioremediation*. Bioremediation is the clean-up of environmental (soil or water) pollutants by biological means. An example is the biological breakdown of toxic organic compounds into innocuous products. Also, remediation of nitrate from drinking water supplies is becoming an increasingly pressing issue. The advantage of using photosynthetic organisms is that no external energy source needs to be provided for growth of the organism if it is in the light, making these organisms very suitable for remediation of aqueous surface environments.

Another utilization of photosynthetic organisms is to have these organisms use solar energy to produce *clean-burning fuels*. Even under natural conditions some photosynthetic systems can produce hydrogen, which probably is the cleanest fuel as it reacts with oxygen to produce water. Another option would be to use photosynthetic organisms for methane production. Even though methane upon combustion will form CO_2, the overall atmospheric CO_2 balance would not be disturbed as an equal amount of CO_2 will have been taken out of the atmosphere upon methane production by the photosynthetic organism.

More to explore

- Do you think that the volume of oxygen released is dependent on the size of the plant?

- Does photosynthesis depend on the wavelength of light?

Related experiments

- Aquarium observation.
- What does the fish breathe?

4. Why do some Animals Huddle in Cold Weather?

Have you ever seen a picture of penguins? Different species thrive in varying climates, ranging from Galapagos penguins on tropical islands at the equator to emperor penguins restricted to the pack ice of Antarctica. How do the later keep warm in an Antarctic winter?

A little bit of the theory

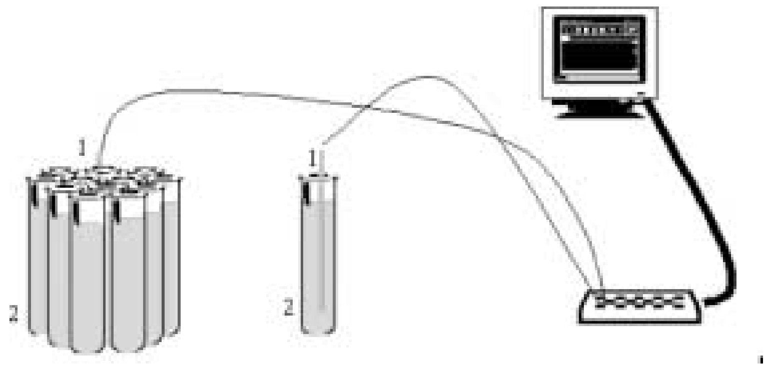
Animals use various methods to prevent heat losses in cold weather. One of them is huddling – an animal huddled with its partners exchanges heat with them, which help it to maintain its temperature better in comparison with a lonely animal.

You can investigate animal behaviour with the help of modelling real animals with test tubes.

What you need

1 – two temperature sensors (0°C – 100°C),
2 – six-ten equal test tubes.

Scheme of the experiment



What to do

- Make a bundle of 5–9 equal test tubes and fasten it to a stand.
- Fasten one separated test tube to another stand.
- Place one temperature probe into the middle test tube of the group and the second temperature probe into the separated test tube.

- Carefully pour hot water into all test tubes.
- Record the temperature changes for 20 minutes.

Look at your data

- Compare temperature changes of the "separate animal" and the "animal in a middle of the huddled animals".
- Interpret the obtained data.

Questions for you

Which place is better for keeping warm?

Science around

Emperor penguins represent a nice example of "huddling" animals. As soon as the female lays her single egg, the male scoops it up onto his feet, positions it against a patch of warm, bare skin, and covers it with a fold of fat-laden skin. To withstand the –57°C temperatures and the howling winds, hundreds of males huddle together on the ice – each taking their turn in the warmer interior of the huddle.

More to explore

- Try to "wear" the separated testing tube, so as it keeps its temperature similarly to the testing tube from the middle of the group. Use the ideas and the results of experiment *Which material protects us the best in cold weather?*
- Contrary to this experiment animals sometimes need to prevent overheating of their bodies. Ideas how they can do this can be found at *How do elephants keep cool?*

Conclusions

The course *Integrated Science through Experiments* was firstly introduced to secondary school teachers at the workshop in June 2002. Individual parts of the course were trialled in a frame of physics teacher training courses at Matej Bel University and tested also at the partner secondary school. The obtained feedbacks indicate that the course will find its addressees in the both target groups – university and secondary school students. It is clear that the integration of ICT into learning activities contributes to making the science lessons more exciting and interesting for students as well as for the teacher.

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All the three authors collaborated at the *ComLab-SciTech* project (2000–2004) and are currently involved at curriculum development project *Real and Virtual Laboratories in Education*. They have presented their work at various national and international conferences.

Integruotas gamtos mokslų mokymas remiantis kompiuteriniais eksperimentais

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Straipsnyje supažindinama su modernia gamtos mokslų mokymo programa ir jos aktyvių įgyvendinimų Slovakijoje. Aprašomi veiksmai buvo atliekami vykdant Leonardo da Vinci II programos remiamą žvalgomąjį projektą “Kompiuterinės laboratorijos mokant gamtos mokslų ir technologijų” (sutrumpintai anglų kalba: ComLab-SciTech). Šio projekto metu parengta mokymo ir mokymosi medžiaga apima ir integruotą mokymo programą, pasižyminčią dvejopa prasme: viena vertus, tarpusavyje suderinamos fizikos, chemijos ir biologijos žinios bei ju mokymosi metodika, kita vertus, pasitelkiama gausybė realių ir virtualių kompiuterinių priemonių eksperimentams atlikti. Straipsnyje pateikiama ir atskirų siūlymų, kaip gerinti besimokančiųjų tiriamuosius įgūdžius, atsižvelgiama į laboratorinių modelių naudą gamtos mokslų mokymui.