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Demonstration of biological processes in lakes and fishponds through computerised laboratory practice*

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Higher education in Slovenia is facing a decline in interest in the study of engineering and science, despite the fact that job opportunities for engineers have continually increased in recent years. In addition, the scientific and technical knowledge of students entering higher education has been observed to be rather theoretical and fragmented with a weak association to technological issues. This article presents an action designed to improve this situation. At a grammar school in Slovenia, inquiry based teaching has been introduced to biology laboratory lessons. The aim of these lessons is to study biological processes in fishponds, focusing on the concentration of dissolved oxygen. Students are asked to predict the outcome in four different situations that may arise in a fishpond. To verify their hypotheses, the students are required to design and analyse computer supported measurements in an aquarium that refelects the processes in the fishpond. Feedback from students during lessons, as well as their responses to a questionnaire administered afterwards are encouraging. Although computerised school laboratory and inquiry-based teaching is not foreseen in the official curriculum, certain prescribed learning goals were fulfilled. Furthermore, students achieved knowledge and skills that are not anticipated in the curriculum, but may be of equal or greater importance.

Keywords: school science laboratory; data acquisition; plant physiology; model experiments; biology teaching; inquiry-based teaching; problem-based teaching

INTRODUCTION

THE FORMAL REGULATION of Slovenian higher education has not significantly changed in recent decades, despite the enormous changes in the economic and community situation in the country. About 15 years ago, a crisis in large industrial systems caused a significant decline in interest in the study of engineering and science disciplines. This was especially alarming since the proportion of the population participating in higher education has been continuously increasing.

In recent years, industry has recovered as the result of a growing number of small and middle sized enterprises that supplement the few larger industries. Economic changes have caused an increased demand for engineering and science graduates. In addition to the fact that higher engineering and science schools have fewer freshmen students, they are also facing a fall in the scientific and technical knowledge and skills that have been obtained by such students in secondary schools. This is particularly true of the engineering and science departments in the universities, which mainly recruit students from the general secondary schools, in Slovenia called 'Gymnasium' (teaching students aged 15 to 19).

One reason for the decrease in technical and scientific literacy of students entering the universities may have been the reluctance of the Slovenian engineering community to participate in the changes in Slovenian secondary education that occurred in the last two decades. The results of these changes in secondary education were not positive from the engineering and science point of view. In lower secondary education (12–15 years), technology is taught until age 14 as a separate compulsory subject, while science is divided into separate physics, chemistry and biology subjects from the age of 13. Furthermore, changes in the curriculum at Gymnasium level in the last decade have completely eliminated topics related to technology and engineering and replaced them with other subjects that emphasise the mother tongue, foreign languages and social studies. Computer science, which used to include an introduction to programming, was transformed into informatics. The curriculum in physics, chemistry and biology developed a more or less theoretical character. Laboratory lessons included in the curricula are predominantly based on the old

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fashioned 'cook-book' approach. Moreover, the designers of the curriculum did not move towards more integration of science subjects. The consequence is that the students' knowledge of science is fragmented to a range of physics, chemistry and biology topics, with limited transfer of information, and mostly has no connection to problems associated with real life or technological issues. The approach in secondary science and technology education described above is especially unsuitable for agriculture and bio-engineering education, where both technical aspects and an integrative approach to science disciplines are essential.

Despite the these deficiencies in science and technology secondary education, several studies have been introduced to improve the situation [1–3]. The Department of Physics and Technology at the Faculty of Education, University of Ljubljana, was involved in national projects supported by the Ministry of Education, Science and Sport. Through the Computer Literacy Programme (called Ro) and Aimed Research Projects (known as CRP projects), computer supported laboratory lessons were introduced to secondary science and technology education. The spectrum of activities involved the development of optional subjects such as Robotics and Electronics for lower secondary education levels as well as the introduction to the use of data acquisition systems, sensors, computerised data analysis and computer simulations in physics, chemistry and biology teaching [4–6]. These national projects were continued in an EU Leonardo da Vinci pilot project called ComLab [7]. This project's courses combine virtual and real computerised laboratory practice as well as attempting to integrate science and technology disciplines [8]. Secondary school teachers were involved not only in testing and evaluation but also in the development of the ComLab courses [9, 10]. These course developments are continuing after the project's lifetime. The new courses under development focus on engineering aspects of science and technology topics, targeting post-secondary vocational and professionally oriented higher education. One such course will be in the area of bioengineering education, specifically directed towards applications of computerised measurements in agriculture and forestry.

Besides introducing 'hi-tech' equipment into science and technology teaching, the ComLab project also addressed the methodology and didactics of teaching. To stimulate creativity and innovation [11, 12], the laboratory lessons were based on inquiry and problem based teaching, the importance of which is frequently emphasised elsewhere [13]. Problem-based work with students in the classroom starts with a presentation of a problem situation, which activates cognitive processes in students, so they can autonomously find solutions. In short, problem solving is a situation when two or more previously learned principles (rules, laws, etc.) are combined in a higher order principle [14]. Afterwards, the discovered principle can be applied to a whole range of similar problems.

Proficiency in understanding biological processes is fundamental for solving problems or finding solutions in agricultural, biological and environmental engineering. However, presentating and clarifying biological processes to the students can be a difficult task for a teacher. Some of the processes are extremely fast with everything happening over a short timescale, while other processes are very slow and the observed variables do not change significantly in hours or even days. On the other hand, understanding most biological processes is closely related to basic physics and chemistry topics.

Researchers in modern scientific and industrial laboratories use computers as indispensable tools, supporting measurement as well as presentation and analysis of measured data. Even higher education curricula, however, do not reflect the importance of applying computers in 'hands-on' laboratory lessons. Many university and secondary school teachers still understand the phrase 'using computer' to mean 'using computer for e-mail or Internet, for a database or as sophisticated typewriter or calculator'. Even when students use computerised laboratory methods within biology lessons, they often have no background knowledge of the data acquisition and control principles involved, of digital signal processing, etc. The process of using such tools is limited to straightforward instructions presented in a recipe format. The introduction of computerised laboratory work in science education would contribute new dimensions to applicable knowledge and skills.

Respecting the existing biology curriculum in Gymnasiums, therefore, our course development strategy was based on a combination of computerised laboratory, inquiry based teaching and consideration of real life problems.

In this paper we present an inquiry-based approach to laboratory lessons on computerised measurements in an aquarium, used as a model for processes in fishponds and lakes. Through a series of experiments, the interdependence of oxygen concentration in water, light intensity and temperature on the biomass of fish and plants is studied. The impact of eutrophication and pollution on water quality is also confirmed.

METHODOLOGY OF INQUIRY-BASED LABORATORY LESSONS

All experiments were performed at the Prva gimnazija Maribor (First Gymnasium of Maribor) high school with students aged 16 to 17. The school science laboratory is equipped with one teacher's set and four student's sets of the eProLab data acquisition system and software [7] and a number of Vernier sensors [15]. For the experiments we present below, two dissolved oxygen concentration sensors, one light sensor and one temperature sensor were used. Before introducing the inquiry-based laboratory lessons, students performed a series of laboratory classes starting with some short term hands-on exercises to introduce the necessary principles of data acquisition and familiarisation with the sensors needed for the experiments.

In the introduction to the series of inquiry-based laboratory lessons, a problem related to fisheries was briefly outlined to the class of 30 students. Here is the text as presented to students:

> Fisheries can produce a limited quantity of fish in a single fishpond. One of the most important limiting factors is the concentration of oxygen in the water. If the concentration is lower than that needed for a chosen fish species, the fish eat less and the result is slower growth. If the concentration drops even more for a longer time, fish die. The sources of dissolved oxygen are atmospheric oxygen, oxygen from incoming water and oxygen from photosynthesis of green plants and algae.
>
> Your task is to draw graphs showing curves of the time dependence of dissolved oxygen concentration for four different problems that may arise in fishponds. The problems are described below. Briefly comment on each of the curves. Then design a series of four experiments to test your predictions.

After 20 minutes of individual work, 20 minutes was spent on consolidation of the predicted curves within eight groups of three or four students.

The second step was the presentation of the graphs by the representatives of each group to the whole class, followed by the discussion.

The third step was to design four model experiments in aquariums to verify the predictions experimentally for each of the four conditions in fishponds. The students were allowed to use the computerised laboratory with a known set of sensors and everything that they could find in the school laboratory. Their first task was to sketch an experimental design for each experiment. Once again, each group presented proposed experiments to the whole class. After a debate, four experimental designs for further work were consolidated.

During the phases described above, the teacher did not comment on the students' work; his role was only to present problems and organise the lessons.

The fourth step was to perform the four experiments and compare the results with the predicted curves. As there were not enough sensors, pairs of students were elected to perform the experiments in the school laboratory. Initially they chose goldfish for the experiments. The reason was that goldfish can be kept in a small aquarium without equipment for filtering and aeration. Goldfish can live for longer periods with a limited supply of oxygen, due to their ability to swallow atmospheric air as an oxygen supply. After the first experiment, the fish were replaced with water snails.

After finishing the experiments, each student received prints of all the experimental plots. The final debate in the class concluded with making the final reports.

EXAMPLE PROBLEMS IN FISHPONDS

Fishery in natural environments as well as in fishponds is a frequent subject of research [16, 17]. Aquariums are often used to model the relationship between variables that influence fish growth [18]. There are studies about the effect of dissolved oxygen concentration on growth and food conversion efficiency of fish [19], on reproductive performances of fish [20], fish mortality [21], eutrophication of water [22], etc. The problems in fishponds presented to students were chosen to reflect real situations. In this section we present the text given to students concerning each of four problems that may arise in a fishpond. Typical prediction graphs of dissolved oxygen concentration drawn by the students are presented as well as the experimental results obtained in the model experiments in aquariums. Each problem concludes with a brief comment.

Problem 1

During a dry season, the supply of fresh water with a high concentration of dissolved oxygen stopped completely. Plot prediction curves for the concentration of oxygen in two similar ponds where the only difference is the biomass of the fish. In the first fishpond, the biomass is much larger than in the second.

All the students predicted that the concentration of oxygen would decrease faster in a fishpond with a larger biomass. The difference was in the shape of the curves as shown in Fig. 1.

Students tested their hypotheses using two aquariums. In the first aquarium they put one goldfish and in the second they put two. In each aquarium they placed one dissolved oxygen sensor and left it there for three days. As seen in Fig. 2, the results differ from the predicted curves. No student assumed that if the biomass of fish is low enough, the supply of oxygen from the atmosphere can be sufficient. A graph was later used as an initial point for discussion about noise in the signal. It was concluded on the basis of observation while the experiment was being performed, that the most important reason for noise is the fact that the fish frequently disturbed the water surface. One important question was also how to determine a suitable sampling frequency.

Problem 2

Predict what would happen in a similar situation to that in Problem 1 in the winter, when the water temperature is low and in the summer, when the water temperature is high. Draw and comment on the curves.

As seen in a typical drawing presented in Fig. 3, students predicted a faster drop in concentration in the warm water.

Water snails were used instead of fish in this case, the reason being that temperature shock can be harmful to fish. So the students decided to put an equal mass of snails in each of two beakers.

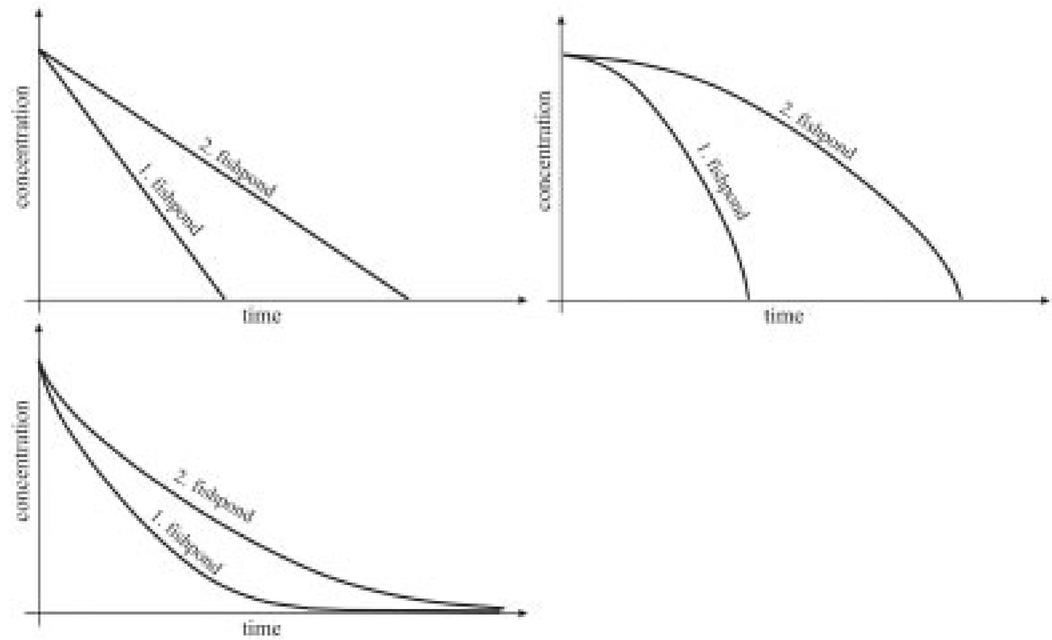

Fig. 1. Three of the most common type of graphs predicting oxygen concentration in two fishponds with different biomasses of fish.

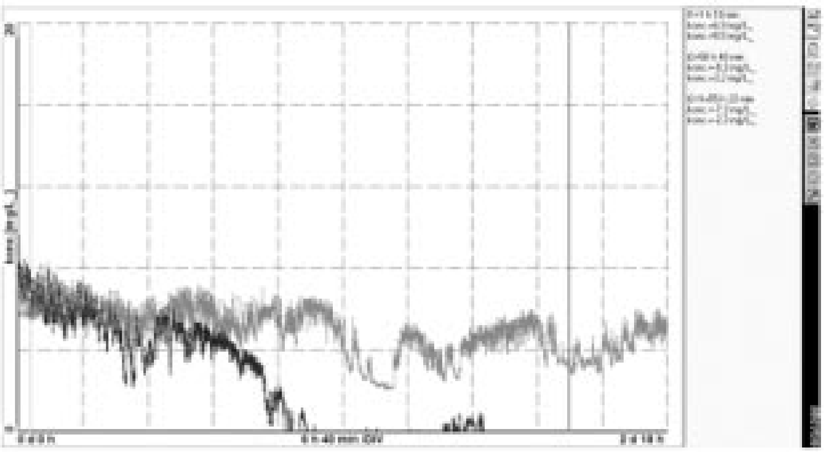

Fig. 2. Oxygen concentration in aquarium with one fish (top curve) and two (bottom curve).

They placed one of the beakers into a water bath with ice cubes and the second in a water bath with warm water. Temperature and dissolved-oxygen sensors were placed in both beakers. The measurements lasted two hours. The oxygen concentration at low temperature remained more or less constant, while it decreased significantly in the warm water.

Problem 3

Predict the influence of green plants on the oxygen concentration in three fishponds. In the first pond, there are only fish, in the second pond, there are fish and green plants and in the third pond, there are fish and twice the biomass of green plants as in the second pond. Predict the curves for three days.

The students predicted that the biomass of green plants would influence the oxygen concentration. One typical example drawing is presented in Fig. 4. An increasing concentration was assumed for the third pond while for the second pond the concentration was considered to be almost in equilibrium.

For testing their hypotheses, the students again used an aquarium with water plants and water snails. They placed an oxygen concentration sensor in the aquarium with a light sensor beside it. They repeated the experiments with different biomasses of plants and snails. The graph in Fig. 5 was obtained with a large biomass of plants. It is clear that the oxygen concentration during the night can drop to zero. Comparing the predictions and experimental results, it is evident that the students did not predict fluctuations in oxygen concentration due to photosynthetic activity during the day and lack of it at night. They did not take into account that plants are also oxygen consumers.

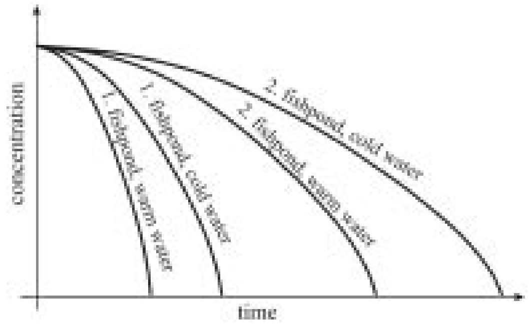

Fig. 3. Predictions for time dependence of oxygen concentration in fishponds with different biomasses and temperature.

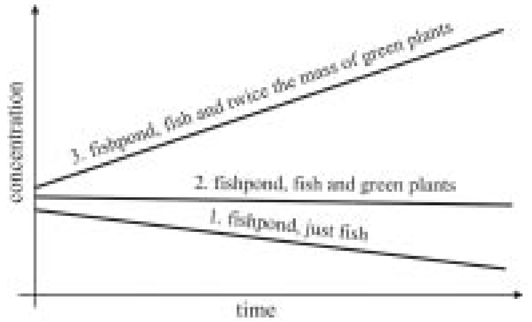

Fig. 4. Typical prediction of oxygen concentration in fishponds with different conditions.

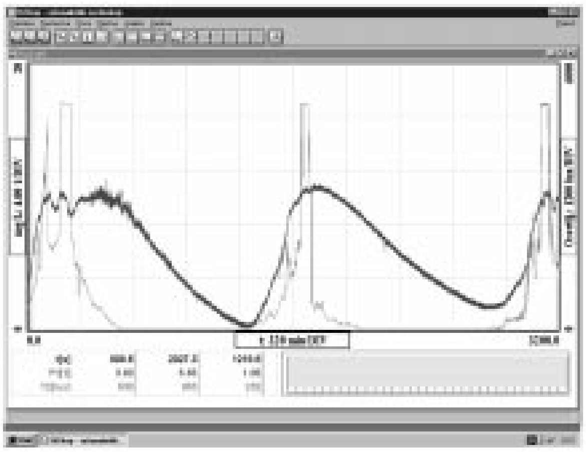

Fig. 5. Experimental plot of light intensity (short-term peaks) with oxygen concentration in water.

Problem 4

The pollution of fishponds with organic matter or waste water can be harmful for water organisms. Predict and plot a curve of oxygen concentration if someone polluted a fishpond with a significant volume of organically polluted water.

All students predicted a faster reduction in oxygen concentration in polluted water. The prediction curves differed only in shape, as in the previous problems. To test their predictions, the students placed dissolved-oxygen sensors in two beakers. Organic material was added to one of them. As observed, the oxygen concentration drops quickly in the beaker with polluted water (Fig. 6) due to bacterial activity, while it remains constant in tap water.

QUESTIONNAIRE ON COMPUTERISED LABORATORY LESSONS

Students were asked to complete a short questionnaire about their computerised laboratory lessons. The questionnaire was divided in two parts: the first part was a closed questionnaire on a five-points Likert scale and the second part allowed for open-ended answers.

From Table 1, one can conclude, that students mostly agreed with the statements offered. The highest value (4.2 ± 0.8 SD) related to the statement that the experiments were interesting, and the lowest (3.2 ± 0.8) SD) to the fact that they did not need much help from the teachers.

There were three open-ended questions.

1. On the question 'Where did you have greatest trouble?', the most common answer was a variation on the theme, that they did not have any trouble. Some students mentioned trouble with the settings of the data acquisition software.
2. On the question 'What was the best?', we would like to underline the statements: 'The way we worked, it was pleasant'. 'Working with modern equipment'. 'Seeing the results immediately on the computer screen'. 'We got the results based on our own work'.
3. On the question 'How would you improve the work?', the most common answer was that the laboratory work does not need further improvement.

CONCLUSIONS

Although the combination of computerised school laboratory and inquiry-based teaching is not foreseen in the official curriculum, we managed to fulfil a great deal of prescribed learning goals from ecology and plant physiology. Furthermore, students achieved knowledge, skills and competences that are not anticipated in the curriculum, but may be of the same or even greater importance. Through the laboratory lessons, based on the real fisheries problems described above, students were introduced to some bio-engineering issues, they used modern laboratory equipment and methods and they needed to integrate knowledge of physics and chemistry. We believe that these 'side-products' of the lessons may be even more applicable and long-lasting than those of the curriculum.

Furthermore, the inquiry based teaching stimulated students to independent formation of

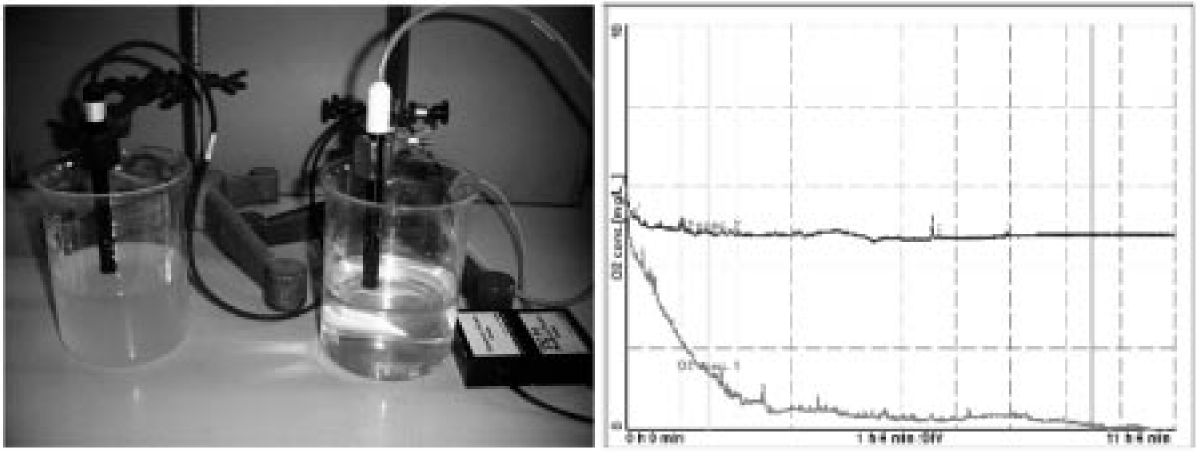

Fig. 6. Experimental design and results of measurements of oxygen concentration in clear and polluted water.

Table 1. Mean values of the answers in the questionnaire (5 Strongly agree, 4 Agree, 3 Neutral, 2 Disagree, 1 Strongly disagree)

	Mean	SD
1. I know the goal of the experiment	3.9	0.8
2. I could arrange the experiments by myself	3.6	0.9
3. I do not need much of the teacher's help	3.2	0.8
4. I do not have troubles with software	3.6	1.0
5. The experiments were interesting	4.2	0.8
6. I understood the graphs	3.8	1.0
7. The lab work proceeded in a pleasant working atmosphere	3.9	1.0

hypotheses, designing new experimental apparatus and analysis of experimental data. The students needed to seek information not only from biology textbooks but also from other sources such as the Internet. During the lessons, the teacher was more a partner then a principal—sometimes even the teacher did not know with any confidence what would be the outcome of a proposed experiment. The ambience was friendly and productive since the students were not punished with low grades for wrong hypotheses or presumptions. Even if it was only representatives who prepared the experiments, the rest of the students were regular visitors to the laboratory while the experiments were being carried out, observing and commenting on real-time plots on the computer screen. They were overheard talking about the experiments before lessons and during breaks.

Encouraged by the results, we are planning to develop new problem and inquiry based situations to teach our future engineers and scientists, as well as lawyers, artists, grammar teachers, etc. about important issues of the world around them.

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