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Teaching basic engineering and technology principles to pre-university students through a computerised laboratory

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ABSTRACT: The *highway* to university studies in Slovenia leads through general secondary schools, which are named *Gimnazija.* Secondary school at Gimnazija study concludes with leaving examinations called *Matura* as an obligatory prerequisite to enter universities. The curriculum in Gimnazija is highly scholastic and is weakly related to engineering and technology topics. Computerised laboratories in physics, chemistry and biology lessons have been introduced as a so-called *backdoor* for connecting fragmented knowledge and teaching students about some of the basic principles needed to understand some of the engineering and technological processes in industry and scientific research.

INTRODUCTION

In the last two decades, Slovenian upper secondary education (for students aged from 15 to 19 years) has changed considerably. Up until the end of the 1980s, programmes were intended to simultaneously prepare students for the labour market and further studies. Nowadays, some shorter programmes of two and a half to three years are primarily vocationally oriented and lead directly to the labour market, while extended 4-year programmes are either largely general (eg the general *Gimnazija school*) or more or less vocationally oriented (eg *Technical Gimnazija* or secondary technical school programmes).

In 1995, the *Matura* examination was introduced to serve as an entrance examination for higher education studies [1]. For those students intending to enrol in a university degree, the *highway* to university education leads through general *Gimnazija* secondary school, with its main goal to prepare students for the *Matura* examination.

Curriculum changes in the last decade have eliminated subjects that are related to technology and engineering; these have been replaced with other subjects that emphasise the native tongue, foreign languages and social studies.

Computer science, along with computer programming, was transformed into the subject of informatics. Science was arranged into three separate subjects: physics, chemistry and biology. These became, more or less, theoretical in character with laboratory work that was founded on an old-fashioned laboratory approach, including very little hands-on experience for students. Moreover, the creators of the curriculum did not succeed in connecting knowledge between different subjects. The consequence is that students' knowledge is fragmented, having limited transfer of information between subjects, and mostly unconnected with problems that may be encountered in real life or with current technology. For most students, the last contact with technology as a part of their education is at the end of low-secondary school (aged 15).

Unsatisfied with this situation, the authors have sought to overcome these identified problems. As a backdoor for some technology related topics, computerised experiments in teaching biology and chemistry at the Prva Gimnazija Maribor, Maribor, Slovenia, were initiated in 1999. The introduction of computerised laboratory was stimulated by the Faculty of Education at the University of Ljubljana, Ljubljana, where a small team developed a data acquisition system called CMC-S2, which was designed primarily for physics and technology education [2].

Following our positive experiences, some other Slovenian schools have also implemented the data acquisition systems (DAQ). New experiments for biology and chemistry were developed and presented through teacher's in-service training courses [3][4]. In 2001, the European Union programme *Leonardo da Vinci*, supported a pilot project ComLab-SciTech [5]; this aimed to develop novel state hardware and software, along with a series of courses dedicated to science and technology teachers. One key feature was software that supported the new DAQ system, called CMC-S3, which enabled data collection and generated output signals [6]. With these possibilities, a series of new experiments were developed, and currently practiced experiments were modified.

TEACHING SCIENCE WITH COMPUTERS

Besides the common use of computers as modern typewriters, information and communication technology (ICT) in education is generally employed for data processing, as a source of information and as a medium for presentations. In addition, there are some specific aspects when using ICT in science and engineering education [7]. Its classroom usage can be divided into the following two general categories:

- Multimedia can generate a so-called *virtual laboratory*. Computers are used to simulate various science phenomena and complicated, expensive and/or inaccessible devices. Multimedia material can also be combined with interactive html documents for Web-based learning.
- The microcomputer-based laboratory (MBL) is a *true laboratory* that employs DAQ system as a key tool (see Figure 1). The importance of practical experimentation and laboratory work has not decreased in the ICT era. MBL is an ideal way to link true and virtual laboratories. Computers are used to measure, monitor and/or control physical quantities, such as temperature, pH, pressure, electrical voltages, pressure, etc.

Figure 1: Students working with the data acquisition system in a biology lesson.

However, it is not so much a question whether or not to emphasise a virtual or true laboratory, as both approaches are complementary [8][9]. The main advantages of virtual laboratory are as follows:

- The possibility to repeat virtual experiments as many times as is needed;
- Students can quickly change parameters;
- Some otherwise hazardous or large-scale experiments can be presented;
- No special or expensive instruments are required;
- Work is completely safe, etc.

On the other hand, in a real laboratory, students gain experiences with real phenomena, organisms and chemicals, and have to cope with ethical and environmental issues. Students can be involved in the whole experimental process, starting with the idea and ending with the final presentation, thereby acquiring some taste of scientific research.

The ComLab-SciTech pilot project developed example courses wherein true and virtual laboratory activities are integrated [10]. A set of simulations was also designed in order to achieve complementary learning goals within the context of true experiments. The simulation software is accessible to be downloaded from the project Web site free of charge [5].

TEACHING SCIENTIFIC PRINCIPLES

In a world where a person can meet all kinds of pseudo-science and false sciences, it is very important to teach students how to distinguish between them and *real* science. Measurements, observation and experimentation are key scientific methods that can be presented to students in a straightforward and attractive manner through computer-supported laboratory [11-13].

There is the possibility to connect other items to the CMC-S3 data acquisition system, including up to eight analogue and two digital sensors. Experimental designs with well-defined control parameters were introduced to secondary school science laboratory exercises (see Figure 2) (eg a lack of control can lead to speculation).

With large sets of commercially available sensors, students were able to measure physical and chemical quantities automatically. They were able combine different sensors and invent new experiments or discover non-trivial relations between phenomena engaged in the experiments. Some traditional experiments were modified from qualitative to quantitative approach. With the aid of computers, some very short-term phenomena could be observed, as well as long-term phenomena occurring in biological systems. Importantly, measurements are large-scaled and computerised in modern industrial and scientific laboratories, so the tendency to follow these trends is necessary for education.

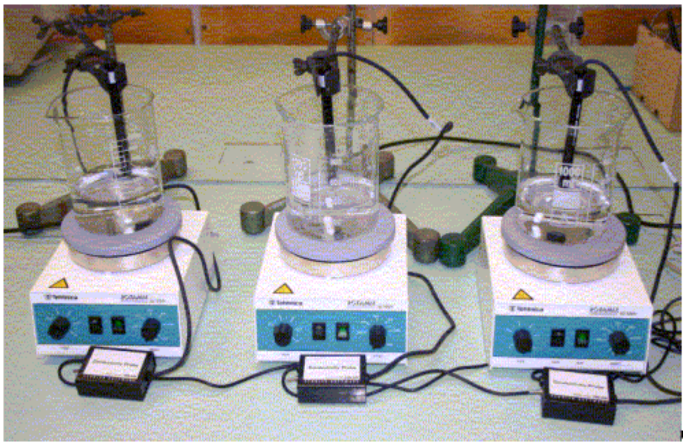

Figure 2: Experimental design for diffusion experiment with three parallel samples and three sensors.

CALIBRATION

The calibration of sensors is an important issue in measurement techniques. Students are rarely involved in this process when attending school. With the use of computers, even future lawyers or language teachers can acquire practical experience with sensors that transform physical quantity to voltage. Furthermore, students learn how to connect these two quantities. Through such experiments, students become familiar with terms, like two-point calibration, best fit polynomial or non-linear sensors (see Figure 3).

PHENOMENA RELATED TO FOOD PROCESSING

Humans encounter food on a daily basis. Food processing and the preparation of food bring together physics, chemistry, biology, medicine, agriculture, plus other disciplines. It is easy to explain basic principles through experiments, such as heat transfer, diffusion, dependence on the speed of reaction and the diameter of particles, etc. The results of an example experiment related to food processing are presented in Figure 4.

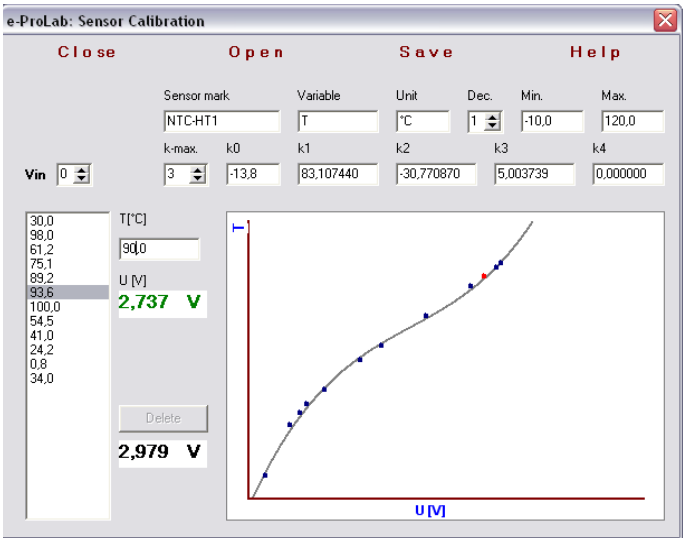

Figure 3: Example plot of a calibration curve for a non-linear temperature sensor.

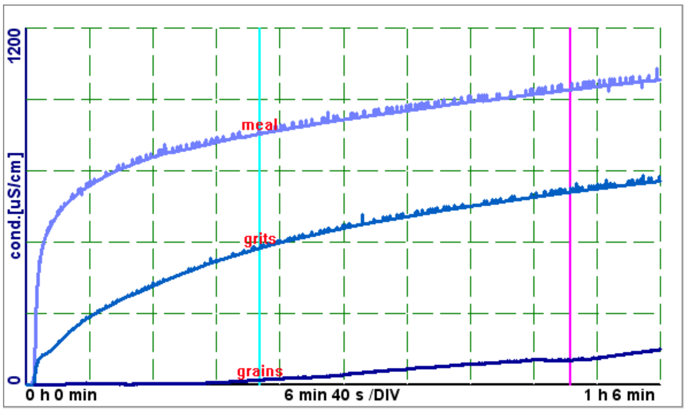

Figure 4: The diffusion of salts from buckwheat into water; the speed of diffusion is determined by the diameter. The lower curve represents whole grains, while the top curve indicates buckwheat meal.

ENVIRONMENTAL ISSUES

Environmental issues have become one of the most important issues at both the local level and on a global scale. Solutions in choosing new technology or processes, or abandoning old habits, cannot be based on faith but rather on clear scientific evidence. Models of some fundamental ecological and environmental principles can also be presented in a school laboratory. A typical example is the depletion of oxygen in polluted water (see Figure 5) and the greenhouse effect (see Figure 6).

INTRODUCTION TO COMPUTER-BASED DATA ACQUISITION AND CONTROL

Nowadays, most science teachers claim that they are not familiar with handling sophisticated equipment used in computerised laboratories. For many science teachers, such equipment was not available when they were trained. Even now, courses for trainee teachers of science rarely incorporate any fundamentals of data acquisition principles and methods.

Figure 5: Experiment showing the depletion of oxygen in polluted water.

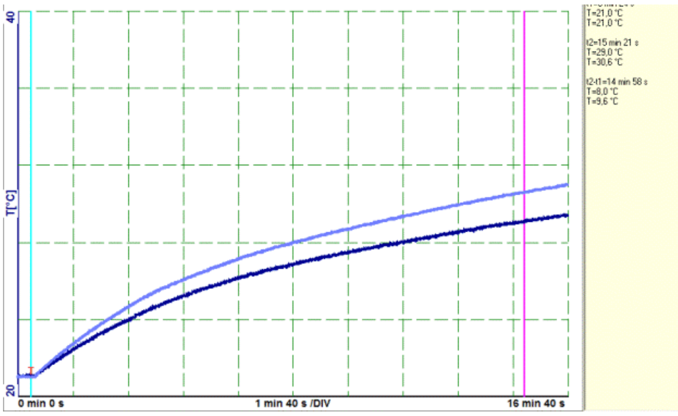

Figure 5: Experimental design and the results of a greenhouse effect experiment.

Commercial suppliers of the DAQ equipment, such as Pasco, Vernier, etc, responded to the lack of knowledge of end users with a so-called *user-friendly* approach [14][15]. They introduced automatic sensor recognition through the DAQ system, the storing of calibration data to sensors, etc. However, not all the traps of using the DAQ systems can be avoided in such a way. Teachers reported that they were often confused when their students asked different questions, like *How does the computer get the information about the pH of the solution?* Some other user-friendly features of the DAQ software can also cause trouble. Plotting a constant signal with the auto-scaling feature can confuse the interpretation of results for a person who has no knowledge about analogue noise, analogue to digital resolution, and the contribution of least significant bits. The choice of using an optimal sampling frequency also invokes some information that is considered essential for the user of DAQ systems; these cannot always be overcome with the user-friendly software.

To avoid the practise of *cookbook* recipes when introducing computerised laboratories in science education, the ComLab-SciTech project developed an interdisciplinary course that covers the fundamental principles of computerised data acquisition and control. The purpose of the course is to generate easy-to-understand theoretical information that is supported by hands-on experimental exercises. The DAQ system is utilised in various practical examples, such as measuring human reaction times, determining the frequency of alternating light at which the human eye cannot detect blinking, the interpretation of analogue to digital (see Figure 6), digital to analogue conversion, etc.

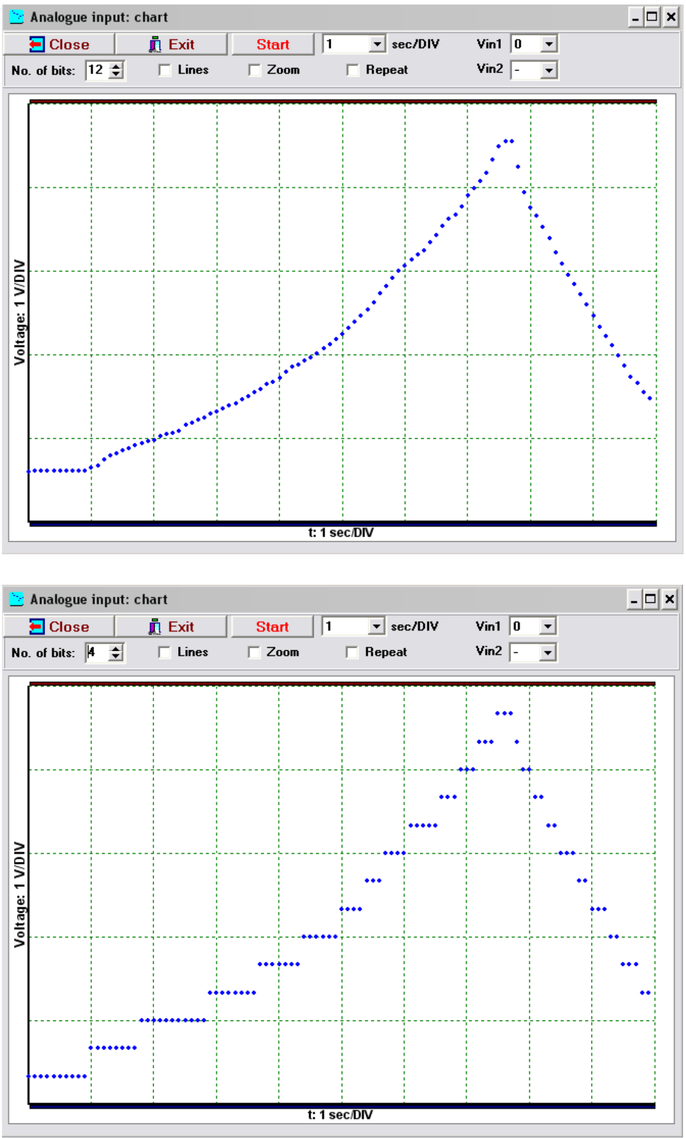

Figure 6: Voltage variation over time as sampled with the DAQ system. The experimental data obtained can be plotted using 12-bit analogue to digital conversion (top), or by using only 4-bit conversion (bottom).

The main target groups of this course are secondary science and technology teachers, as well as scientists and engineers, who are not specialists in the specific topics involved.

CONCLUSIONS

Similar positive reflections with those found in Slovenia have been reported worldwide when introducing computerised laboratories to secondary school science education [16-18]. Some positive side effects have been recognised in the last years. Largely fragmented knowledge, which was being taught in physics, chemistry and biology lessons, tended to become more integrated because teachers from the science disciplines started to unify protocols; this resulted in time savings. Moreover, science subjects can utilise the same basic equipment in computerised laboratories, which was not the case for traditional laboratory practice. Academic knowledge was enriched with practical issues and school laboratory work has become more connected with everyday life.

Most importantly, both teachers and students have become more partners than opponents. Computerised laboratories have introduced a greater element of fun for both parties: for those who are teaching and for those who are learning. What can be better?

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