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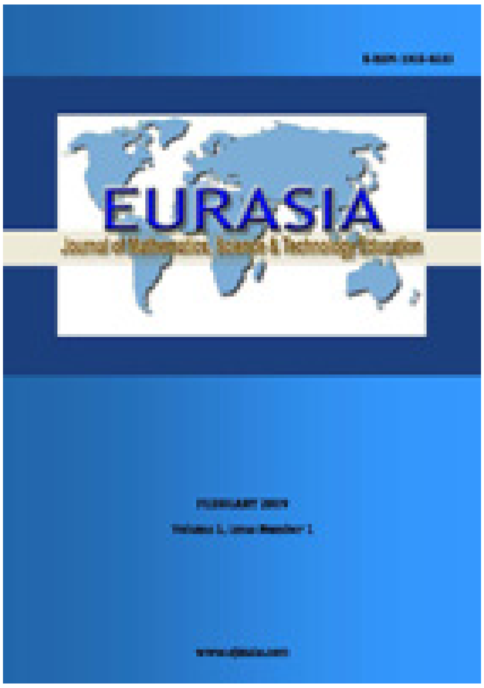

False Reality or Hidden Messages: Reading Graphs Obtained in Computerized Biological Experiments

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Information and communication technology (ICT) has become an inseparable part of schoolwork and a goal of education to prepare scientifically literate and digitally competent citizens. Yet the introduction of computers into school work has been much slower than its introduction in other spheres of life. Teachers' lack of knowledge/skills and difficulty in integrating ICT into instruction affect the realization of computer-related goals in schools. Another hidden obstacle that can affect the introduction of computers into the Biology laboratory can be discomfort with the interpretation of graphs obtained by data-loggers. We can group these difficulties with graph outcomes into 4 areas: 1) Explanations of the curves that lie beyond the domain of Biology, in Physics, Chemistry or some other discipline; 2) Hardware properties; 3) Unknown properties of experimental components; 4) Occasional equipment breakdowns or crashes.

Keywords: Biology, computerized laboratory, data-loggers, ICT, laboratory work

INTRODUCTION

Nowadays the teaching of Biology at Slovenian general upper secondary schools differs radically from the clichéd situation in the past when Biology was clearly divided into Botany, Zoology and Human Anatomy, and Ecology was not seen as a synonym for environmental problems. In that era presentations of objects, stuffed animals, models, pictures, and teacher demonstrations were the prevailing "active" methods in the classroom, and the sampling of herbs to produce a herbarium was a common homework assignment. From our personal experience of Slovene schools about thirty years ago, we know that students performed not one single experiment during Biology lessons, and almost all experiments in Physics and Chemistry were presented as demonstrations. Almost everything a teacher needed for successful classroom survival was learned at university and mastered over the first few years of school work. In the middle of the 1970s schools were reformed. The curriculum in Slovenia was dramatically changed in 1976. Because secondary schools were obligated to prepare students for both further study and professional work, a greater amount of school time was assigned to practical work. The basis for the Biology syllabus and the accompanying laboratory work became the translation of the textbook Biological Science: Molecules to Man (BSCS – Blue version, 1968) into Slovene. New, active methods were introduced into the teaching of Biology, and specialized laboratories with standardized equipment were established in schools. Teachers were forced to learn new laboratory skills, and assessment of laboratory work became a new addition

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State of the literature

- It is the almost consensual conclusion among educators that active teaching methods yield better results than traditional teaching.
- Students like computer-supported real laboratory exercises.
- New sensors and probes are being developed and made commercially available on a daily basis.
- Computer-supported laboratory, even with its well known educational benefits, is not being used in classrooms to its full potential.

Contribution of this paper to the literature

- It was recognized that one of the obstacles in introduction of computerized biological experiments in school was that the graphs obtained were not straightforward to interpret.
- Graphs whose outcomes are difficult to explain most often belonged in the following areas: a) Explanation of the curves is beyond the domain of Biology, but lies in Physics, Chemistry or some other discipline; b) Hardware properties; c) Unknown properties of experimental components: d) Occasional equipment breakdowns or crashes.
- Insufficient knowledge of other disciplines is one of the most common major problems in interpretation of graphs obtained in biological experiments.

to their workload. In 1995 the system changed again, and the idea of simultaneous preparation of students for work and study was abandoned. However, the concept of the importance of laboratory practice and active methods is still alive among many teachers and supported by innumerable articles and books about the benefits of laboratory practice (e.g. Finn et al., 2002; DiCarlo, 2009; Michael, 2006; Šorgo, 2007).

The second event that has exerted a significant influence on the life of every teacher was the introduction of computers into schools. In the seventies and eighties, the main goal of Computer Science was programming, which was left to teachers of this subject. Failure to use a computer on the part of a Biology teacher was not seen as a handicap. After only a few years, computers were everywhere. Computer science was abandoned and replaced by the subject Informatics. Students learned about the internet, e-mail, word-processing, spreadsheets and presentations. If a teacher did not want to be left behind, he/she had to attend in-service training again to master new skills, and free afternoons were lost forever. The difference in the new knowledge is that software changes on a daily basis and equipment every few years, with possibilities of use never before imagined. The literature about computers in education became enormous, covering almost all aspects of school life, yet major breakthroughs are yet to be seen (Hepp et al., 2004).

An explosive combination for the Biology teacher emerged when someone recognized that computers equipped with an interface and couple of sensors could be used as data-loggers; thus experimenting became possible in a virtual world. Laboratory work with computers is nowadays a widely accepted practice in many schools, as both virtual and real laboratory (Šspernjak & Šorgo, 2009; Puhek & Šorgo, 2010). Virtual laboratory involves software where students have the chance to manipulate experimental parameters, although the computer is not connected to a "real" experiment. Many advantages to the use of virtual laboratory have been reported; these include price, safety, ethical issues, and reduction of complexity. There are no waste products, and students can perform experiments at any time and at any place outside specialized laboratories (Kocijancic & O'Sullivan, 2004). In a real laboratory situation, the computer is equipped with a data-logger (analogue – digital interface), so that we can sense, measure, analyse and present data in tables or graphs.

It has been reported that real laboratory work with computers has many advantages in teaching biological processes. With the aid of computerized measurements teachers can experience the following benefits: i) processes that are very slow, very fast, or unpredictable can be tracked; ii) results are presented to the students in real time; iii) different sensors in almost limitless combinations can be combined (Šorgo et al., 2002). Laboratory work based on problem- and inquiry-based teaching is most often reported as beneficial to scientific literacy (Finn et al., 2002; Šorgo, 2007). Such knowledge is recognised as important not only in the academic domain but in industry and research institutions, as well (Duggan & Gott, 2002). Students can gain deeper insight into the research process (Schallies & Lembens, 2002). The role of such work in teaching basic engineering principles has also been recognised (Šorgo & Kocijancic, 2004, 2006). In fact, much laboratory work conforms to engineering principles more than scientific ones. The main difference is that, in science, the major output is new knowledge, while, in engineering, the major output is a product. In engineering, safety, cost and limitations on material, time, etc. are important constraints (Hills & Tedford, 2003). Reported benefits are largely dependent on the context. One of the most often cited is that results are presented as graphs on the computer screen, a mode of visualization that can be beneficial for comprehension of experimental outcomes (Barton, 1997; Newton, 2000); moreover, students cope more readily with anomalous results (Newton, 2000).

Nevertheless, if problem-based teaching and computerized laboratory are such advantageous methods, why then do teachers so rarely use these methods in their laboratory practice? (Šorgo et al., 2010; Špernjak & Šorgo, 2009). Newton (2000) has reported that usage in schools is patchy even when equipment is available. In a survey SITES M2 conducted in 26 countries (Pelgrum, 2001), "Teachers' lack of knowledge/skills" and "Difficulty integrating it into instruction" were listed as the second and third most important obstacles affecting the realization of computer-related goals in schools. The most important obstacle was "Insufficient number of computers". One potential reason could involve problems with interpreting the results of laboratory work (Šorgo et al., 2007). Interpretation of graphs obtained by computers is not always easy and could be seen as an obstacle by teachers considering introducing new laboratory work into regular school practice. This paper presents some typical problems that emerged during work with students in a computerized Biology laboratory, the solutions to which lay largely outside the biological domain.

METHODOLOGY

The present study is based primarily on reflective judgement from the teaching practice of the first author as a Biology teacher in general secondary school, and with the second author as supervisor, from computer-supported laboratory work between 1999 and 2009. In a decade of cooperation several inquiries were performed, some structured as research, concerning computers in laboratory work. All the experiments described (Šorgo & Kocijancic, 2004, 2006; Šorgo et al, 2008) were performed at the "Prva gimnazija Maribor" high school (Slovenia), with several hundred students aged 15 to 18. The school science laboratory was equipped with one teacher set and four student sets of the e-ProLab data acquisition system (DAQ) and software (http://www.e-prolab.com/comlab) , four student sets of Vernier's LoggerPro and a number of Vernier sensors (http://www.vernier.com). Work was performed in two ways: With the whole class or as individual student work. In these years more than 50 different laboratory exercises (e.g. Šorgo, 2005) were tested in the classroom. Additionally the authors have been involved in numerous teacher training workshops offered as part of a science teacher's in-service training with more than 150 participating teachers. Contacts with teachers as well as in- and after-class discussion with science teachers attending in-service training or via e-mail communications with them provide deeper insight into their opinions about and problems with the introduction of computer-supported laboratories into their teaching practice. During our work with both teachers and students, on several occasions it was recognized that the graphs obtained were not straightforward to interpret. Graphs whose outcomes are difficult to explain most often belonged in the following areas:

1. *Explanation of the curves is beyond the domain of Biology, but lies in Physics, Chemistry or some other discipline.*
2. *Hardware properties.*
3. *Unknown properties of experimental components.*
4. *Occasional equipment breakdowns or crashes.*

Examples from each category are presented in the results section.

RESULTS

Explanation of the curves is beyond the domain of Biology, but lies in Physics, Chemistry or some other discipline

One possible reason that many teachers avoid problem-based teaching is the recognition that they lack answers to every question (Šorgo et al., 2007). For them, problems generated by students can seem like a nightmare. As long as students follow the textbook manuals for well-tested, classic laboratory work from the era before computers, a teacher is relatively safe. Outcomes are predictable and explanations well documented. The problems presented by the teacher are relatively safe for him, too. Normally they are based on the teacher's previous knowledge and experience. Even in this situation however, unpredictable outcomes are possible. Trouble arises when the teacher leaves behind familiar pathways, enters the jungle of solutions to problems generated by students and encounters results that are hard to interpret. With problems generated by students, the teacher can compare himself to the leader of an expedition into Terra incognita. In such cases, a Biology teacher not trained in Physics, Chemistry, Mathematics, and Computer Science has difficulty finding an explanation at the moment when it is needed. A complementary situation can be observed when Physics tries to explain Biological phenomena (Kocijancic & O'Sullivan, 2003). The same is true with computers. From the interviews (Newton 2000), one can verify that teachers need considerable training before they are willing to introduce new methods into the classroom. Additional problems unknown in classical laboratory work arose along with one of the benefits of data acquisition systems. With continuous sampling, one can observe onscreen phenomena that could not be recognized if only the starting and end points of the process were registered.

One graph where the answer to the question posed by a student lay outside the biological domain appears in Figure 1, where students analyze the properties of starch. One such property is gelatinization.

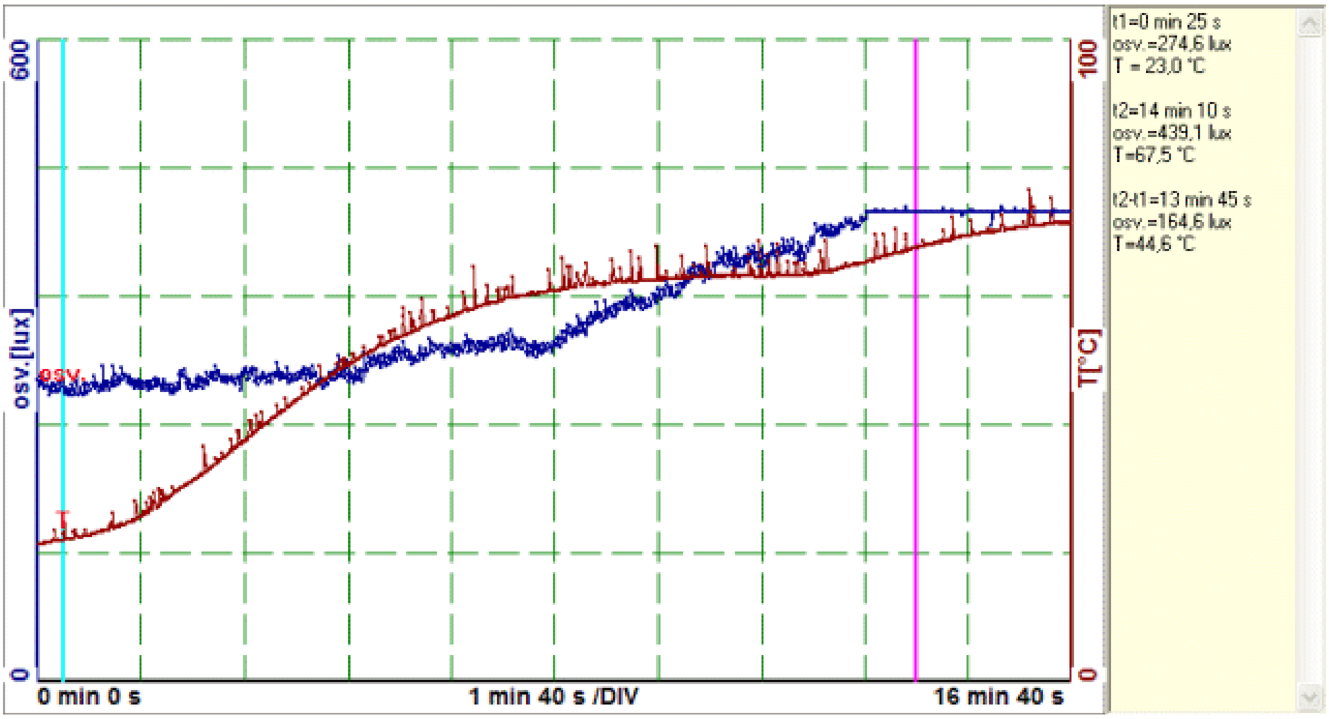

Figure 1. Graph obtained in measuring transparency of starch solution during gelatinization induced by heat.

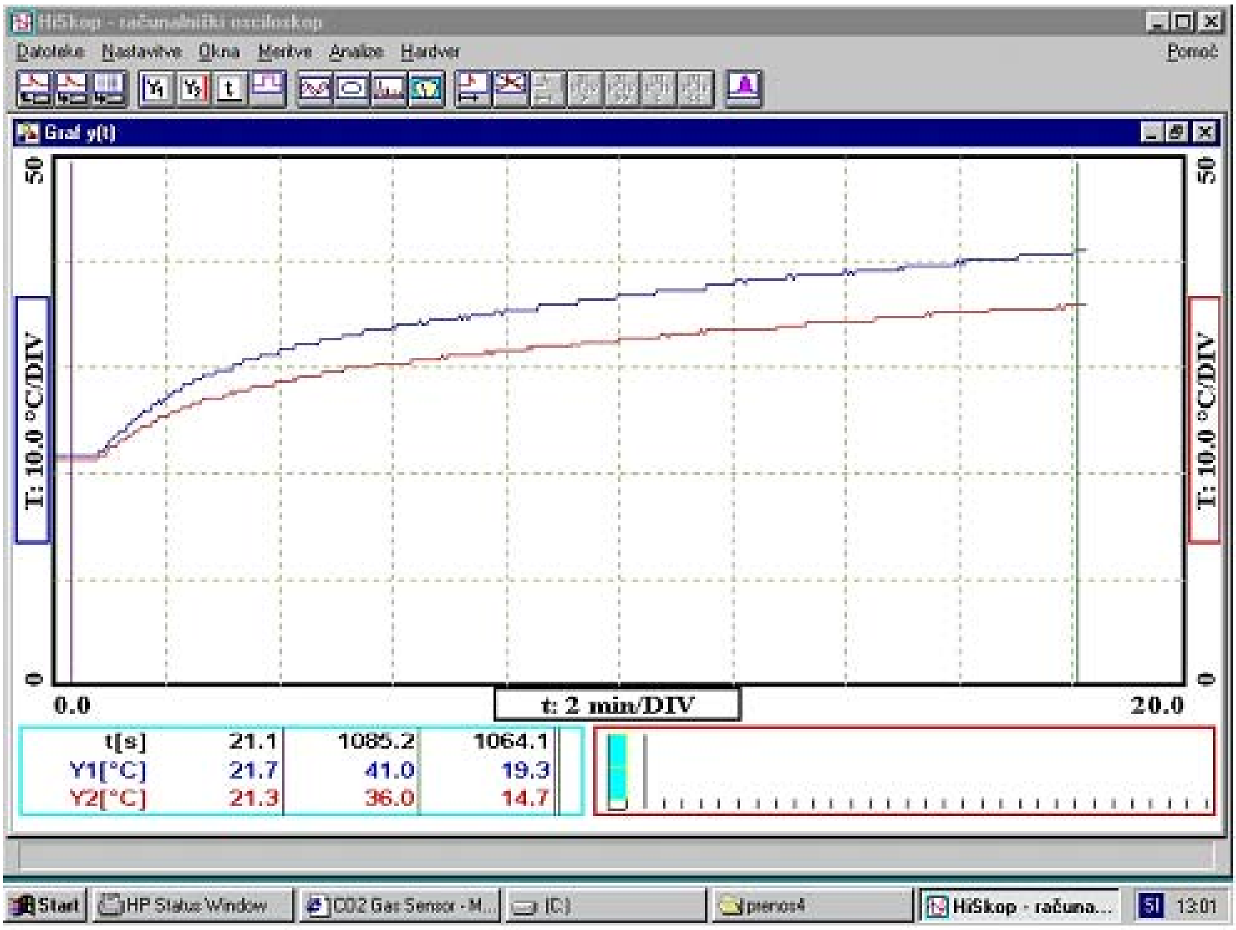

Figure 2. Graph of differences in temperature changes in a bottle with air and a bottle filled with carbon dioxide obtained during a Greenhouse Effect laboratory exercise.

Starch gelatinization is of great importance in food processing and in the preparation of bakery products (Cuq et al., 2003; Saif et al., 2003) or parboiled rice (Elbert et al., 2002). Starch gelatinization is a process of biopolymer melting in aqueous media. When a water starch suspension is heated, a phase transition is observed. As a result, the optical properties of starch change (Douzals et al., 1996). The student has constructed an experiment to identify the temperature of starch gelatinization in different commercially obtained starches, like corn starch, wheat starch, etc. She placed some starch in distilled water and put the beaker on a magnetic stirrer at medium temperature. She placed an electric light to one side, a light sensor on the other side, and a temperature sensor in the solution. From the graphs obtained, a temperature range for gelatinization was recognised, owing to the greater transparency of the solution. The not so easily answered question was why the temperature curve was not linear (Figure 1).

The teacher of Biology or Food Technology cannot find an answer to this in their domains but only in that of Physical Chemistry. Starch gelatinization is an endothermic transition, which in laboratory praxis can easily be identified by differential scanning calorimetry. This method allows the characterization of melting parameters, i.e., enthalpy of gelatinization and temperature of melting (Douzals et al., 1996; Jyothy et al., 2003). Differential scanning calorimetry is a method never mentioned in high school Biology, not to mention the lack of appropriate apparatus. In our case, we recognised from the curve of temperature growth that heat was used to break down hydrogen bonds between molecules of amylase and amylopectin in starch granules. During the process of gelatinization, granule molecules leach out of the micellar network and diffuse into the surrounding aqueous medium outside the granules; thus, the rigid structure of the granules is lost. If heating is slow enough, the temperature stays constant as long as the whole crystal structure is broken. (Kladnik, 1979). The result yields the shape of temperature curve.

Hardware properties seen on the graph

The most common questions posed by students are about patterns formed around analog – digital conversion and noise.

Analog – digital conversion

The question "Why are our graphs so stepped?" often arose with the earlier, 8-bit analog digital converters. Nowadays, when most converters are 16-bit, this pattern is recognized mainly when students try to zoom into the curve. As an example, consider a graph (Figure 2) that was obtained as a screen capture during a laboratory exercise called 'Greenhouse effect'. The step pattern can be recognised as the result of 8-bit analog-digital conversion. During such conversion, continuous measurement is transformed to $(2)^n$ discrete values.

Such a pattern can be explained to students by converting experimental plots to a lower conversion, for example a 4-bit conversion (Figure 3). In real life, explaining such a phenomenon to students far exceeds the knowledge of a teacher untrained in informatics and computer science. In practice,this means almost every teacher who has been in the classroom for more than 20 years. Even younger teachers rarely have the appropriate knowledge. They know how to use the computer as a typewriter, a storage device, a presentation tool, and for access to the Internet, but they rarely possess this kind of knowledge.

Unknown properties of experimental components

Every part of the experiment can be a source of noise, which is sometimes clearly visible on graphs. Students will easily identify such noise as a regular pattern. Many properties of the physical world are recognized on the basis of our senses. One of the most important senses is the eyes. What we intuitively know about the nature of light and the properties of light sources is sometimes a misconception, which is uncovered when a data acquisition system is in use. Many important experiments involve light sources. Experiments about the effect of light on the rate of photosynthesis can be considered as classic. When a teacher wants to use an artificial light source, new patterns can arise. In Figure 4 we see the difference in stability of four sources of light. The most stable is white LED diode, while light from an electric bulb or a halogen lamp oscillates in a frenzied rhythm. The patterns are displayed in Figures 1, 4 and 5.

Accidental equipment breakdowns or crashes

"Why are the temperature curves so different?" was a question asked the next day after performance of this bacterial culture exercise. In this experiment the student tried to investigate the effect of temperature on the population growth of a bacterial culture by measuring with a light sensor the turbidity of bacterial cultures placed on thermostatic magnetic stirrers. To one side of the cultures was an electric lamp, and on the other side were light sensors. The student set up the experiment and went home. The graph was checked on the next working day. Something went wrong with temperature regulation in one of the stirrers (Figure 5). Such a graph can be recognized either as a disaster or as a great opportunity for productive discussion in the classroom

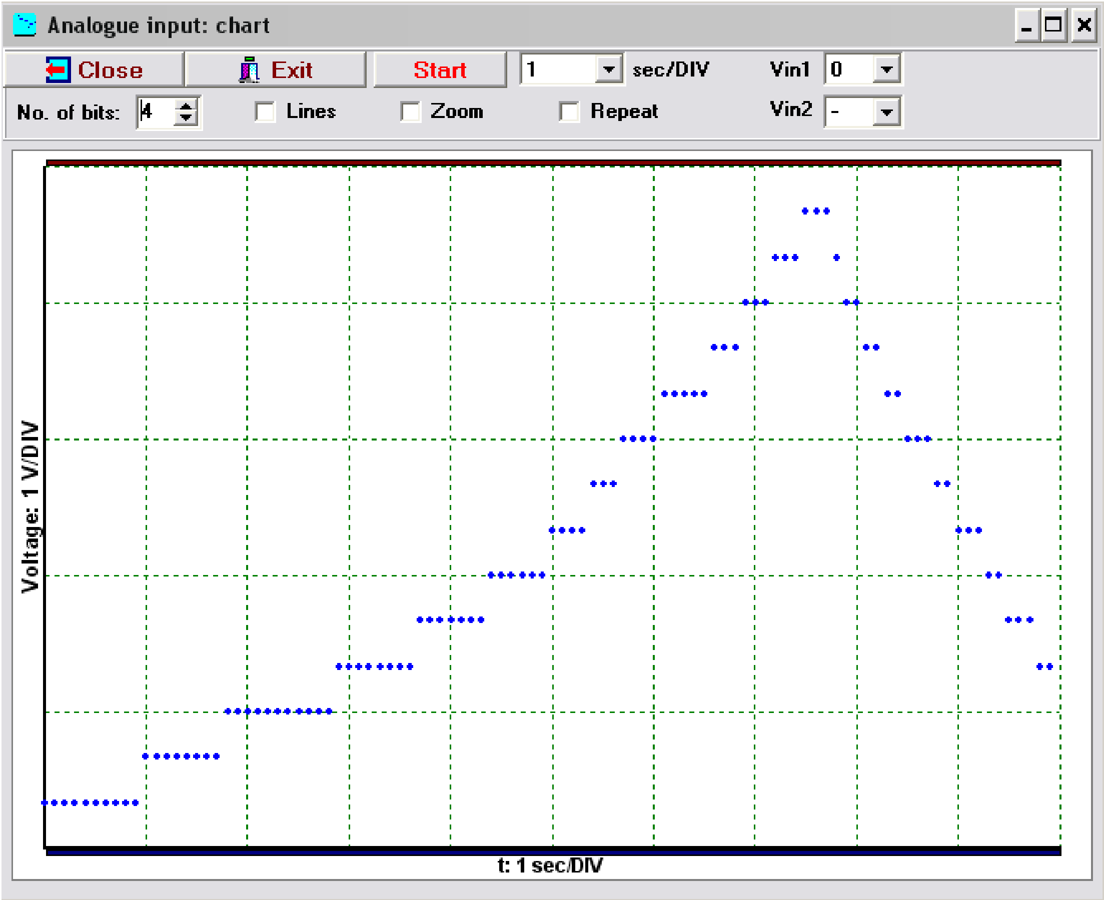

Figure 3. Voltage varying over time as sampled with the DAQ system. The experimental data obtained is plotted using 12-bit analog to digital conversion (left) and using only 4-bit conversion (right).

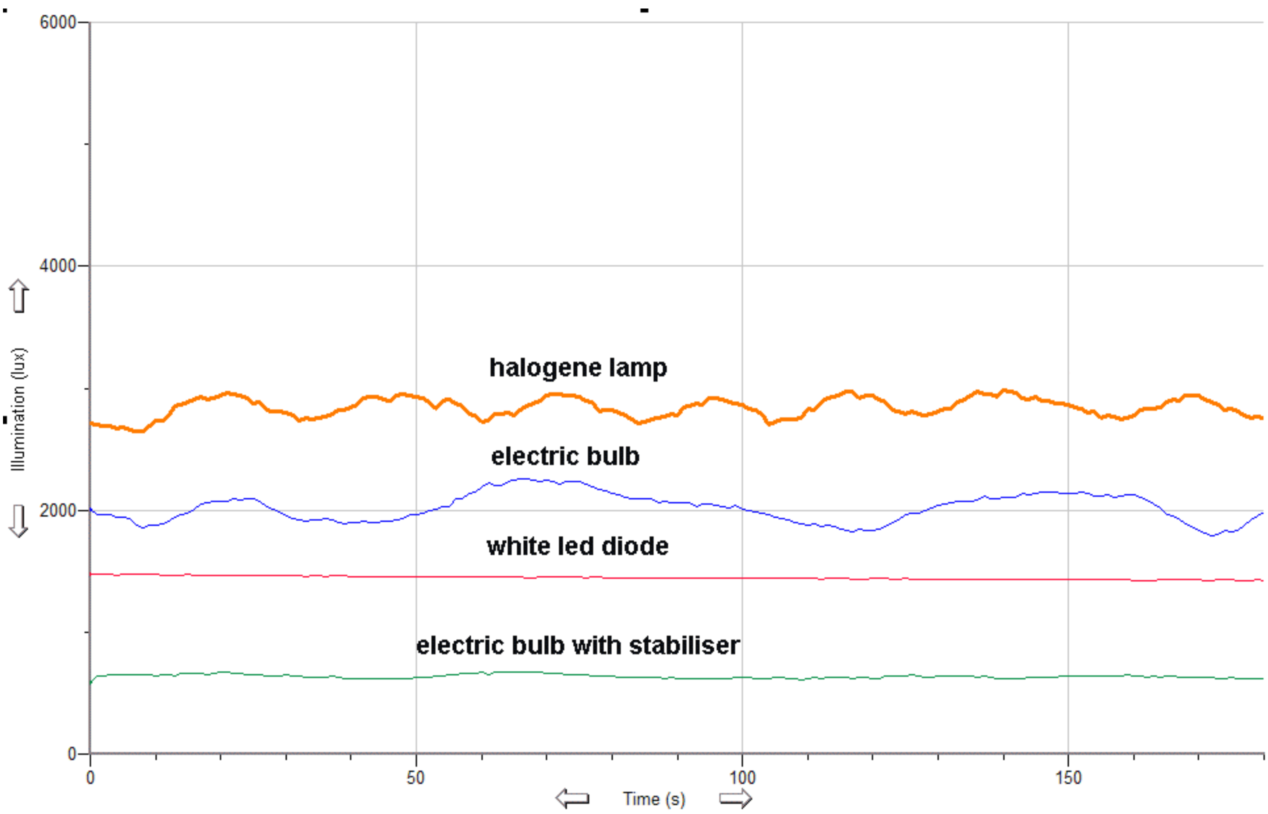

Figure 4. The difference in stability of four sources of light can be recognized as noise in some experiments.

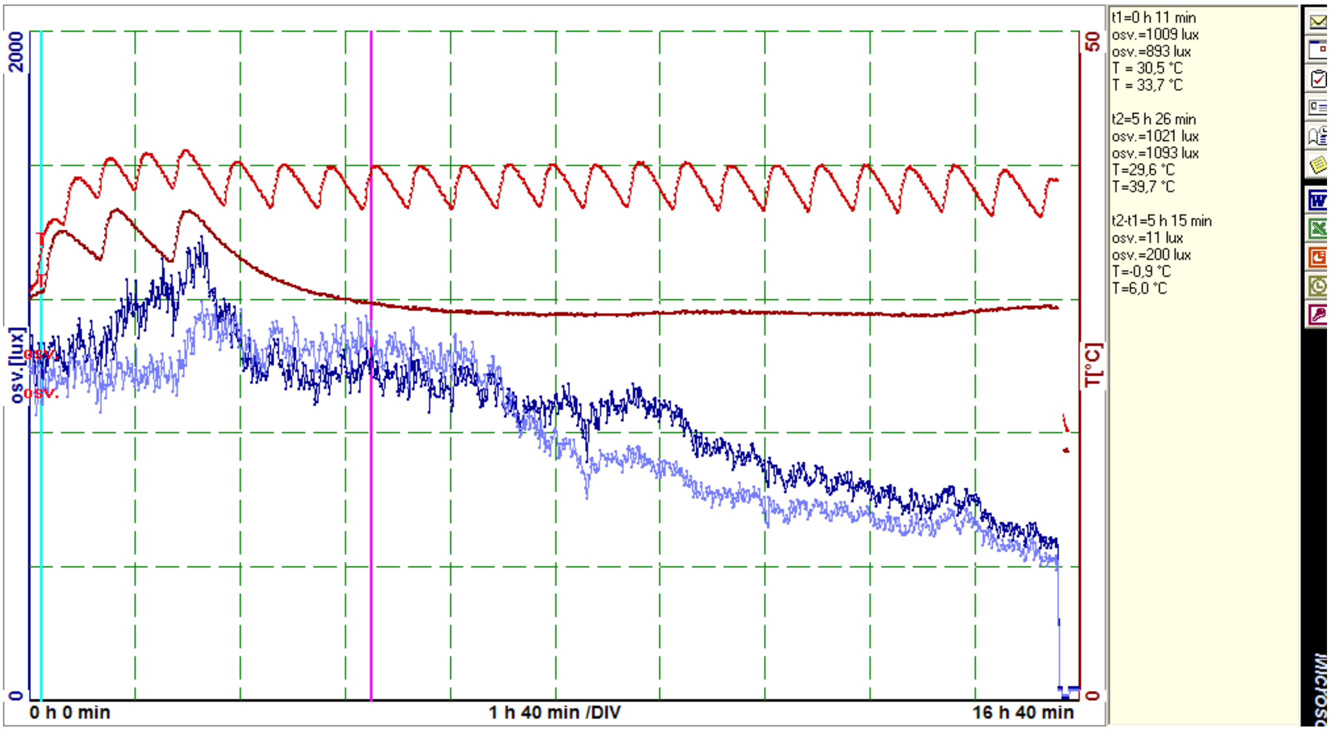

Figure 5. Graph of growth in bacterial culture, measured by changes in turbidity

(Newton, 2000). Another possibility was chosen, whereby students had to research the graph as a collaborative activity followed by discussion. In this case they were encouraged to find what went wrong and decide how to improve the experiment.

They found that one of the magnetic stirrers had stopped working. But the shape of the upper curve was not so easily explained. Why did the temperature rise rapidly and then drop? The answer is in regulation of temperature by a thermostat. The difference between the upper curves (T) and the lower curves (light) was explained by noise. This graph is another one where the teacher needs knowledge about regulation and physics, which are normally not part of teacher training.

CONCLUSIONS

Several graphs obtained in a computerized laboratory have been presented. Because data sampling was continuous, there were some patterns that could not be observed when measured manually. Some have no interpretations within the domain of Biology, so when high school students try to discuss these results, they and their teachers are faced with many problems in addition to well known generic problems with graph interpretations (Alacaci, et al., 2011).

The fragmented and limited state of knowledge within the discipline and lack of confidence is one such problem (Šorgo et al., 2007; Bingimlas, 2009). In higher and university courses, teachers are experts in their fields. If they do not have a solution, other experts are normally in the neighbourhood, or they can ask students to seek a solution in the literature. In contrast, the high school teacher is normally not a specialist with deep insight into a single narrow topic. S(he) can be seen as a generalist with broad but shallow knowledge. In the outcomes of problem-based teaching, s(he) regularly faces unfamiliar situations with limited knowledge of the relevant phenomena. Only a teacher who is unafraid of the words “Sorry kids, I do not know what is going on, but we are going to find a solution” will introduce problem-based work into his regular school practice.

Insufficient knowledge of other disciplines is one of the most common major problems. The ideal Biology teacher should be trained in Physics, Chemistry, Earth Sciences, Environmental Sciences, Mathematics, and Computer Science, not to mention teaching-related disciplines. For interpretation of graphs obtained from biological systems, a teacher needs proficiency in understanding not only Biology but other disciplines as well. When working with computers and equipment for measurements, s(he) will face problems such as analog-digital processing, nonlinearity, noise, sampling, log-linear transformations, etc.

Limited access to primary sources is another major problem. Access to databases and scientific journals can be a minor problem at the university level but can be a serious obstacle at the high school level. High schools normally do not have access to scholarly databases. In some cases students can find primary sources on the Internet, but more often they cannot. Even when they do find a promising abstract, they are limited by budget, so they often cannot obtain the full article. And when they are able to find an article, they cannot understand it because of the jargon. If their mother tongue is not English, their problems are even greater (Puhek & Šorgo, 2010). In recent times the majority of scientific output has appeared in English. So, students or teachers whose mother tongue is not English can face severe problems.

What can be done? In the first place it is necessary to encourage teachers to start problem-based teaching (Kendler & Grove, 2004; Rehorek, 2004). Every outcome must be carefully investigated, and many hidden messages can be found. Even from mistakes a great deal can be learned. If hard questions arise, teachers must become self-confident in explaining to students that teachers do not know everything, but that conclusions can be sought in cooperation with others. Through this kind of work, they will transfer to students a message about curiosity: why it is so important to peek over fences. Most important, the world around us is more complex than it appears on idealized graphs or textbook diagrams.

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