The use of computer aided experiment in enhancing the ability of students to understand the graphical presentation of chemical processes

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Abstract

The results of international PISA study indicate that solving of problems aimed at the graphical presentation of natural process is the "Achilles' heel" of Slovak students. They fail to identify the relations among variables displayed in graphs, charts and diagrams; they are unable to read or interpret the information. The following paper presents the research findings, which was conducted during years 2012 – 2013 on a sample of 140 students attending the 8th grade of primary school. The educational research was focused on the development of graphic skills of students supported by digital technology. The goal was to develop the ability of students not only to read and correctly interpret the information, but also to contribute to the attractiveness of chemistry learning by establishing a set of experiments in inorganic chemistry. Their implementation has been done as a combination of real laboratory activities and a school measurement system. Two groups of respondents (experimental and control) were compared during the implementation of laboratory exercises that utilized various approaches in the evaluation of obtained experimental data. Based on the research results, it may be concluded that computer-aided experiments are an effective tool for the development of abstract thinking in students; they encourage active student research and streamline data acquisition and they have a positive impact on the development of skills required for the complex solution of specified laboratory tasks.

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1. Introduction

Microcomputer-based science laboratories have more than ten years of tradition in Slovak schools. The initial idea to implement computers in school experiments was founded in the late seventies of the last century in the United States. Tinker (1984a) have been the first to demonstrate the cognitive potential of computers as tools for the implementation of laboratory experiments. The first foreign studies have shown that students who worked in the microcomputer-based laboratory have improved not only in the interpretation, reading and creating of graphs, but have been able to better understand the nature of monitored phenomenon, as well.

A microcomputer-based laboratory give teachers the opportunity to implement research activities in chemistry teaching, where students have ample space for the reflection of their own thoughts, the opportunity for deeper and more detailed analysis of practical problems. Held, Proksa & Osuska (1993) points out that students, who do not receive such an opportunity, are unable to adopt an attitude in testing (or in real life) of non-standard tasks, tasks in non-standard conditions, application of information from one school subject in another. The paradoxical situation arises due to the fact that they do not acquire scientific knowledge meaningfully, they lack reciprocal links between different pieces of scientific knowledge, they do not form a structure of knowledge, but it is acquired only by memory as verbal chains.

1.1. Microcomputer-based Laboratory (MBL) in Science Education

The implementation of MBL in science teaching has been addressed by the didactic community especially after the publication of negative results of our students in the PISA study, where Slovak students, or rather, the Slovak education system, which these pupils represented, achieved only average overall performance. The results show that graphical tasks are our “Achilles heel” and Slovak students fail to identify the relations between values displayed in graphs, cannot read, and interpret information from graphs, tables and diagrams. In this way, they have provided a simple and concrete way to the development of mathematical competence in science education (Brestenska, 2014; Melusova & Vidermanova, 2012).

Tinker (1984b) summarized the benefits of using computers at school lab in the following statements:

- A computer program provides a quick and easy transformation of data from numerical format to graphical form.
- Microcomputer-based Laboratory removes monotonous activities related to the collection and recording of empirical data and allows students to focus on the subsequent interpretation and evaluation of graphical data.
- Computers offer students an immediate feedback and reduce the time between the collection and interpretation of data.
- Computers offer students an attractive, dynamic and interesting laboratory.

One of the advantages of experiments performed in this way is that the results of the measurements are proper graphs. The work in MBL depends on how well are students able to obtain relevant information from graphs and to work with them (Jeskova & Pencakova, 2000; Horvathova & Rakovska, 1999).

The most common misconception linked to the evaluation of graphs is that pupils, students, and often teachers themselves, perceive the graph as picture (Barclay, 1985; Murphy, 1999). Also, they do not know how to recognize information that is encoded in them; they do not know how to find a corresponding graph to physical laws and physical relations; they have problems identifying dependent and independent variables (Branisa & Reguli, 2009, 2010; Kwon, 2002; McDermott, Rosenquist & van Zee, 1987; Mokros & Tinker, 1987; Svec, 1999).

2. Method

2.1. Objectives of the study

The main objective of the research was to develop graphical skills of 13 and 14 years old primary school pupils. A set of chemistry experiments was created, which were performed by implementing MBL. The research was
carried out during the years 2012/2013 with 140 students of the lower secondary level of education. Before the research, it was necessary to determine the nature and extent of problems, which were perpetrated by students in reading and interpreting graphs, and to propose a set of quantitative experiments that would solve the problems found by us.

2.2. Participants

140 students attending the 8th grade of primary school participated in this study.

2.3. Hypothesis

Students, who have been shown the relation between examined values on the computer screen during an experiment in progress, achieve better results in the knowledge test (namely graphical items) than students, who had to attempt to manually create (draw) a graph.

2.4. Process of Research Method

The design of research applied to the experimental (EG) and control group (CG), the research methods and the course of the research are shown in Table 1.

| Groups                          | Measurement | Process                                      | Measurement          |
|---------------------------------|-------------|----------------------------------------------|----------------------|
| Students of the 8th grade of primary school | Pre-Test    | Micro-computer Based Learning/Graph automatically generated by measurement system | Post-Test            |
| (N= 71)                         |             |                                              |                      |
| Control Group (CG)              |             | Micro-computer Based Learning/Manually drawn graph |                      |
| (N= 69)                         |             |                                              |                      |

Pre-tests were given to the groups a week before the activities. By the results of the admission test, students were divided into two groups: experimental and control. Both groups performed experiments with school measurement systems, but acquire experimental data by two different methods. During the experiments, the first group (experimental) was allowed to automatically draw graphs on the computer screen. The second group (control) students also performed experiments with MBL, but the obtained experimental data were recorded in a prepared table and subsequently, a graph was manually created. The minimal number of performed quantitative experiments was seven.

In the final phase of research, students were given a test (post-test), which again made up of tasks and issues containing graphical records and their content was focused on general and inorganic chemistry. Post-tests were applied one or two weeks after the activities.

3. Results

The pre-test was focused on reading data from graphs and tables depicting situations of everyday life. In the test evaluation, consisting of 6 graphics tasks, it was examined whether students are able to draw a graph using the values listed in the table, to select the appropriate scale of the coordinate axes, to identify the dependent and independent variables, to find the corresponding graph illustrating physical laws, and vice versa, to find the right physical interpretation of the given graph, and to create a table for the given graph. The results of the pre-test and a
list of the most common errors made by students in the design and interpretation of graphs are summarized in Table 2 and Table 3.

Table 2. Pre-test results of the experimental and control group scores

| Groups | N   | X   | S.D. | C. V  | t   | p   | df |
|--------|-----|-----|------|-------|-----|-----|----|
| EG     | 71  | 4.08| 1.131| 26.61 | -0.61| 0.54| 138|
| CG     | 69  | 3.97| 1.06 | 27.68 |       |     |     |

Table 3. Overview of errors made by students in the construction and interpretation of graphs

| skill      | problem                                                                 |
|------------|--------------------------------------------------------------------------|
| construction| Assigning variables to axes, i.e. not knowing, which variable to put on the x-axis, and which variable to put on the y-axis |
|            | Choosing a suitable scale for each axis                                  |
|            | Constructing a table from a graph                                       |
|            | Constructing a graph from a table                                       |
|            | Correctly identify and name the axes (with the appropriate units)       |
| interpretation| Comparison of graphical data                                            |
|            | Identification of the x and y co-ordinates of a point                   |
|            | Describing relationships between variables                              |

The results of the pre-test indicate that students fail to solve complex graphical tasks. The most common problems were:

- Students perceive graphical output / graph as an image
- Students confuse graphs with a “true picture” of ongoing process; they make hasty conclusions and are able to interpret only the graphs known from textbooks
- Students understand “a certain type of exemplary problems”, but are unable to solve tasks by a new (unrehearsed) method

Working with conceptual tasks (pictures, tables, graphs, etc.) should lead students to new questions and to the interpretation of observed phenomena. If students are unable to explain dependence between two variables by using a graph, subsequently they are unable to find a way to solve the problem, to discover analogies and thus, they are unable to understand issues and discussed topics (Kramarekova, Kopcova & Pucherova, 1999; Krizanova & Brestenska, 2014; Reguli, 2001).

The second phase was dedicated to experimental work performed in the laboratory. Students conducted seven quantitative laboratory exercises (distillation, solubility curve of salts, dilution of acids, neutralization, heating of carbonic acid, conductometry, process of fermentation, photosynthesis, etc.). Performed experiments were supported by digital technologies. The experimental work took place within the time period of 10 months. The experimental group worked with graphic output with MBL. The control group noted the experimental values obtained from MBL in a table and then manually constructed a graph.

The last phase followed after performing of specified experiments. Students were given a test consisting of 17 test items, 8 of which were related with interpreting and creating graphs. Their aim was to verify a positive development of mathematical competence. We used the test to examine, whether students from the experimental group achieved better results in the knowledge test (namely in graphical test items) than their classmates who had to
process the collected from experiments and manually construct a graph. To obtain better view of the success of students in graphic questions, we summarized the test results in Table 4.

Table 4. Success rate of students in graphical test items

| Sub-category | Question no. | Knowledge and skills tested in question | Percentage of students |
|--------------|--------------|-----------------------------------------|------------------------|
|              |              |                                         | Right answer | Wrong answer | No answer |
| Interpretation | 2            | Ability to use algorithms for decoding information in the graph. | 69 (EG) | 27 (EG) | 4 (EG) |
|              |              |                                         | 91 (CG) | 5 (CG) | 4 (CG) |
|              | 5            | Ability to translate visual information from a table into a conceptual message. | 82 (EG) | 18 (EG) | 0 (EG) |
|              |              |                                         | 88 (CG) | 12 (CG) | 0 (CG) |
|              | 10           | Ability to translate visual information from a graph into a conceptual message. | 55 (EG) | 44 (EG) | 1 (EG) |
|              |              |                                         | 74 (CG) | 25 (CG) | 1 (CG) |
|              | 13           | Ability to attach meaning to a graph they have constructed according to a set of rules or grammar. Ability to convert visual image into meaningful information. Ability to give a qualitative description of what a graph depicts. | 90 (EG) | 10 (EG) | 0 (EG) |
|              |              |                                         | 78 (CG) | 22 (CG) | 0 (CG) |
|              | 16           | Ability to read annotations of a graph and to give a qualitative description of what the graph depicts. This includes: Ability to establish what is being represented on each axis. Ability to explain what is happening | 49 (EG) | 28 (EG) | 23 (EG) |
|              |              |                                         | 75 (CG) | 14 (CG) | 11 (CG) |
| Construction | 6            | Ability to correctly label the axes of a graph they have constructed (including the units of measurement). | 45 (EG) | 49 (EG) | 6 (EG) |
|              |              |                                         | 59 (CG) | 30 (CG) | 11 (CG) |
|              | 14           | Ability to plot points on a graph from data provided in a form of a table and to link the points. Ability to identify dependent and independent variables from data provided in tabular form. Ability to work out an appropriate scale for a graph. Ability to correctly label the axes of a graph they have constructed (including the units of measurement). | 44 (EG) | 45 (EG) | 11 (EG) |
|              |              |                                         | 59 (CG) | 32 (CG) | 9 (CG) |
|              | 15           | Ability to predict changes in trends when a variable is manipulated. | 62 (EG) | 32 (EG) | 6 (EG) |
|              |              |                                         | 59 (CG) | 32 (CG) | 9 (CG) |

The high success rate of both groups suggests that students have already met with some of the tasks. However, we were interested in how would they be able to manage graphical items that were new to them. Here, too, it may be concluded that they performed rather well. As mentioned above, 140 primary school students of the 8th grade were examined. The experimental group consisted of 71 students; the control group had 69 students. The students achieved average score in the test. In the experimental group, the students achieved 10.68 points and in the control
As may be seen from the table, the differences between the median values are statistically significant. Based on the obtained results, it appears that students of the control group, who had to record the obtained experiment data and to manually construct the graph, were more successful in solving tests than their classmates, who had graphs displayed on the computer screen. Thus, it is possible to conclude that the hypothesis, which assumed that the students from experimental group would be more successful, was not confirmed.

4. Conclusion

Graphic tasks are associated with formal thinking, which is, in the case of younger students (the lower secondary level of education), just starting to develop. As Herron recommends, the processing and evaluation of experimentally obtained data should be done in successive steps; from the collection of measured data through the table layout and graphical representation to the interpretation of the observed phenomenon. In the lower secondary of education, not much attention is given to the issue of the development of graphical skills of students in MBL. From the results of research, it may be concluded that students who had to construct a graph from the experimental data, not only better solved the test aimed at the decoding and reading of graphical information, but also showed that with the obtained knowledge, they are able to perform better than their classmates from the experimental group, who used graphs automatically constructed by the computer. The result may be justified by the fact that in the processing of real experiment results, the control group of students used several senses, and thus, the sustainability of acquired knowledge was greater.

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