Effectiveness of multimedia laboratory instruction

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Abstract: To develop further a strategy of computerised assistance for laboratory experiments, three functions (pre-experimental, syn-experimental and post-experimental function) were employed. A set of computer programs was prepared and used to assist the conduction of chemical experiments and the statistical analysis and interpretation of the results. The programs constitute the basis for three kinds of instructions prepared as a prelude to conducting the experiment 'empirical equations of reaction kinetics'. The effectiveness of using interactive laboratory instruction was tested, together with the significance of multimedia and interactive elements in the course of such preparation. The findings show that the use of interactive multimedia instruction shortens the time of completions of given experiment and reduces laboratory errors, as compared to the paper or video instruction. [*Chem. Educ. Res. Pract.*, 2006, **7** (1), 1-12]

Keywords: multimedia laboratory instruction; multimedia; computer-linked laboratory interface; interactive instruction

Computer programs in chemical education

The chemical experiment should be a fundamental teaching source (Hofstein, 2004). The preparation for, conduction of and interpretation of the data from an experiment using educational computer programs can increase the effectiveness of teaching and learning chemistry (Lagowski, 1989). The functions of educational computer programs in that field depend on whether they precede, follow or simultaneously accompany the experiment (Miranowicz and Burewicz, 1995). The computer may function as a didactic source to present subject matter or methodological information in conducting an experiment (the pre-experimental function of an experiment) (Nicholls, 1999). It may also be a laboratory instrument for directing the laboratory experiment or monitoring its course (the syn-experimental function) (Allen et al., 1984). Finally, it may serve as a tool for a qualitative or quantitative analysis of the gathered data and in the interpretation of results (the post-experimental function) (Miranowicz and Burewicz, 1996; Nicholls 1998).

The combination of different types of computer-aided laboratory experiments creates examples of an effective broadening of the chemistry course curriculum, including computer-controlled laboratory experiments (Durnham, 1990; Brattan, et al., 1999). Educational computer programs may thus become not only a richly varied description of tasks to be carried out during the lesson, but may also serve as a fundamental methodological introduction to conducting an experiment, a sequential monitoring of laboratory processes, and, finally, data analysis and assistance in the formulation of conclusions (De La Cuetara and Labma, 1995). The use of multimedia computer systems also allows for the creation of multimedia decision-making games and advisory systems, assisting the teaching of chemistry and environmental protection by means of laboratory chemical experiments (Jenkinson, 1989).

Numerous examples and experiments conducted also at the Department of Chemistry Education of Adam Mickiewicz University in Poznan prove that computer assisted chemical experiments at various levels of complexity lead to an increased effectiveness in chemistry teaching. Simulation of research procedures in chemistry teaching by means of computers increases student activity and enhances the more frequent and effective use of the problem solving approach during a lesson (Burewicz and Miranowicz, 1995).

‘Kinetics’ – a set of computer programs

A set of more than twenty multimedia computer programs concerning the kinetics of a chemical reaction has been developed in our Department. Examples employing the computer in assisting chemical experiments within all three of the functions under discussion have been included.

For the purpose of this research study, the program ‘Empirical equations of a reaction kinetics’ has been chosen. The program deals with the oxidation of ethanol by potassium manganate (VII). Measurements are performed colorimetrically. The program serves as an example of computer based laboratory instruction.

Computer based laboratory instructions

The purpose of the program is (i) to conduct an experiment illustrating the determination of an empirical kinetic equation of a chemical reaction; (ii) to teach the user as to what role the experiment itself plays in describing this equation. A secondary aim is (iii) to acquaint the user with the technique of colorimetric measurements of reaction kinetics and (iv) methods of computer assisted chemical experimentation.

This program, first of all, presents the techniques of setting up the given computer interface equipped with appropriate sensors for laboratory measurements for performing the experiments. It describes available selection of interface elements and the conditions of their use. The description also identifies some of the problems encountered in the instrumentation of laboratory measurements (Figure 1).

In its second phase, the instruction prepares the user to employ the software of controlling the measurements with the use of laboratory computer interface. It presents a start-up and initial preparation method for program work in setting measurement parameters and the mode for presenting results.

In the final phase, the program presents the way of preparing reagents to perform a given experiment. It describes the amount and concentration of reagents, methods of their initial preparation, as well as the path leading directly to making measurements.

Figure1. Components of interactive, computer-based instruction preparing for the experiment: ‘Empirical equations of the kinetics of a reaction’

Empirical equations of the kinetics of a reaction

The exercise ‘Empirical equations of the kinetics of a reaction’ is designed to show that a stoichiometric equation of a chemical reaction tells us nothing about the kinetics of the reaction (House, 1997). The lesson may be effectively conducted by the problem solving method. Presenting the general form of kinetic equation of a reaction may easily create a problem-solving situation. In considering the reaction described by the stoichiometric equation:

$$5\ C_2H_5OH + 4\ MnO_4^- + 12\ H^+ \rightarrow 5\ CH_3CO_2H + 4\ Mn^{2+} + 11\ H_2O$$

as well as the general form of the kinetic equation of the reaction, $v=\pm kc$, the question arises: “*The concentration of which of the reagents is described in the kinetic equation of the reaction?*” Among the hypotheses, there certainly appear suggestions to take into account every possible combinations of reagents mentioned in the stoichiometric equation. It is also necessary to stress the question: “*In what way does the rate of reaction depend on the indicated concentration of reagents?*” This may be a step in the direction of describing the order of the reaction. The group of hypotheses may be quite easily verified experimentally.

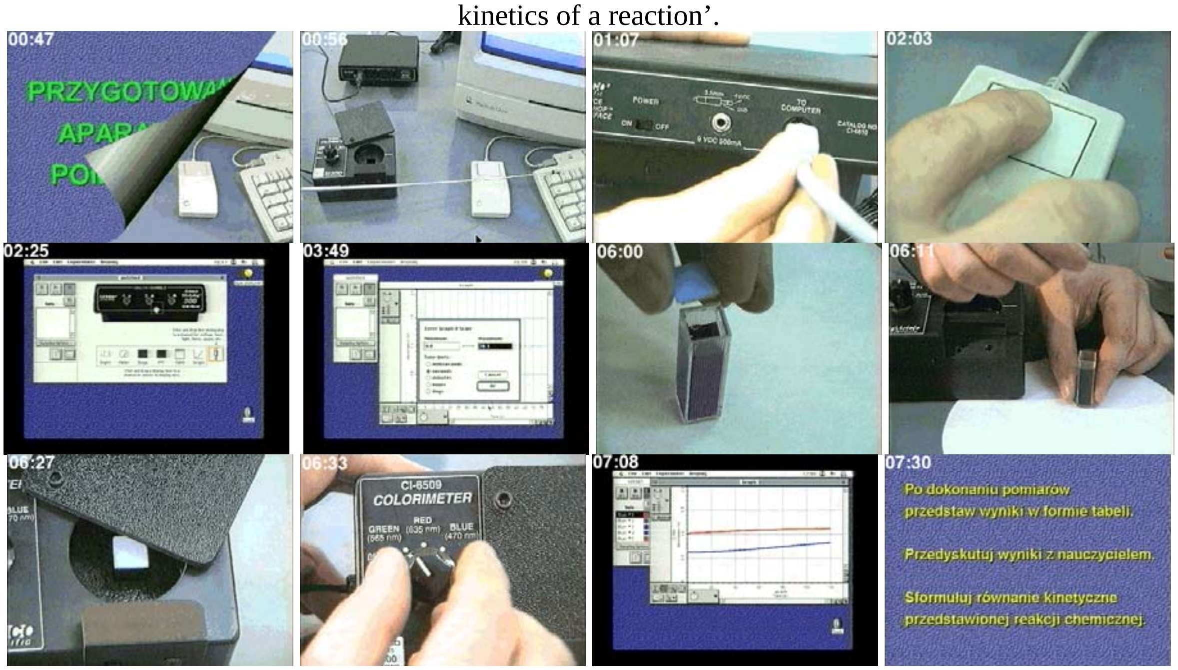
Using the ‘problem based laboratory method’ (Mayer, 2003) in the given situation is also one way of conducting this lesson in conditions of limited time constraint. The performance of an appropriate series of experiments by the teacher or by students in a ‘guided discovery method’ (Ricci & Ditzler, 1991) is connected with a minimum of three series of three experiments (measurements of the kinetics of the reaction with three different concentrations of chosen reagent) lasting a minimum of three minutes, giving a time of about 30 minutes for the completion of an experiment. In the problem solving approach, it is possible to divide the tasks among three groups of students, thus to conduct the experimental part in a shortened time and combine results at the end. At that level students are capable of formulating a hypothesis verified by the experiment. They also have enough skill to complete the experimental requirements (Lorimer & Mason, 1984). The task of preparation (theoretically, methodologically, and technically) for performing the experiment was done by additional laboratory instruction.

Methodology

In recent years a pedagogical experiment was designed to assess the influence of the kind of instruction on effectiveness in assisting the completion of various phases of the chemical experiment. Three types of such instruction were prepared:

- The first is a traditional written instruction.
- The second is video instruction presenting these problems (Figure 2). The instruction is presented by means of a video. The content is identical with the paper instruction, the only difference being its video format.
- The third is an interactive video-illustrated computer program, which shows the way of preparing the apparatus, reagents and monitoring program. It presents the theoretical and methodological aspects of the task (see Figure 1).

Figure 2. Components of video instruction preparing for the experiment: ‘Empirical equations of the kinetics of a reaction’.



The comparative effectiveness of written instruction, video instruction and computerized instruction was tested. Three forms of instruction for the experiment entitled ‘Empirical equations of the kinetics of a reaction’ were prepared.

A group of seventy-seven 4th year students of chemistry performing laboratory exercises were subjected to testing.

The research was conducted according to the rules of the ‘parallel groups test’. The students were randomly divided into three groups: group A following written instructions (24 subjects), group B, working with video instructions (26 subjects) and group C, working with interactive programs (27 subjects).

The effectiveness of using the various kinds of instruction was tested by analysis of two measured parameters. The first was the time taken by respondents to acquaint themselves with the instruction, as well as the time devoted to the performance of specific phases of the assignment. The second was the number of incorrect or uncertain responses to given phases of a task. The results were combined through the use of the multiple regression-correlation method.

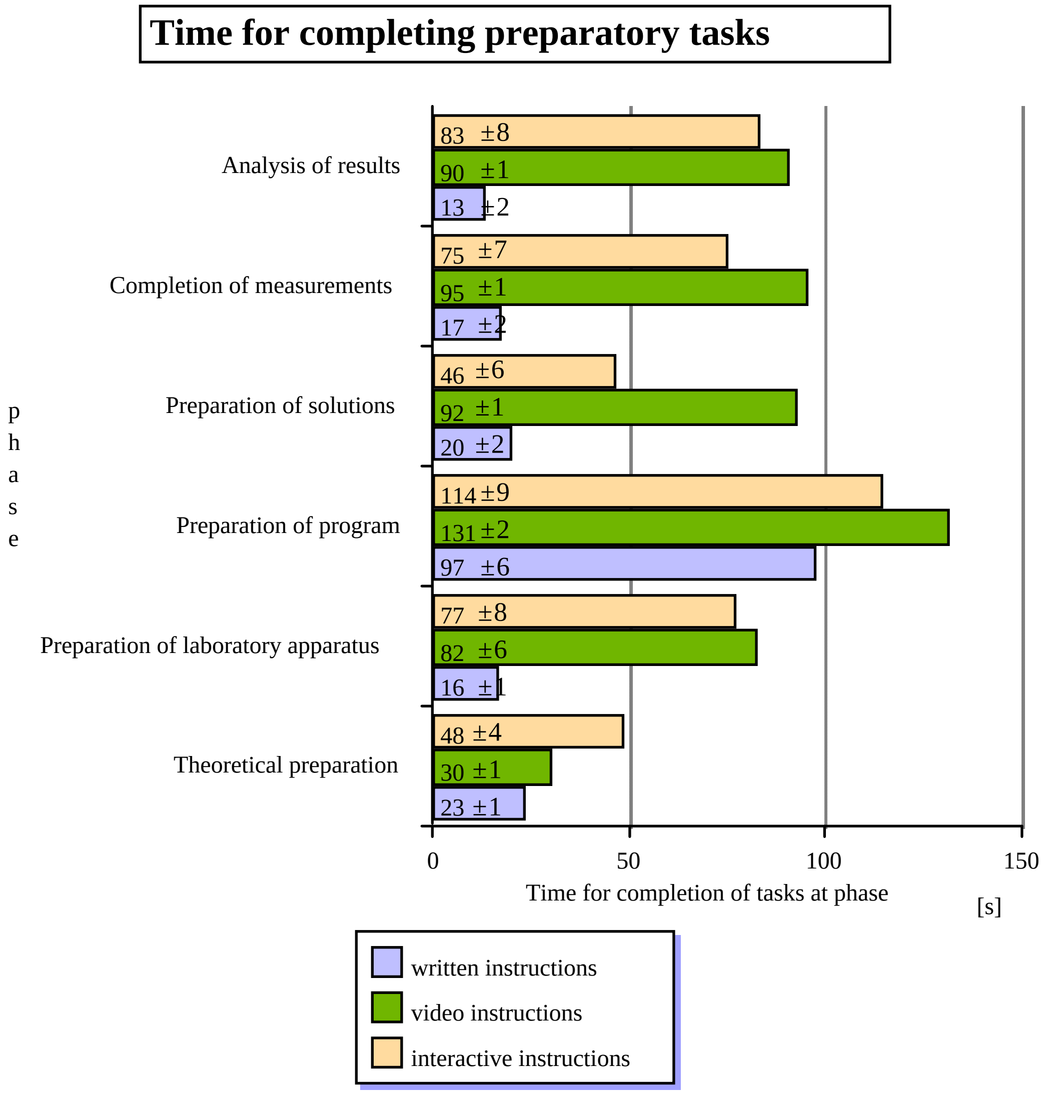
Results

The research was conducted in such a way as to be able to determine not only the overall effectiveness of using various forms of instruction but also the comparative effectiveness of each instruction at various phases of task completion. Six phases were selected: theoretical preparation, setting up of measuring apparatus, setting up of the monitoring program, preparation of reagent solutions, measurements, data analysis and interpretation. A graphic comparison of the time for completion of each of the given phases of a preparatory task is presented in Figure 3. For the detailed description of the various stages of the experiment as shown in the written instructions see the Appendix.

The graph shows three groups of data representing results of the groups described earlier. The time devoted to understanding the written material in the group A was, on the average, the shortest (186 seconds). In the group B working with video instructions, the average time for acquainting oneself with instructions was equal to 522 seconds. In the experimental group C, the time for acquiring the interactive instructions was, on the average, equal to 444 seconds. It can thus be seen that the use of video instructions considerably extends the time of acquainting oneself with the materials. The transmission of this same information by means of interactive materials, although somewhat shorter than that for video instructions is, nevertheless, two and a half times longer than in the case of written instructions.

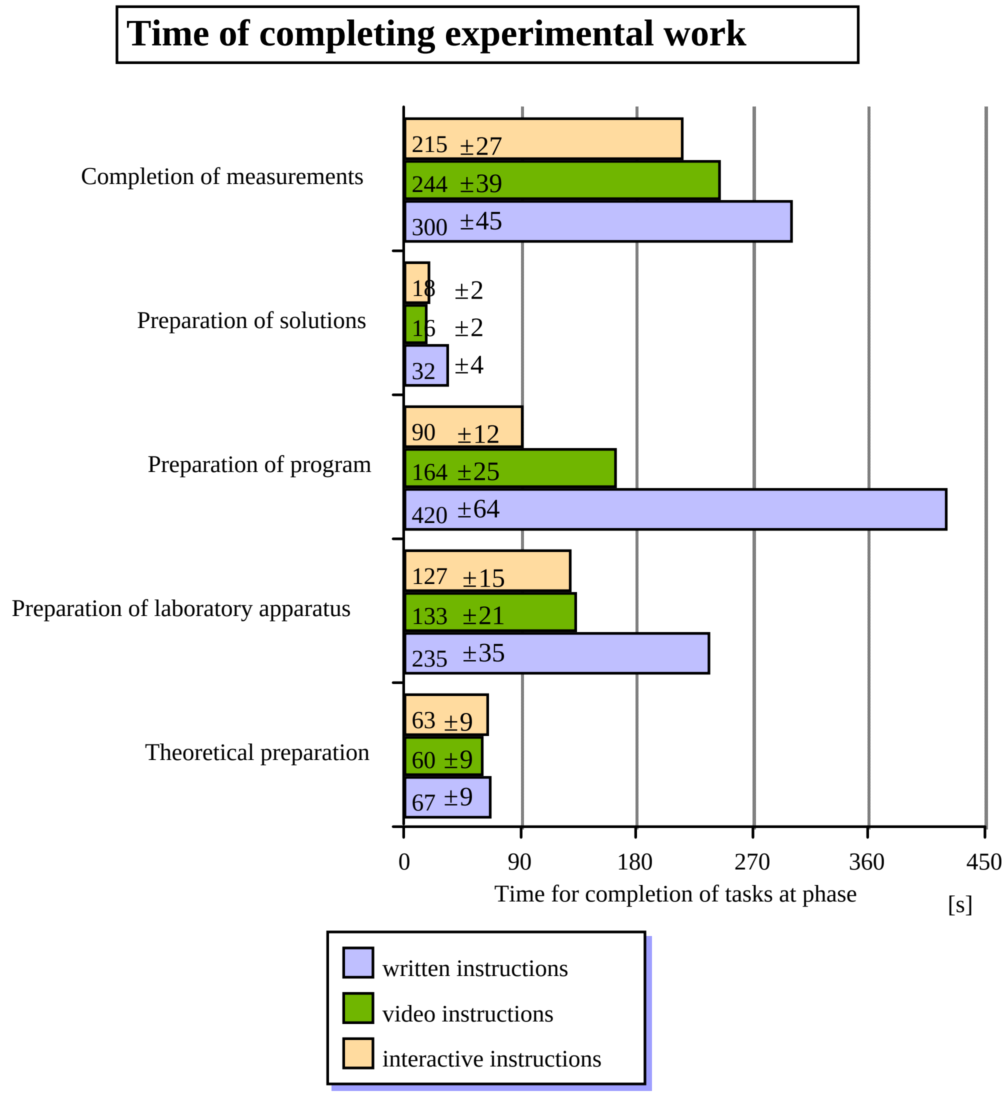
The measurements were made by noting the time chosen student under observation moved to next step of the task; the measurements do not show the effect of the process, only the timing.

Figure 3. A comparison of time taken by students to complete the various phases of the preparatory task shows that the use of paper instruction in almost all phases of preparatory work before the experiment was more time-efficient in theoretical preparation than the use of video or interactive instruction.



Results of further measurement concerning the time of performing an experiment after acquainting oneself with the respective paper, video and interactive information are shown in the graph in Figure 4.

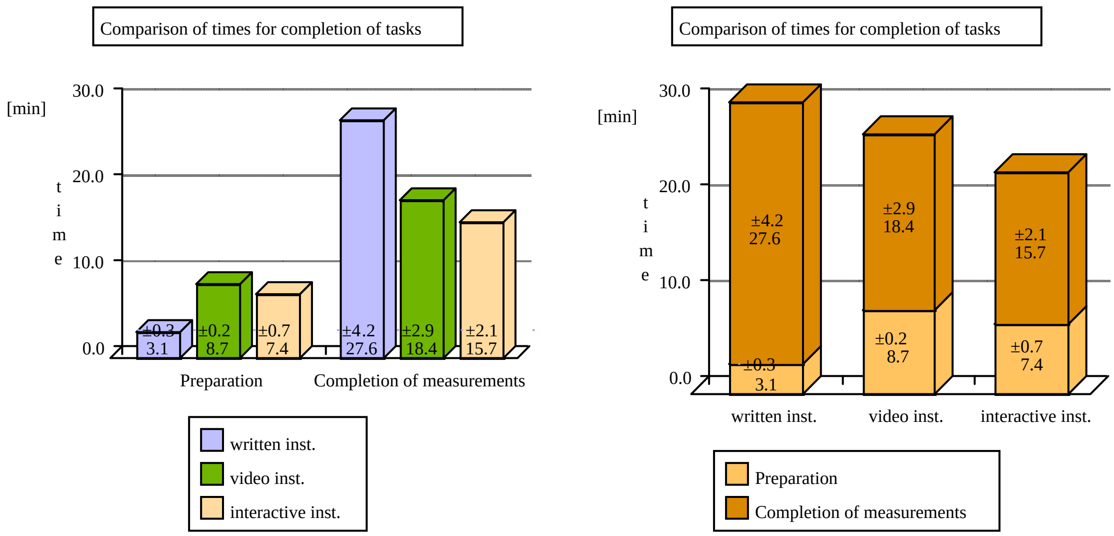
Figure 4. A comparison of time for completing given phases of a experimental task shows that the use of interactive or video instruction in almost all phases of experimental work during the experiment is more time-efficient then the use of paper instruction.



These measurements have shown that video and interactive instructions increased the practical skills of subjects tested during an experiment. These two groups were more time-effective in performing the operational tasks assigned them. This is particularly clear in the case of tasks concerning the setting up of measuring apparatus, the setting up of a monitoring program and the completion of measurements. However, the differences between video and interactive instructions were clearly visible in those phases concerning tasks connected with servicing the program ('preparation of a monitoring program' and the 'completion of measurements').

The three forms of instruction appear to be equally effective in exercises connected with theoretical work. Manual activity is clearly well assisted by instructions presenting video clips (video and interactive instructions). On the other hand, work connected with the use of a computer program is best assisted by interactive instruction.

Figure 5. A comparison of the time for completing given tasks shows that even the partial differences for interactive instruction, on the whole, remain more time efficient than do video or paper instructions.



The results presented above show that in the case of the above mentioned task the use of interactive instruction increases the effectiveness of performing an experiment and shortens the time of its completion by 25%, despite the fact that getting acquainted with it requires more time than does classical written instruction. Also, in the case of the above-mentioned task (Figure 5), a similar effect was noticed with using video instructions, which shortens the time of performing the task by 12.7%.

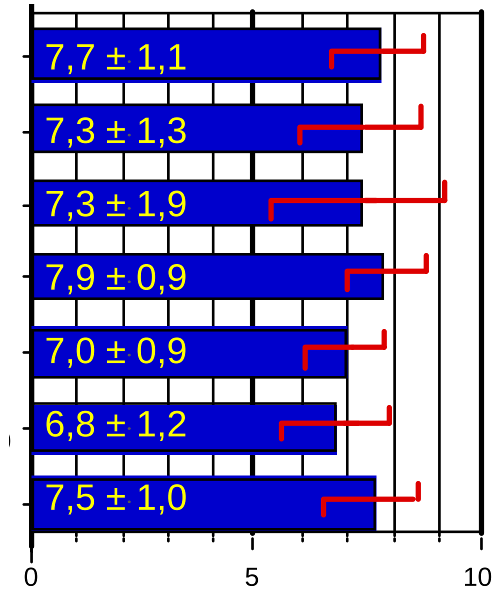
Questionnaires were presented to the same group of students to find out their opinions on the experiment and the instructions. Participants using the interactive program in the experiment were asked to respond to the following questions:

- “Does this instruction help in understanding the nature of the experiment? (from ‘no’ to ‘yes’).”
- “How would you describe these instructions? (from ‘unclear’ to ‘too obvious’).”
- “The way of presenting information in this form makes it (from ‘accessible’ to ‘inaccessible’).”
- “In comparison with written instructions, these are (from ‘worse’ to ‘better’).”
- “The use of these instructions is (from ‘easy’ to ‘difficult’).”
- “The theoretical level of the instructions is (from ‘poor’ to ‘ideal’).”
- “These instructions raise comprehension and skills (from ‘not at all’ to ‘considerably’).”

All respondents answered by assigning values on 10 points Likert type scale with values ranging from of 1 to 10. The value 5 was the central value, which respondents chose when they felt that the instruction was not significantly different from the traditional text instruction. Every deviation from the initial value to the right indicates that the respondent considered the instruction as being better and to the left, as being worse (Figure 6).

Figure 6. Results following analysis of questionnaires. The value 5 was a central value.

- "Does this instruction help in understanding the nature of the experiment? (from 'no' to 'yes')."
- "How would you describe these instructions? (from 'unclear' to 'too obvious')."
- "The way of presenting information in this form makes it (from 'accessible' to 'inaccessible')."
- "In comparison with written instructions, these instructions are (from 'worse' to 'better')."
- "The use of these instructions is (from 'easy' to 'difficult')."
- "The theoretical level of the instruction is (from 'poor' to 'ideal')."
- "These instructions raise the comprehension and skills (from 'not at all' to 'considerably')."



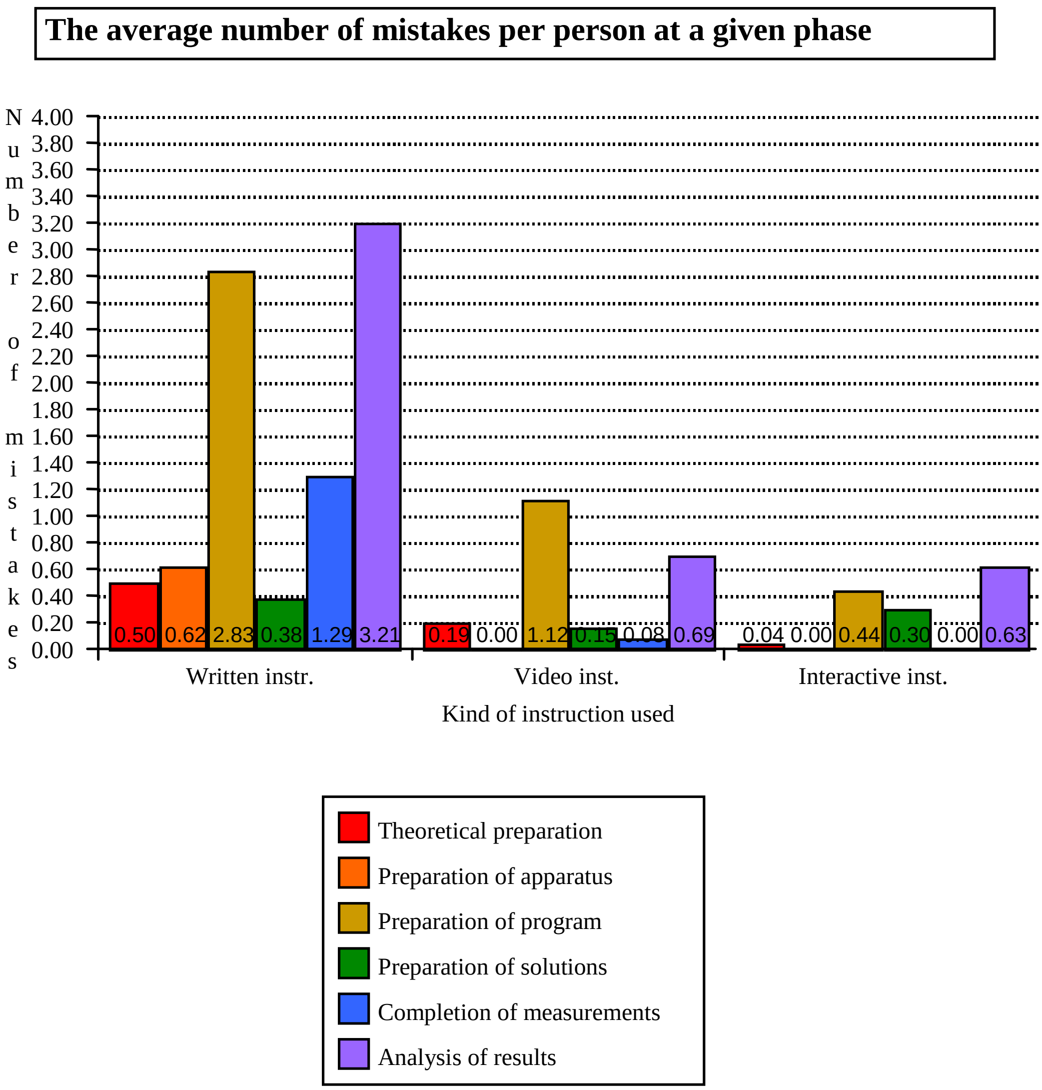
In order to confirm the above results with the results of data analyses obtained during the same teaching experiment, the effectiveness of realizing experimental phases was measured by the number of incorrect or uncertain tasks performed by respondents. Mistakes in laboratory tasks as well as enquiries for help indicating an unfamiliarity or indecisiveness on the part of respondents, were duly noted. The research dealing with matters concerning tasks is listed in Table 1.

Table 1. Incorrect or uncertain tasks performed by respondents.

A.	**Theoretical preparation**	**D.**	**Preparation of solution**
	a lack of understanding of the aim of the experiment based on an incorrect statement of lesson aims		wrong choice of solution concentrations
B.	**Preparation of apparatus**		wrong sequence of introducing concentrations
	wrong connection of power to the computer or interface		wrong amounts of solutions introduced into cuvettes
	wrong connection of the colorimeter		wrong means of introducing solutions
	wrong setting of the colorimeter switch		wrong closing of cuvette or lack of same
C.	**Preparation of program**		wrong introduction of cuvettes into colorimeter
	wrong description of the colorimeter interface connection		wrong mixing of solutions in cuvettes or their non-mixing
	wrong opening of the monitoring program	**E.**	**Completion of measurements**
	wrong choice of measurement sensor		wrong opening of data registration
	wrong choice of graph for display of data		wrong interpretation of data on graph
	hiding of graph under program window		wrong reading of data from graph
	wrong choice of time for automatically shutting down measurements		wrong counting of data from graph
	wrong choice of parameters described on axes	**F.**	**Analysis of results**
	wrong choice of scale on graph axis		wrong quantitative and qualitative conclusions

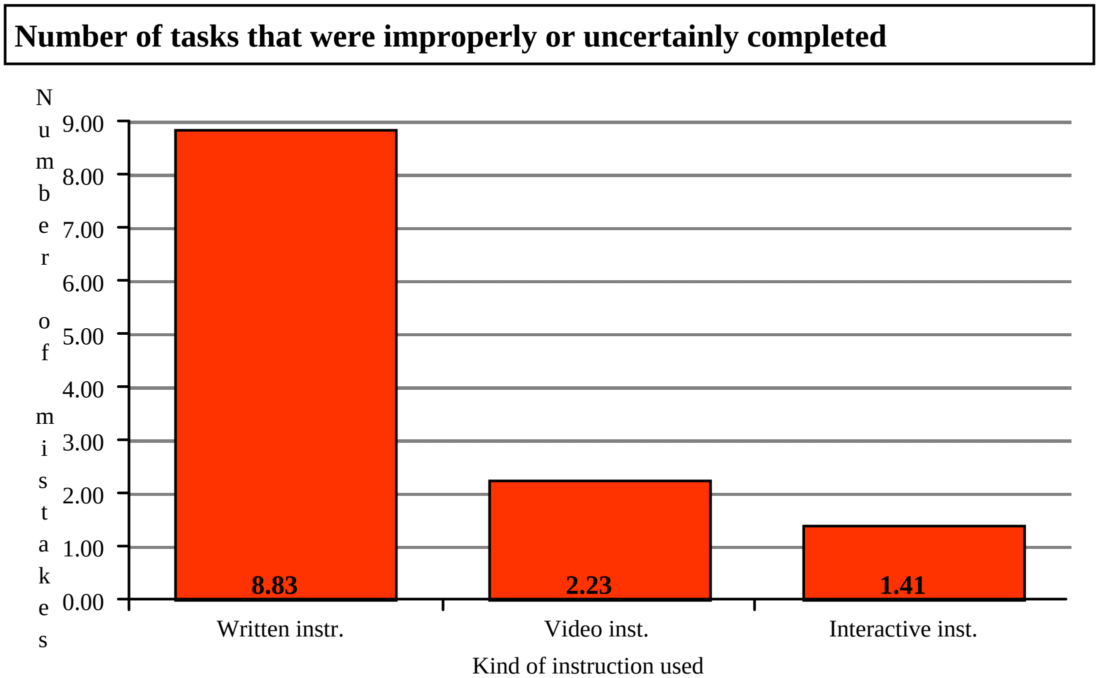
The experiment shows that generally most mistakes and uncertainties were shown by students who were instructed by written material. Those receiving video and interactive instruction made fewer wrong or uncertain responses in each phase of the experiment.

Figure 7. The results of effectiveness analysis in performing experimental phases show that the use of interactive or video instruction practically eliminates the number of errors compared with paper instruction.



The tabulation of tasks for particular phases confirms the conclusion of the previous data analysis that, by comparison, the biggest problem is caused by activities connected with operating the monitoring program (its preparation, performing measurements and elaborating results). Use of instructions within a video presentation practically eliminated the number of errors in the tasks of preparing apparatus and performing measurements. The difference in the number of mistakes at the phase of preparing solutions suggests that this is a factor independent of the kind of instruction employed.

Figure 8. Comparing effectiveness results in the completion of given experimental phases.



In summary, in the experiment under investigation, the use of video instruction, in comparison with the use of paper instruction, lowers the number of incorrect or uncertain responses by 74.7%. The use of interactive instruction, as compared to paper instruction, lowers the number of improper or uncertain responses by 84%. Employing instruction showing video clips (video and interactive instruction) increases the effectiveness of completing various phases connected with the performance of manual tasks. The interactive element in instruction, however, is most effective in activities connected with the use of a monitoring program.

Summary and conclusions

In the course of our research into a strategy of computer assistance for chemical experiments, the effectiveness of using interactive laboratory instruction was tested, together with the significance of multimedia and interactive elements in such preparation. To this end, three kinds of instruction in preparation for conducting the experiment ‘Empirical equations of the kinetics of a reaction’ were prepared.

Each instruction appears to perform its task equally in exercises connected with theoretical work. However, due to different pace of information delivery by each of instruction, the use of paper instructions in the experiment considerably shortens the time of studying the materials in comparison with the interactive and video instruction. Much more important is that the use of video and interactive instructions raises the level to which manipulative skills are developed by the students. Manual activities are well assisted by video and interactive instructions, that is those presenting video clips. On the other hand, work connected with the use of a measurement software is best assisted by interactive instruction i.e. a computer.

Overall results of the research show that the use of interactive instruction increases the resulting laboratory skills and while it shortens the time of its completion it helps in a change of pace of laboratory work. What is also important, the use of interactive instruction, as compared to paper instruction, lowers the number of erroneous or uncertain responses, which is one of the measures of the change in the quality of laboratory work.

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