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# Chemistry Education Research and Practice

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# Chemistry Education Research and Practice

The journals, *University Chemistry Education*, published by The Royal Society of Chemistry, (http://www.rsc.org/uchemed/uchemed.htm) and *Chemistry Education Research and Practice*, published from the University of Ioannina, (http://www.uoi.gr/cerp/) have merged with effect from January 1st 2005. The new, fully electronic journal is published by The Royal Society of Chemistry under the title: ***Chemistry Education Research and Practice,*** and it will continue to be available free of charge on the Internet**.** There are four issues per year.

The new journal is edited by Georgios Tsaparlis (gtseper@cc.uoi.gr) and Stephen Breuer (s.breuer@lancaster.ac.uk) and intends to maintain the high standards set by its predecessors. Its editorial policy will be the following.

**'*Chemistry Education Research and Practice*'** is the journal for teachers, researchers and other practitioners in chemical education. It is the place to publish papers on:

- research, and reviews of research in chemical education;
- effective practice in the teaching of chemistry;
- in depth analyses of issues of direct relevance to chemical education

Contributions can take the form of full papers, preliminary communications, perspectives on methodological and other issues of research and/or practice, reviews, letters relating to articles published and other issues, and brief reports on new and original approaches to the teaching of a specific topic or concept.

The new journal welcomes contributions of the type described above; these should be sent to cerp@rsc.org.

# Chemistry Education Research and Practice

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## Guidelines for Authors

### Submission of contributions

Chemistry Education Research and Practice (CERP) is the journal for teachers, researchers and other practitioners in chemical education. It is published free of charge, electronically, by The Royal Society of Chemistry, four times a year. It is the place to publish papers on:

- research, and reviews of research in chemical education;
- effective practice in the teaching of chemistry;
- in depth analyses of issues of direct relevance to chemical education

Contributions can take the form of full papers, preliminary communications, perspectives on methodological and other issues of research and/or practice, reviews, letters relating to articles published and other issues, and brief reports on new and original approaches to the teaching of a specific topic or concept.

1. The original contribution should be submitted electronically, preferably in Word for Windows format. Any associated diagrams should be attached in JPG or GIF format, if possible. Submissions should be made by e-mail as a file attachment to cerp@rsc.org, or directly to the editors: Stephen Breuer at s.breuer@lancaster.ac.uk or to Georgios Tsaparlis (gtseper@cc.uoi.gr).

2. Submitted contributions are expected to fall into one of several categories (listed above). Authors are invited to suggest the category into which the work should best fit, but the editors reserve the right to assign it to a different category if that seems appropriate.

   A word count (excluding references, tables, legends etc) should be included at the end of the document.

3. Presentation should be uniform throughout the article.

   Text should be typed in 12pt Times New Roman (or similar), with 1"/ 2.5 cm margins, double-spaced, unjustified, ranged left and not hyphenated.

   Always use an appropriate mix of upper and lower case letters: do not type words in uppercase letters either in the text or in headings. **Bold** or *italic* text and not upper case letters should be used for emphasis.

   All nomenclature and units should comply with IUPAC conventions.

   Tables and figures should be numbered consecutively as they are referred to in the text (use a separate sequence of numbers for tables and for figures). Each should have an informative title and may have a legend.

Equations should be written into the text using the word processing program, either as normal text or using the program's equation facility.

Structures should, wherever possible, be treated as a figure and not incorporated into text.

References should be given by the name of the author (or the first author, if more than one), followed by the year of publication. If an author has more than one reference from the same year, then it should be given as Smith 2001a, Smith 2001b, etc.

Footnotes should be generally avoided and important additional information may be referenced and included in the reference list.

4. A title page must be provided, comprising:
   - an informative title;
   - authors' names and affiliation, full postal address and e-mail; (in the case of multi-authored papers, use an asterisk to indicate one author for correspondence, and superscript a, b, etc. to indicate the associated addresses);
   - an abstract of not more than 200 words;
   - keywords identifying the main topics covered in the paper

5. Wherever possible articles should be subsectioned with headings, subheadings and sub-sub-headings. Do **not** go lower than sub-sub-headings. Sections should not be numbered.

   The introduction should set the context for the work to be described; include references to previous related work, and outline the educational objectives.

   A concluding section (which need not be headed conclusion) will include an evaluation of the extent to which educational objectives have been met. A subjective evaluation may be acceptable.

6. The formatting of references should follow the following practice:

   Books and Special Publications:
   Author A., (year), *Title of the book italicized*, Publisher, Place of publication, page no. if applicable.

   Journal Articles:
   Author A., Author B. and Author C., (year), Title of the article in Roman type, *Full Name of the Journal Italicised*, **Volume no. in Bold**, inclusive page numbers.

   For example:
   Osborne R. and Freyberg P., (1985), *Learning in science: the implication of children's science*, Heinemann, London.

   Jackman L.E. and Moellenberg W., (1987), Evaluation of three instructional methods for teaching general chemistry, *Journal of Chemical Education*, **64**, 794-96.

7. All contributions submitted will be refereed anonymously by two independent referees. In case of a disagreement a third referee will be consulted. The decision of the Editors on

the acceptance of articles is final.

8. Authors grant *CERP* the exclusive right to publish articles. They undertake that their article is their original work, and does not infringe the copyright of any other person, or otherwise break any obligation to, or interfere with the rights of such a person, and that it contains nothing defamatory.

9. Articles will be published on the Web in PDF format.

# 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.

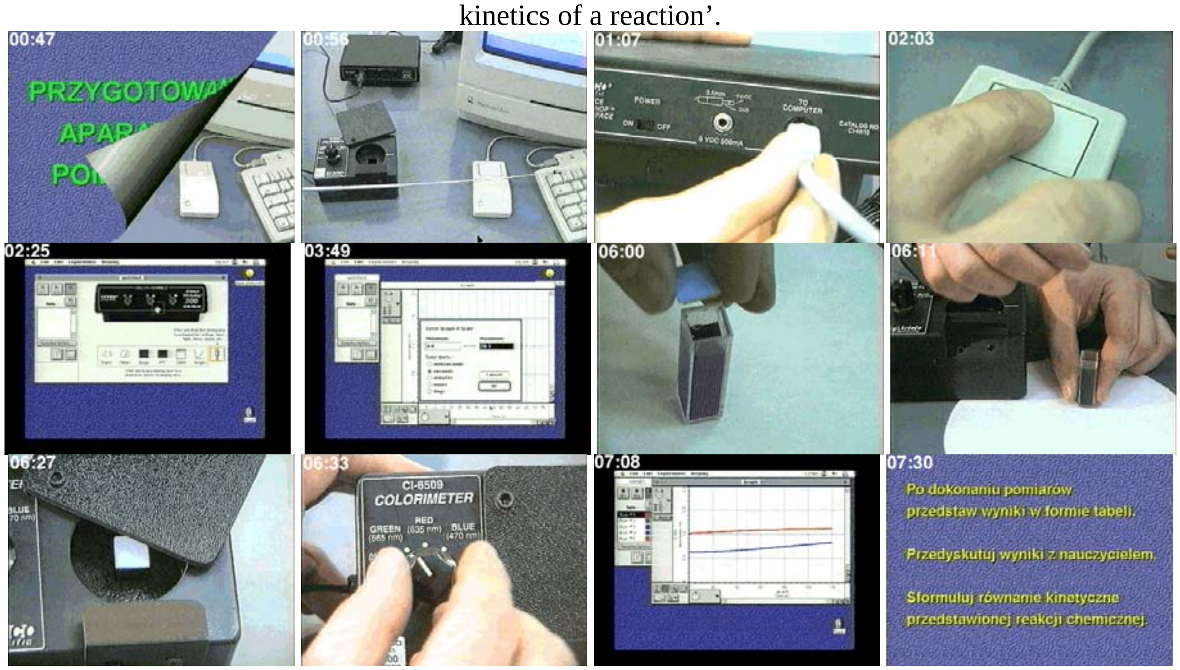
Using the 'problem based laboratory method' (Mayer, 2003) in the given situation is also one way of conducting this lesson in conditions of limited time constraint. The performance of an appropriate series of experiments by the teacher or by students in a 'guided discovery method' (Ricci & Ditzler, 1991) 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 4$^{th}$ 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.

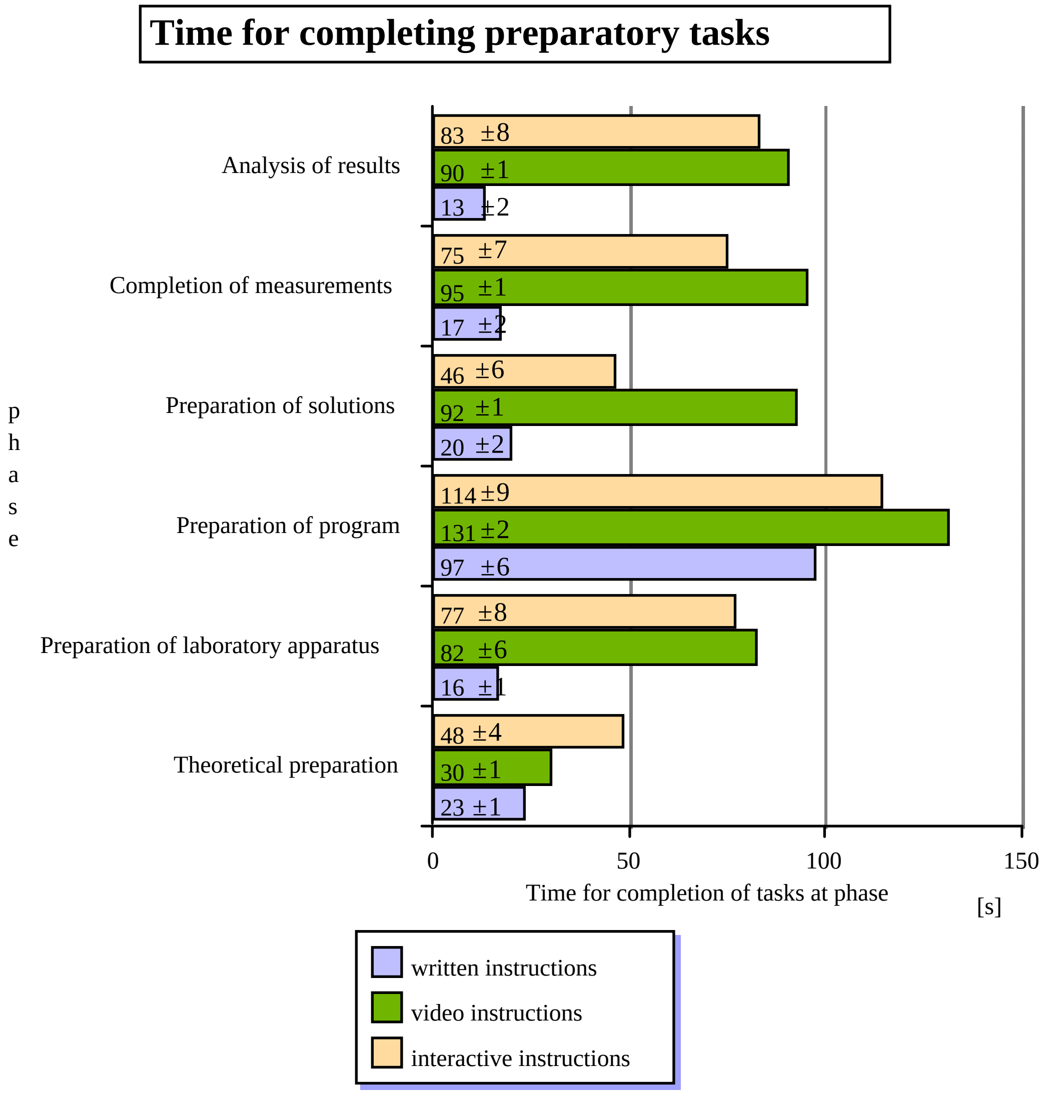
## Results

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.

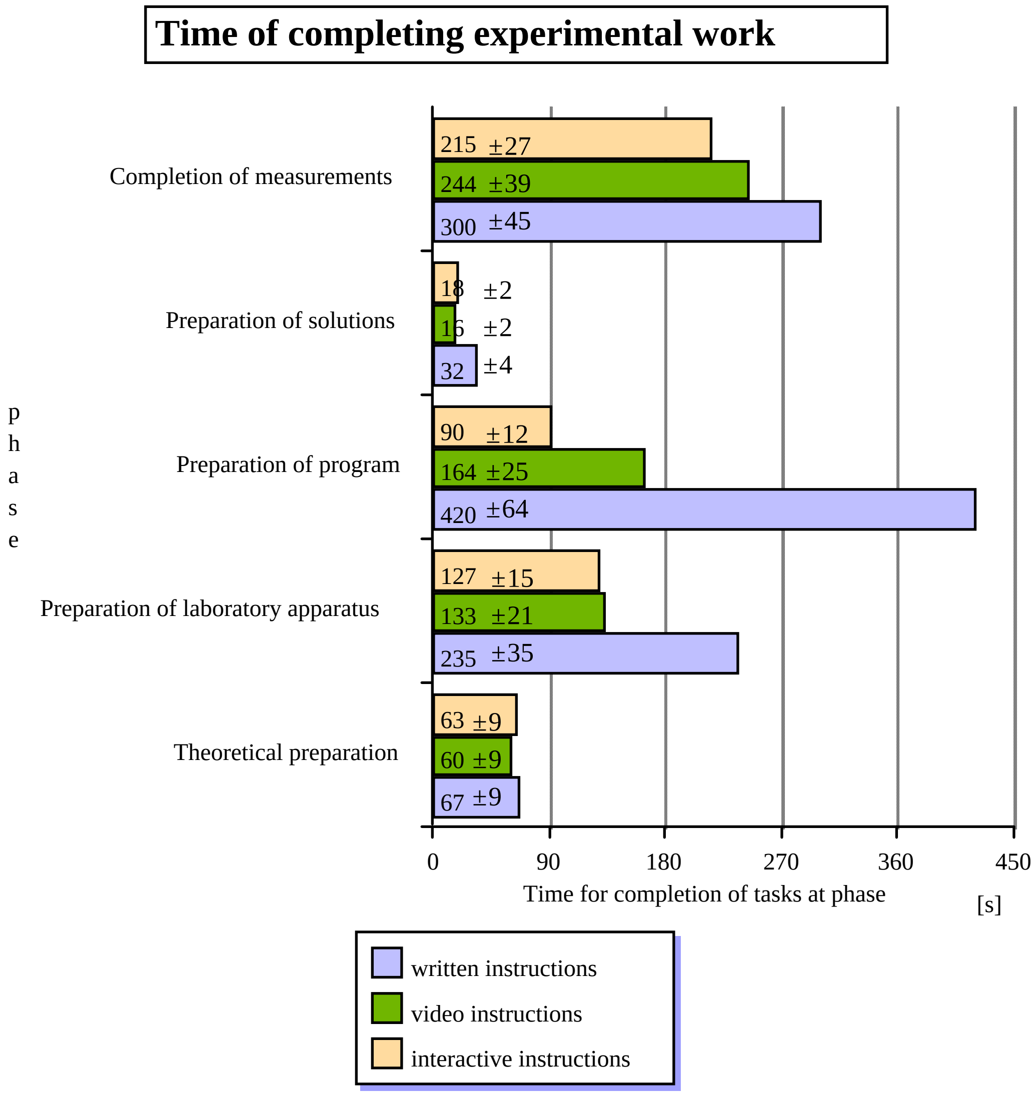
The measurements were made by noting the time chosen student under observation moved to next step of the task; the measurements do not show the effect of the process, only the timing.

**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.

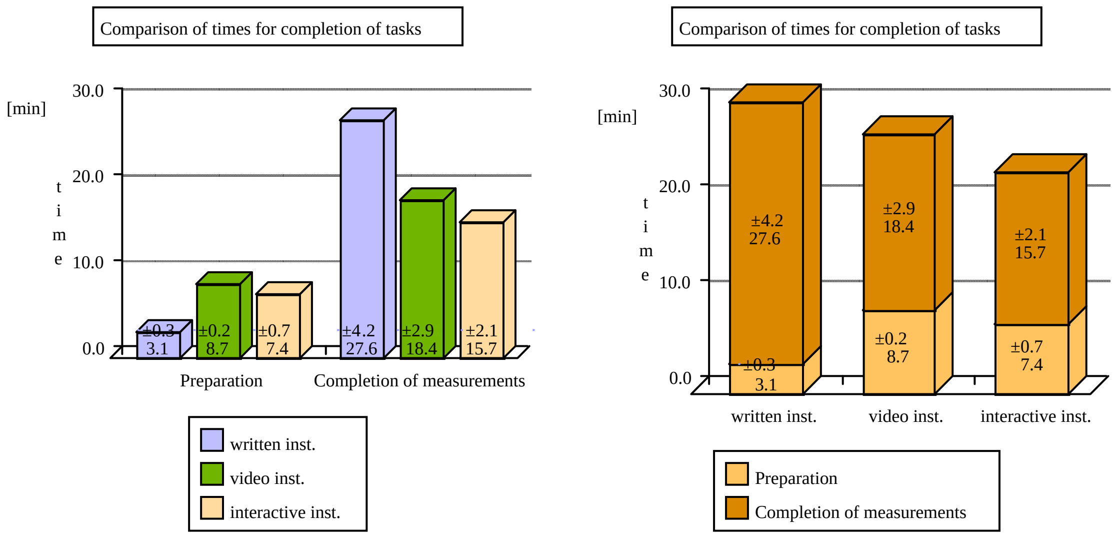
**Figure 4**. A comparison of time for completing given phases of a experimental task shows that the use of interactive or video instruction in almost all phases of experimental work during the experiment is more time-efficient then the use of paper instruction.




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%.

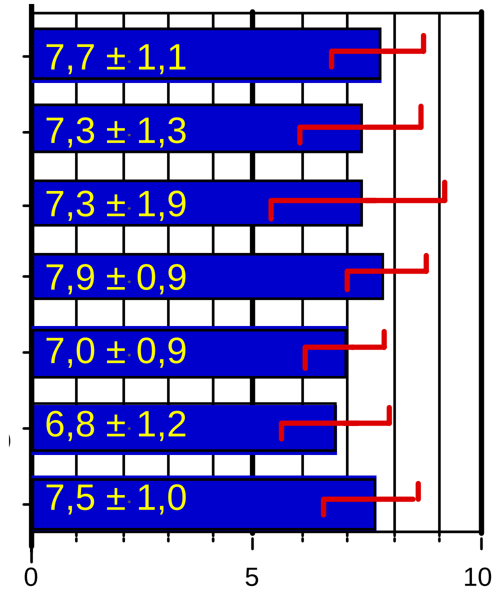
Questionnaires were presented to the same group of students to find out their opinions on the experiment and the instructions. Participants using the interactive program in the experiment were asked to respond to the following questions:

- “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')."



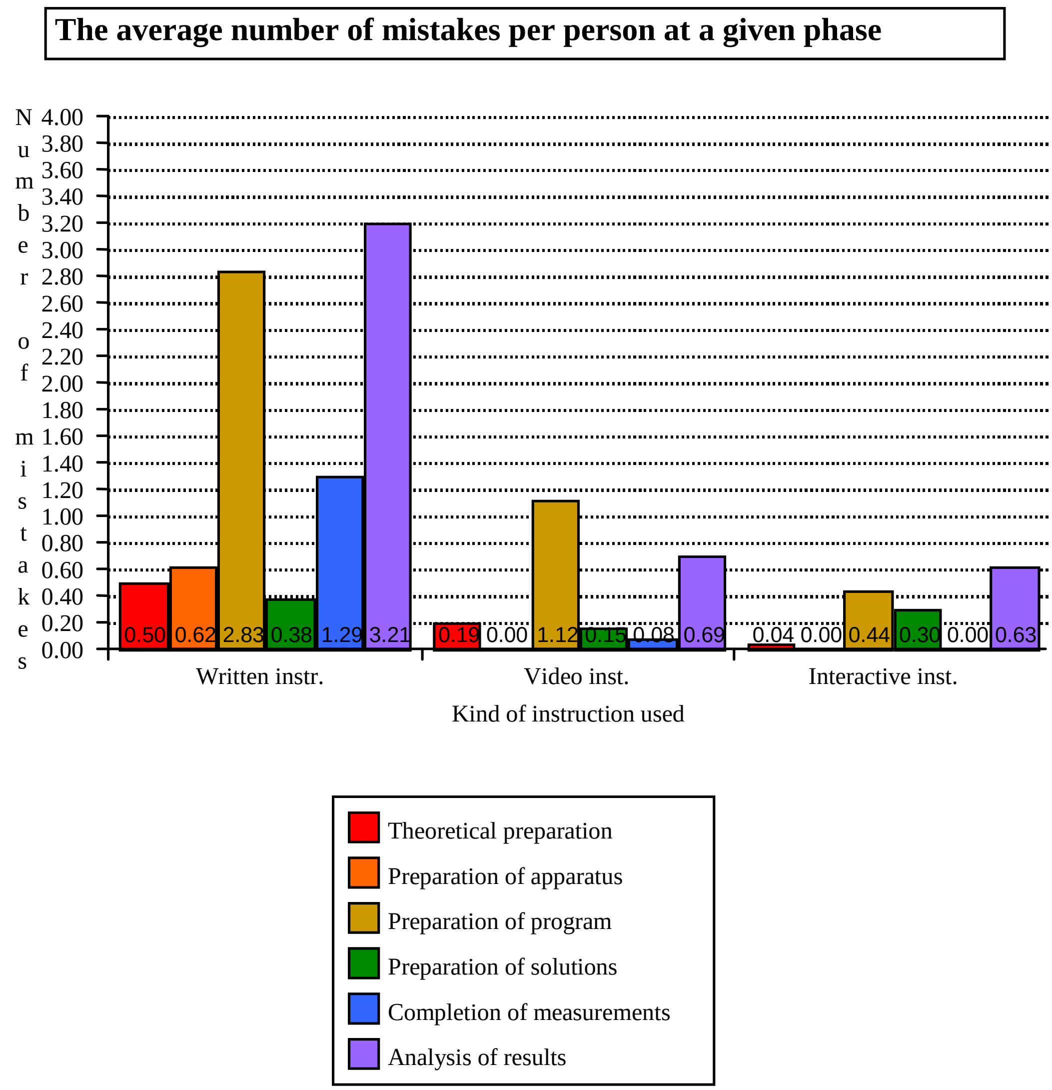

In order to confirm the above results with the results of data analyses obtained during the same teaching experiment, the effectiveness of realizing experimental phases was measured by the number of incorrect or uncertain tasks performed by respondents. Mistakes in laboratory tasks as well as enquiries 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 |

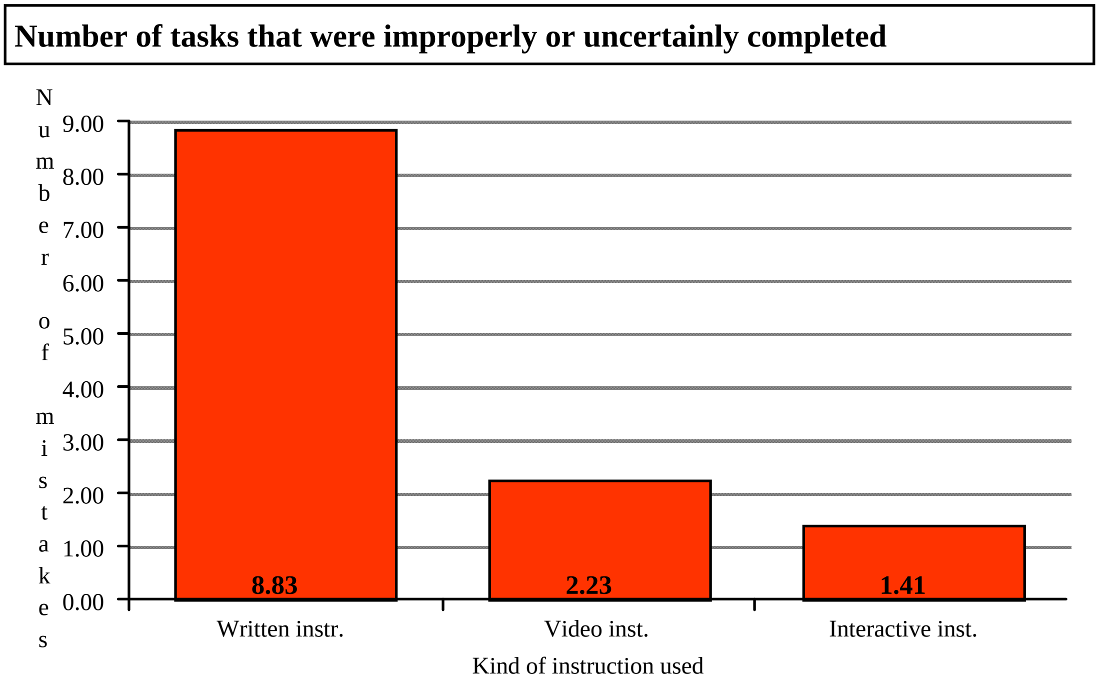
The experiment shows that generally most mistakes and uncertainties were shown by students who were instructed by written material. Those receiving video and interactive instruction made fewer wrong or uncertain responses in each phase of the experiment.

**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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Educational Research

# Programmed instruction revisited: a study on teaching stereochemistry

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**Abstract:** This study is aimed at comparing the success of programmed instruction with the conventional teaching approach on teaching stereochemistry, and whether gender has any effect on student success. Forty chemistry teacher trainees attending the same class in the Department of Chemistry Education in a large state university in eastern Turkey were the subjects of the study. Of the forty trainees twenty were selected as the experimental group and the other twenty as the control group. The study was implemented in a total of sixteen lecture hours (each 50 min) in four weeks (four lecture hours per week). The subject, stereochemistry in organic chemistry, was taught to the experimental group by the researcher through 'programmed instruction' and the control group was taught by the course lecturer through traditional teaching. The data collection tools were: Stereochemistry Achievement Test (SAT), programmed stages (frames), and the views of the students. An ANCOVA (Analysis of Co-Variance) showed that there was a statistically significant difference between programmed instruction and conventional teaching approach on the success level of students' learning in stereochemistry. In addition, it was found that female students were more successful than their male counterparts in the experimental group. The findings suggest that programmed learning could be considered as a better alternative to conventional lecturing in teaching stereochemistry. [*Chem. Educ. Res. Pract.*, 2006, **7** (1), 13-21]

**Keywords:** chemical education research, university (tertiary) level, stereochemistry teaching, programmed instruction-based teaching and learning, student-centred learning.

## Introduction

Higher education courses in chemistry at universities and other institutions have, perhaps, mainly been centred on the lecturer's comprehension of a topic rather than that of the student. Nevertheless, in the past four decades student-centred learning has aroused considerable interest at all levels of education systems, including universities (Hinchliffe, 1982). Several alternative methods, based on students being at the centre of control, have been suggested since the days of Aristotle. These have come down to us mainly in the form of the tutorial/seminar system. During the past decades, personalized (i.e. individual) instruction by experiment or even fully autonomous learning has been developed for teaching in all areas (Boland, 1977).

One feature of many of these alternative methods is that they are self-paced. Students plan their own time schedule, usually by receiving and completing only one assignment at any one time, and thereby raise their achievement in a subsequent test performance. However, there are studies that opposed the self-pacing approach because it offers little improvement on traditional lectures (Cassidy, 1973; Reiser and Sullivan, 1977). Another beneficial feature claimed for student-centred methods is that they allow more time to be spent by the teacher tutoring individual or very small groups of students. This has been claimed, in particular, by the advocates of computer-assisted learning (Hinchliffe, 1982).

Programmed learning is one of the better-known methods of student-centred learning, and its potential advantages have been fully discussed (Skinner, 1958; Young, 1961; Young 1966; Beard, 1973; Boland, 1977; Hinchliffe, 1982). Programmed instruction was among the first in historical significance for instructional developments and analytical processes, important to instructional design. The programmed instruction movement extended the use of printed self-instruction to all school subject areas to adult and vocational education as well. Later, as the technology developed, other media, such as radio, television video and computer, came into use. Computer-assisted instruction, which both tests students' abilities and marks their progress, may supplement classroom activity or help students to develop ideas and skills independently.

The first teaching machine was invented by Pressey (1927), but it was not until the 1950s that practical methods of programming were developed. Programmed instruction was introduced in 1954 by B. F. Skinner of Harvard (Skinner, 1954), and much of the system is based on his theory of the nature of learning. As programming technology developed so did the range of teaching machines and other programmed instruction materials. Programs have been devised for the teaching of spelling, reading, arithmetic, foreign languages, physics, psychology, and a number of other subjects. Some programs are linear in concept, allowing advancement only in a particular order as the correct answer is given. Others are branching, giving additional information at the appropriate level whether a correct or incorrect answer is given (Young, 1966).

Although there has been considerable controversy regarding the merits of programmed instruction as the sole method of teaching, many educators agree that it can contribute to more efficient classroom procedures and supplement conventional teaching methods. Programmed instruction enables students to work individually, calling for active participation of the learner. In some areas, such as industry and the armed services, programmed instruction is often used to train personnel. A primary feature of programmed instruction is that information needed by the student is presented in an order that is most helpful to him/her, particularly if he/she is a beginner in the field. Comprehensive knowledge of a topic is ordered in textbooks in terms that are appropriate to the subject, rather than to the students. It is clear, therefore, that programmed instruction should be an adjunct; it cannot replace textbooks and reference books in university education (Young, 1966).

Teaching organic chemistry at the introductory level has made it obvious to the teachers that understanding stereochemistry can be difficult and sometimes traumatic for students. Stereochemistry is frequently a source of confusion when students are first exposed to it, and unfortunately, this feeling may linger even after repeated exposure (Bowen and Bodner, 1991; Bodner, 2003). Visualizing the three-dimensional aspects of molecules and their relationships to other molecules is difficult (Brand, 1987). When dealing with principles that are particularly difficult to visualize or conceptualize, such as stereochemistry, teaching aids and mnemonic devices have been invaluable in the learning process. Realizing that all teaching aids and devices cannot be presented by the instructor in the lecture, these methods can be passed on most efficiently through teaching assistants and tutors due to the one-on-one nature of student contact time. Often these devices help individual students make a connection between the new material and their own experiences and prior knowledge base. For that reason, a variety of methods have been established that cater to the respective strengths of each individual. These methods vary from mathematical approaches to two-dimensional Fischer projection techniques to the three-dimensional models (Barta and Stille, 1994).

Although several different approaches and computer-assisted learning materials have been developed throughout the developed countries, there has been no study carried out in Turkey on students' learning difficulties in stereochemistry, and also, no programmed instruction materials developed on stereochemistry in Turkish. Therefore, this study is an attempt to develop a programmed instruction material that could be used in teaching introductory Organic Chemistry courses in Turkey.

This study is aimed at comparing the success of programmed instruction with the conventional teaching approach on teaching stereochemistry, and whether gender has any effect on student success. Gender effect was included as a factor potentially affecting learning in stereochemistry, as suggested in the literature (see Boothroyd and Chapman, 1987). Hence, two null hypotheses tested in this study were worded as follows. *(a)* There is no significant main effect of gender on the students' mean scores taught through programmed instruction and conventional teaching approaches, and *(b)* there is no significant main effect of the teaching approach on students' mean scores taught through programmed instruction and conventional teaching approaches.

## Methodology

### *Sample*

The sample of the study was composed of forty second year undergraduate students (chemistry teacher trainees; twenty male and twenty female) enrolled to Organic Chemistry-I course (4 hours per week and 14 weeks in a semester) at the Department of Chemistry Education of a large state university in Eastern Turkey at the first semester of 2002-3 academic year. Before dividing the students into groups, an achievement test specifically developed for this study, was applied as pre-test. Since the students' scores showed homogeneity, they were divided into two groups as experimental and control groups by only considering the equality of the gender distribution. An independent sample t-test was carried out, and no statistically significant difference was found between the students' pre-test scores in terms of gender ($t=1.97$; $p>0.05$; see Table 1). The number of students in the groups and the mean scores in the pre-test could be seen at Table 3.

**Table 1.** Pre-test means, std. dev. and std. error means, according to gender.

| | Gender | N | Mean | Std. Dev. | Std. Error Mean |
|---|---|---|---|---|---|
| **Pre-test** | Male | 20 | 20.9 | 7.8 | 1.7 |
| | Female | 20 | 16.9 | 4.6 | 1.0 |

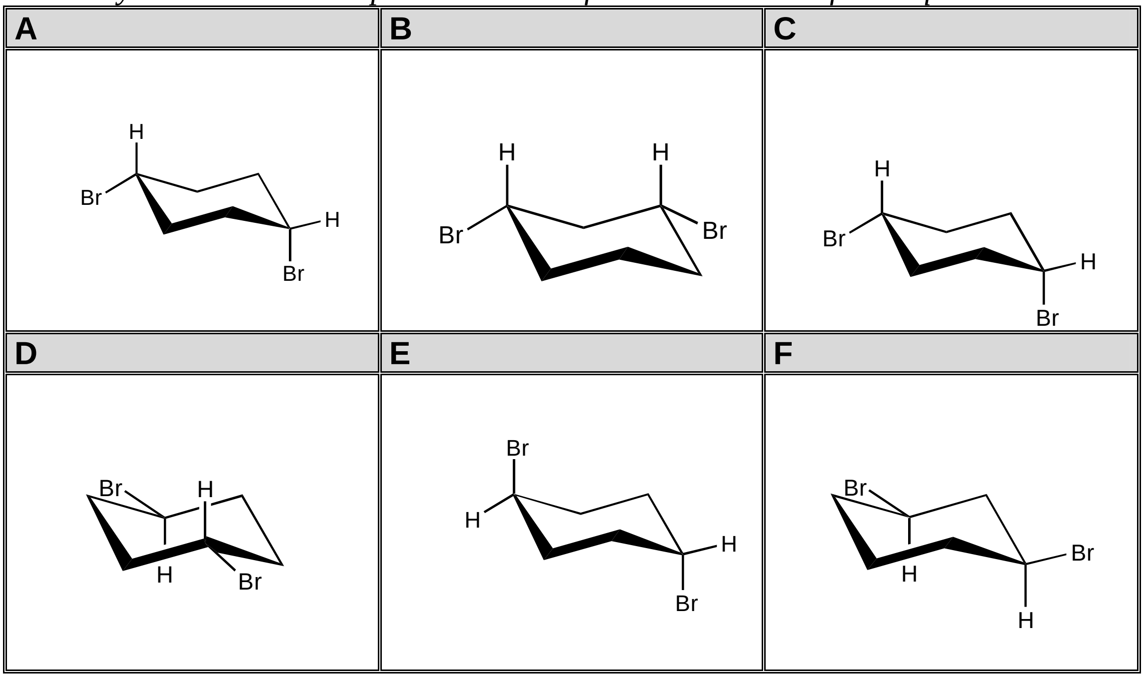
($t=1.97$; $p>0.05$)

### *Materials and Procedure*

*Stereochemistry Achievement Test (SAT):* An achievement test, composed of 12 open-ended questions, each having sub-questions, was developed using the literature and textbooks. Questions in the SAT were mainly at knowledge/comprehension levels according to Bloom's taxonomy. The validity of the test was achieved by consulting five organic chemistry professors. With respect to the reliability, SAT was administered to a group of forty-seven students who took Organic Chemistry-I course the year before. The Kuder-Richardson formula was used for determining the reliability of SAT and reliability coefficient was found as ($\alpha= 0.62$). This level of reliability coefficient for an achievement test indicates that the test could be considered satisfactorily reliable (McMillan and Schumacher, 2001; p.243). A sample question can be seen in Figure 1.

**Figure 1**. A sample question used in SAT.

**Question 2.** Examine the following formulas and select those pairs that satisfy the following conditions: Be sure to enter two letters (and only two) in each answer box. *Please note that there may be more than one possible answer for the second and fourth questions.*




■**1**- Which are identical in all respects? ....................................

■**2**- Which are configurational isomers? ......................

■**3**- Which are conformational isomers……………………….....

■**4**- Which are structural isomers? .....................................

*Programmed Frames:* Programmed instruction is based on a series of very small steps, called frames. Each frame contains some information and a statement with a blank that the student fills in. The student then uncovers the correct answer before going on to the next frame. If the student's answer was correct it is positively reinforced by progress to the next frame; if not, the student immediately sees the correct answer. Each frame may introduce either a new idea or repeat material covered earlier. The lessons start from the student's initial knowledge and in small steps proceed to a final learning goal. Because of active student participation, small steps, immediate feedback and reinforcement, programmed learning can be very effective. All students work through the same sequence (Anderson and Fretzin, 2004). The answer to the question in a frame is given in the following frame. In this study linear sequencing was employed. A total of sixty-five frames were prepared, covering all stereochemistry concepts and principles at introductory level. A sample of frames could be seen in Figure 2.

**Figure 2**. A sample frame of programmed steps

**Frame No:1**

**Isomerism in Carbon Compounds**

Different compounds that have the same molecular formula are called **isomers**. There are two main classes of isomers, **structural isomers** and **stereoisomers**. Structural isomers will have the same number and types of atoms, but they are connected differently (they have a different 'structure'). A simple example of structural isomers is ethanol and dimethyl ether, shown below.

| | |
|---|---|
| $C_2H_6O$ | $C_2H_6O$ |
| $CH_3$-$CH_2$-OH | $CH_3$-O-$CH_3$ |
| ethanol | dimethyl ether |

**Structural isomers; interconverted in a different sequence**.

**Question**

**Please write your answer to the following space**.

**1-** Different compounds that have the same molecular formula are called **………………….**

**2-** There are two main classes of isomers. These are called **………………….**and **…………………..**

**Frame No:2**

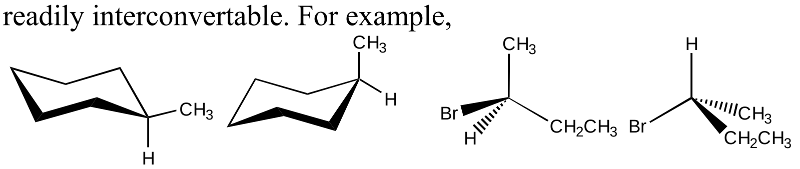
**Answer**

**No:1**

1. Isomers

2. Structural isomers, stereoisomers

In stereoisomers the atoms are connected sequentially in the same way, such that condensed formulas for two molecules are identical. The isomers differ, however, in the way atoms are arranged in space. There are two major sub-classes of stereoisomers; **conformational isomers**, which interconvert through rotations around single bonds or flipping of ring systems, and **configurational isomers**, which are not readily interconvertable. For example,




**conformationals isomers; interconverted by single bond rotations**

**configurational; not readily interconverted**

**Question**

*Procedure:* Treatment was completed in a total of sixteen lecture hours (a short hour) in four weeks (four lecture hours per week). The control group was taught by a lecturer from the department with over twenty years of experience in teaching Organic Chemistry. The students were guided, as in previous years, by using a conventional teaching approach. This was mainly delivered by lecturing, and molecular models were used by the lecturer. In the experimental group, where programmed instruction was administered, the teaching responsibility was taken by one of the researchers. There was no lecturing in the experimental group. Each student was given a frame according to the sequence shown in Table 2 (the control group also followed the same graded sequence). When a student completed the given frame, he/she was presented with the next frame. The rate of progress depended on the students. In this way the speed of the students ranged from 3 to 5 frames in each lecture hour. The researcher took mainly a tutoring role rather than that of an instructor. He guided the students in the use the frames and helped them in places where students needed explanations and extra help. In this way, all the students were kept active, and they were involved in the learning process. During this process neither additional information was given nor extra problems solved beyond those which were given in the frames. However, students were free to get information outside of class hours. Each student had the chance of learning about stereochemistry at his/her own pace. When the treatment was completed, both the control and experimental groups were given the SAT as a post-test. Moreover, students' views about the programmed instruction were gathered from the experimental group. For this purpose, students were given a blank sheet and they were asked to write their views about the treatment. They were asked not to write their names on the sheets in order to ensure confidentiality.

**Table 2**. Distributions of the topics covered within stereochemistry according to the weeks in the control and experimental groups.

| | |
|---|---|
| **1st Week** | • Isomerism<br>• Structural isomers<br>• Stereoisomerism<br>• Conformational isomerism |
| **2nd Week** | • Configurational isomerism<br>• Diasteromers (Geometric isomerism in alkenes) |
| **3rd Week** | • Enantiomers (Chirality and a chiral carbon)<br>• Determination of the configuration of enantiomers: R and S system, Fischer projections (Determination of R and S configuration in Fischer projections) |
| **4th Week** | • Diastereomers containing stereogenic centers<br>• Diastereomers with chiral carbons (meso compounds)<br>• Isomers of disubstitued cyclocompounds |

*Data analysis:* Data was analyzed by using SPSS10.0 (Statistical Package for Social Sciences). The significance level was set to 0.05 since it is the most used value in educational studies. In other words, the probability of rejecting the true null hypothesis (probability of making Type I error) was set to 0.05 a priori to hypothesis testing. In order to find out the effect of the treatment (programmed instruction) on students' learning of stereochemistry ANCOVA (Analysis of Co-variance) was used, since it gives the pre-test as true co-variant rather than a focus of interest in itself (Dugard and Todman, 1995).

## Results

Descriptive statistics related to total scores of pre-test and post-test were categorized according to groups and gender, and are presented in Table 3.

**Table 3**. Descriptive statistics for mean scores of pre-test and post-test according to the groups and gender.

| Group | Treatment | Gender | N | Means of Pre-Test | Means of Post-Test |
|---|---|---|---|---|---|
| **Experimental** | Programmed Instruction | Male | 10 | 20.8 | 64.7 |
| | | Female | 10 | 18.2 | 76.4 |
| | | **Total** | **20** | **19.5** | **70.5** |
| **Control** | Conventional Instruction | Male | 10 | 21.1 | 42.9 |
| | | Female | 10 | 15.8 | 50.8 |
| | | **Total** | **20** | **18.4** | **46.9** |

As shown in Table 3, mean scores (70.5) of the students in the experimental group were higher than that of in the control group (46.7) in the post-test, while their scores were similar in the pre-test (19.5 and 18.4 for experimental and controls groups, respectively).

Table 3 also indicates that while female students scores were slightly lower than that of their male counterparts in the pre-test, they were significantly better than their male counterparts in the post-test (see Table 3 for the mean scores). Independent sample t-test indicates that there was no statistically significant difference between them in pre-test; however, ANCOVA results in Table 4 show that females performed better through programmed instruction than males [$F(1,39) = 10.8$; $p<0.05$], (see Table 5 for the calculated means of groups and gender for post-test).

**Table 4**. ANCOVA Results (Tests of between-subjects effects dependent variable: post-test)

| Source | df | Mean Square | *F* | Significance |
|---|---|---|---|---|
| Corrected Model | 3 | 2429.9 | 18.4 | 0.000 |
| Intercept | 1 | 7997.6 | 60.5 | 0.000 |
| Group (Control –Experimental) | 1 | 5213.3 | 39.4 | 0.000* |
| Gender (Male-Female) | 1 | 1428.8 | 10.8 | 0.002* |
| Pre-test | 1 | 743.4 | 5.6 | 0.023* |
| Error | 36 | 132.3 | | |
| Total | 40 | | | |
| Corrected Total | 39 | | | |

a $R^2 = 0.605$ (adjusted $R^2 = 0.572$)

* Significant at 0.05 level

**Table 5.** Calculated means of groups and gender. (Dependent Variable: Post-test)

| | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|
| **Group** | | | Lower Bound | Upper Bound |
| Experimental | 70.2 | 2.6 | 64.9 | 75.4 |
| Control | 47.2 | 2.6 | 42.0 | 52.5 |
| **Gender** | | | | |
| Male | 52.4 | 2.6 | 47.1 | 57.8 |
| Female | 64.9 | 2.6 | 59.6 | 70.3 |

This result refutes the first hypothesis that there is no significant main effect of gender on the students' mean scores taught through programmed instruction and conventional teaching approaches. This result contradicts the findings of Boothroyd and Chapman (1987) in which male students were more successful than their female counterparts. In our study, female students' better performance through programmed instruction-based learning perhaps could be explained by their interest in the study and also by their greater self-discipline. It is known that attitude and motivation are important factors in learning. During the treatment, female students liked and showed greater interest in the study than the male students, therefore it was an expected result that female students performed better. In addition, since the programmed instruction is cumulative, attendance at the course is one of the most important factors affecting the achievement. Some of the male students were absent from some sessions of the treatment, and they had to study more frames in the following lectures, therefore this might have affected their performance in the course.

ANCOVA results shown in Table 4 confirm the effect of programmed instruction on students' learning of stereochemistry [$F(1, 39) = 39.4$; $p<0.05$]. This result also refutes the second research hypothesis that there is no significant main effect of teaching approach on students' mean scores taught through programmed instruction and conventional teaching approaches. The ANCOVA results also suggest that there was a significant main effect of pre-test factor on students' performance at post-test [$F(1,39) = 5.6$; $p< 0.05$]. This result confirms that it was a correct action taking pre-test scores as a co-variant.

With respect to the students' views of the programmed instruction, there was an overwhelming student satisfaction according to the student survey. These results suggested that students liked the structure of the programmed instruction following a graded sequence in small steps so that students can work according to their own learning speed, having no time restrictions, and being able to use frames given to them as a supplementary material at home. All these views are in agreement with the previous studies (Powell, 1963; Boothroyd and Chapman, 1987).

## Discussion and implications

Using both pre-test and post-test results, it was shown statistically that while there was no difference between the groups prior to intervention, the experimental group performed significantly better than the control group after the treatment. This is consistent with the claims made for programmed instruction based on student impression (Hinchliffe, 1982). The limited but objective results in this paper suggest that substantially self-paced programmed learning is a better technique than the conventional lecturing in stereochemistry. Another important aspect is that programmed instruction forces student active participation in the teaching-learning process. It shifts the responsibility for learning back to the student, where it should be. Because it provides for a self-paced, logical sequence of small steps, and immediate confirmation or correction, it helps to overcome the wide spread of abilities and interest among university chemistry students (Powell, 1963).

However, the field remains wide open for further, carefully documented work using computer-assisted learning materials, especially in Turkish. The next stage of this study is going to be the development of a computer program by using the frames in this study to apply to a wide range of students from different departments. It would also be desirable to conduct research on different areas of chemistry at the undergraduate level. Further research would include comparing the developed computer programs with programs that use more conventional techniques. But even more important than such research is the further refinement of these techniques.

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# Students' understanding of matter: the effect of reasoning ability and grade level

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**Abstract:** This study aims at investigating the effect of grade level on students' achievement in matter concept and reasoning abilities, when their test anxiety was controlled. The data was collected from 8th, 10th and 11th grade students by the administration of The Matter Concept Test, Test of Logical Thinking, and the Motivated Strategies for Learning Questionnaire. The results revealed that there was a significant effect of grade level on students' achievement in favor of 11$^{th}$ grade students and the linear combination of reasoning abilities was significantly related to students' achievement. In the Matter Concept Test, the 10th graders did better than 8th graders and the 11th graders did better than either. The only exception to this general observation was the 8th graders' better performance on a small number of questions, which related to topics that were taught and nationally examined in the 8th grade. It seems likely, therefore, that the more chemistry a student is taught the better he/she is likely to be, except that if a topic is examined while it is reasonably fresh in a student's mind the results are likely to be better than if the test is carried out 2-3 years later. [*Chem. Educ. Res. Pract.,* 2006, **7** (1), 22-31]

**Keywords:** chemical education research, cross-age, reasoning ability, matter, test anxiety

## Introduction

The development of the concept of matter is one of the fundamental aims of chemistry courses. In Turkey, the elementary chemistry curriculum as a part of science course begins with a brief introduction of the matter concept at the age of 12-13. It is expected that the aspects of matter concept progress in a sequence from recognizing states of matter, physical and chemical changes, differentiating pure substances from mixtures, decomposition of compounds, combination of elements and atomic structure models during the course. Then, at the age of 13-14 the students are taught chemical bonding and conservation of mass which underlie the matter concept. For high school students at the age of 14-15, the formal chemistry lessons concentrate on the solubility of gases in water, change in terms of atoms and molecules, separation of components of a mixture, and the structure of matter.

Some cross-age studies have been conducted in which the explanations of how children classify different sets of substances were explored. Lovell (1971) suggested that differentiation between the properties of objects in a set is the first step in the process of classification. This is followed by the differentiation of properties that are specific to an object from those which are common to the set. Generalization of the characteristics that form the sets leads to the development of new concepts. Literature review has shown that schoolchildren from age 11 to 14 develop undifferentiated alternative concepts on ‘object’ and ‘matter’ (Johnson, 1998; Solomonidou & Stavridou, 2000). Students at these early ages could not discriminate the concepts of object from the concepts matter.

Krnel, Glazar & Watson (2003) explored how the ability to recognize a substance in various objects changed with age. The authors focused on two aspects of the criteria used for the classification. The first aspect was whether the classification was based mainly on intensive properties or on a mixture of intensive and extensive properties. The second aspect was the role of action in developing a scheme that leads to differentiation of matter and object. They proposed that one key feature in the early development of the concept of matter is that children learn how to distinguish matter and objects. The differentiation of such interlinked concepts is seen as a key process in the formation of stable scientific concepts. In this process, the authors see the importance of the ability to distinguish between intensive properties that characterize matter and extensive properties that characterize objects. Intensive properties do not change with size, shape, or quantity of objects, and are identical in each part of the object. Therefore, intensive properties characterize the substance of which the object is made. By contrast, extensive properties are changed when objects are divided or the number of objects is changed. A second key feature argued by the authors in the formation of matter concept is that children learn the differentiation of such interlinked concepts by acting upon and observing the natural world. Krnel, Watson & Glazar (2005) conducted a further study in order to investigate the relationship between the formation of object and matter concepts. Consistent with the findings of their previous research, older students preferred to use intrinsic properties of matter to describe the substances, whereas younger students used a mixture of both extensive criteria and intensive criteria to classify substances. It was also indicated that description of objects and substances by their uses, which is also related to intrinsic properties of matter, increased with age. It was attributed to the fact that the relationship between the properties of substances and objects and their use are more emphasized in school at later grades and in everyday life.

In a research study, Novick & Nussbaum (1981) proposed that students’ understanding of basic aspects of matter concept increases as the amount of relevant information presented increases. However, they found that cognitive difficulties raised by certain aspects are real and not overcome by many older students. So, it was suggested that relative difficulty of various aspects of matter concepts should be taken into consideration while preparing curriculum materials. Besides, Stavy (1990) conducted a study to examine the students’ (ages 9-15) conception of changes in the state of matter from liquid or solid to gas, as well as their understanding of the reversibility of the process. The results showed that students who recognized weight conservation in one of the tasks did not necessarily recognize the same in another task. Students thought that gas has no weight, or that gas is lighter than the same material in its liquid or solid state. Until the age of 12, specific perceptual inputs from the task such as color dramatically affected students’ responses to the conservation of weight task.

Lee, Eichinger, Anderson, Berkheimer and Blakeslee (1993) investigated the understanding of the conceptual frameworks that 6$^{th}$ grade students use to explain the nature of matter and molecules. They revealed that students’ initial conceptions differed from scientific concepts in various ways. These differences included molecular conceptions concerning the nature, arrangement and motion of molecules as well as macroscopic conceptions concerning the nature of matter and its physical changes.

In addition, the study carried out by BouJaoude & Giuliano (1994) revealed that there was a significant relationship between students' reasoning ability and chemistry achievement. Apart from these, results of Abraham, Williamson & Westbrook (1994) in their cross-age study found that both reasoning ability and experience with concepts (grade level) account for the understanding of chemistry concepts: chemical change, periodicity, phase change, dissolution of a solid in water, and conservation of atoms. It was found that differences in understanding across grade level were significant for the concept of chemical change, dissolution of a solid, conservation of atoms and periodicity. Results also indicated that the use of particulate terms increase across the grade level. In addition, reasoning ability was found to be a significant factor for students' understanding of conservation of atoms and periodicity. According to Abraham et al. (1994), cross-age studies where students of different ages are simultaneously sampled can provide insight into the role that reasoning ability and instructional exposure play in the students' development of scientific concepts. In fact, cross-age studies provide an opportunity to observe the shifts in concept development that occur as students' mature in intellectual development, and they receive additional instruction. Studies indicated that although children's notions of scientific phenomena change over time, certain alternative conceptions persist from preschool through university.

In recent years, there have been some researches focusing on how cognitive and motivational factors interact and jointly influence student learning and achievement. The researchers suggested that students need both cognitive skills and motivation to do well in school (Pintrich & Schunk, 2002). The integration of motivational and cognitive factors was facilitated by social cognitive models of motivation assuming that students can be motivated in multiple ways. Accordingly, in the discussion of motivation as an academic enabler, test anxiety was one of the aspects of student motivational factors that should be considered (Pintrich & Linnenbrink, 2002). A variety of evidence suggested that high levels of test anxiety caused students to perform poorly on a test. Individuals with high test anxiety believe that their test scores accurately represent their ability levels (Cassady & Johnson, 2001). Therefore, the present study investigated the effect of grade level on students' understanding of concept of matter and five reasoning modes when their test anxiety was controlled.

## Research Questions

The following questions guided the study:

1. Is there an effect of grade level on students' achievement in matter concepts and reasoning abilities, when their test anxiety was controlled?

2. Is there a relationship between students' reasoning abilities and their achievement in matter concepts?

## Method

### *Sample*

The subjects of this study consisted of thirty $8^{th}$ grade students from a randomly selected class of an elementary school, thirty $10^{th}$ grade and thirty $11^{th}$ grade students from two randomly selected classes of a high school in Ankara. The mean age of $8^{th}$ grade students was 14.0 years, that of 10 graders' was 16.2 years, while the mean age of $11^{th}$ graders' was 17.3 years. Schools involved in the study were located in an urban area and students came from families with medium to high socioeconomic status.

***Instruments***

The data collected from students included three kinds: (1) The Matter Concept Test, (2) The Test of Logical Thinking, (3) Motivated Strategies for Learning Questionnaire

*Matter Concept Test (MCT).* The Matter Concept Test was developed by the researchers of the present study. It consisted of 15 multiple choice items related to the solubility of gases in water, heat and temperature, changes of state, solubility and ionization, the effect of temperature on the solubility of gases, diffusion of gases, change of state and expansion, change of state and temperature, solid-liquid equilibrium, effect of pressure on boiling point, boiling point and expansion, conservation of mass, elasticity. The questions were related to real life applications of the topics, and written mainly at comprehension and application levels, according to Bloom's Taxonomy.

Three experts in the field of chemistry education examined an initial version of the test regarding: (a) the adequacy of the chemistry content covered in the test with respect to their developmental appropriateness and relationship to the Turkish curriculum, and (b) appropriateness of the distracters. A pilot study of the Matter Concept Test was conducted in one randomly selected elementary school and one randomly selected high school. A total of eighty-three students were enrolled in the pilot study. The format of 2 questions on the solubility of gases in water and the effect of pressure on boiling point was changed due to their ambiguities. Reliability of the test was found to be 0.70 by calculating internal consistency values using Cronbach's alpha.

*Test of Logical Thinking (TOLT).* The Test of Logical Thinking (TOLT) developed by Tobin & Capie (1981) was used to determine the formal reasoning ability of students. The test consists of ten multiple-choice items designed to measure students' five reasoning abilities; namely, controlling variables, proportional reasoning, probabilistic reasoning, correlational reasoning, and combinatorial reasoning. Students select a response from five possibilities and then they are provided with five justifications from which they choose. The correct answer is the correct choice plus the correct justification. Cronbach's alpha reliability of the test was found to be 0.81.

*Motivated Strategies for Learning Questionnaire (MSLQ).* This is a Likert-type questionnaire developed by Pintrich & DeGroot (1990). MSLQ consists of 22 items and 3 scales, namely self-efficacy, intrinsic value, and test anxiety. Only the test anxiety scale of the questionnaire was used in the current study to measure students' affective or emotional reactions to the tests. Test anxiety is one of the important factors affecting science achievement, so it is assigned as covariate.

***Procedure***

The first author visited one elementary and one high school after receiving the permission for the administration of the tests. The students were informed about the purpose of the study and the procedure for completing the instruments. They were also told that their identity would be kept secret, and the results of the tests would not affect their school grades. Furthermore, the students were required to complete the questionnaire on their own, which took about 50 minutes.

***Statistical Analysis***

The Statistical Package for the Social Sciences (SPSS, version 11.0) was used to analyze data. Means and standard deviations were determined through descriptive statistics to assess participants' reasoning abilities and their achievement on the matter concept test, which were considered as dependent variables. Grade level was regarded as an independent variable. To determine the effect of grade level on students' achievement and their reasoning abilities when test anxiety was controlled, appropriate mean scores were compared by using multivariate analyses of covariance (MANCOVA). MANCOVA is carried out as a procedure to control the effects of an extraneous variable, called a covariate, by partitioning out the variation attributed to this additional variable (Hinkle, Wiersma & Jurs, 1998). Finally, multiple regression analysis was conducted to detect how well the reasoning abilities predicted students' achievement in matter concepts.

## Results

Descriptive statistics concerning 8$^{th}$, 10$^{th}$ and 11$^{th}$ grade students' responses to MCT and TOLT is summarized in Table 1. MCT aimed to measure students' achievement (ACHV) on matter concepts while TOLT scores were used to measure students' five reasoning abilities; namely, controlling variables (CONT), proportional reasoning (PROP), probabilistic reasoning (PROB), correlational reasoning (CORR), and combinatorial reasoning (COMB).

**Table 1.** Descriptive statistics for eighth, tenth and eleventh grade students with respect to achievement and reasoning abilities.

| | 8$^{th}$ Grade | | | 10$^{th}$ Grade | | | 11 Grade | | |
|---|---|---|---|---|---|---|---|---|---|
| | Max | M | S.D. | Max | M | S.D. | Max | M | S.D. |
| ACHV | 12 | 7.97 | 1.77 | 14 | 9.23 | 3.75 | 15 | 11.77 | 1.99 |
| CONT | 2 | 0.37 | 0.56 | 2 | 1.70 | 0.60 | 2 | 1.73 | 0.45 |
| PROP | 2 | 1.67 | 0.55 | 2 | 1.70 | 0.65 | 2 | 1.80 | 0.55 |
| PROB | 2 | 1.27 | 0.78 | 2 | 1.30 | 0.70 | 2 | 1.67 | 0.61 |
| CORR | 2 | 1.80 | 0.41 | 2 | 1.67 | 0.66 | 2 | 1.90 | 0.31 |
| COMB | 2 | 1.50 | 0.63 | 2 | 1.73 | 0.64 | 2 | 1.93 | 0.25 |

Multivariate analysis of covariance evaluates whether means on the dependent variables (students' achievement and reasoning ability subscores) are the same across levels of independent variable (grade level), adjusting for differences on the covariate, which is test anxiety. Thus, multivariate analysis of covariance (MANCOVA) was conducted to determine the effect of grade level on students' achievement and reasoning ability subscores, when their test anxiety was controlled. Results showed that there was a statistically significant effect of grade level on the collective dependent variables when the test anxiety was controlled Wilks' $\Lambda$= 0.270 $F(12, 162)=12.44$, $p<0.001$. The multivariate $\eta^2$ =0.33 indicated that 33 % of multivariate variance of dependent variables was associated with the independent variable.

The univariate ANOVA on each dependent variable were conducted as follow-up tests to the MANOVA. The results revealed that there was a significant effect of grade level on students' achievement, controlling variables, and combinatorial reasoning, $F(2, 86)=16.79$, $p<0.001$; $F(2, 86)=57.68$, $p<0.001$; and $F(2, 86)=3.89$, $p=0.024$, respectively.

Follow-up pair wise comparisons based on simple and repeated contrasts were conducted to evaluate the mean differences between grade levels. Significant differences in the adjusted means between 8$^{th}$ and 11$^{th}$ grade students, and 10$^{th}$ and 11$^{th}$ grade students with respect to achievement were found ($p<0.05$). Moreover, results indicated that there were significant differences in the adjusted means between 8$^{th}$ and 11$^{th}$ grade students, and 8$^{th}$ and 10$^{th}$ grade students with respect to controlling variables ($p<0.05$). Also, there was a significant mean difference between 8$^{th}$ and 11$^{th}$ grade students with respect to combinatorial reasoning ($p<0.05$). Eleventh grade students had the largest adjusted mean while 8$^{th}$ grade students had the smallest adjusted mean on these variables. Adjusted means with respect to dependent variables are presented in Table 2. Therefore, 11$^{th}$ grade students appeared to be the most successful on controlling variables and combinatorial reasoning. In addition, although it was not statistically significant, they had the highest mean subscores on TOLT items measuring other reasoning abilities. Moreover, mean scores indicated that 11$^{th}$ grade students outperformed on MCT.

**Table 2.** Adjusted means with respect to achievement and reasoning abilities.

| | 8$^{th}$ Grade M | 10$^{th}$ Grade M | 11$^{th}$ Grade M |
|---|---|---|---|
| ACHV | 8.37 | 8.96 | 11.63 |
| CONT | 0.40 | 1.68 | 1.72 |
| PROP | 1.64 | 1.72 | 1.81 |
| PROB | 1.27 | 1.30 | 1.66 |
| CORR | 1.81 | 1.66 | 1.90 |
| COMB | 1.54 | 1.71 | 1.92 |

When students' responses to individual items were examined, it was also found that percentage of students who answered items correctly was the highest for 11$^{th}$ grade students for all but 3 items. For example responses to item 6 (see Table 3) showed that percentage of correct responses was 23.3, 66.7, and 80.0 for eighth, tenth, and eleventh grade students respectively. This question was based on a daily life experience concerning a property of water that is independent of sample size. Students were required to infer the reason for the breakage of water pipes in very cold days. To be able to answer this question, students had to be able to use their knowledge on changes in density and volume of freezing water, as well as the relationships among these measures. Eleventh grade students performed best on this item.

Similarly, students' responses to item 11 (see Table 3) revealed that eleventh grade students was the most successful on this item as well and they could better use their knowledge on change of state which is an intensive property of matter. To be able to answer this question students had to know when a matter changes state, mass does not change but the physical properties of matter such as density and volume do.

Item 14 aims to test students' ability to distinguish between intensiveness and extensiveness. Student responses to item 14 reflected an increase in the percentage of correct responses across grade levels. While 53.3 % of eighth grade students answered this item correctly, 93.3 % of eleventh grade students selected the correct answer.

However, for 3 items on solubility and ionization, solid-liquid equilibrium, and electrical conductivity, the situation was reverse: percentage of eighth grade students who answered these items correctly was higher than that of eleventh grade students. For example, 63.3 % of eighth grade students answered the item 4 (see Table 3) correctly while 50.0 % of eleventh grade students gave the correct answer. But, in general, as grade level increased, percentage of correct responses increased.

**Table 3.** Selected items of MCT.

| Example Items | Percentage of Correct Responses | | |
|---|---|---|---|
| | 8th Grade | 10th Grade | 11th Grade |
| Item 4. Under the same conditions, which one of the followings has the poorest electrical conductivity?<br>A. Mercury (at room temperature)<br>B. liquid sodium chloride<br>C. vinegar<br>D. cologne<br>E. soap water | 63.3 | 58.2 | 50.0 |
| Item 6. In very cold days during winter, when water in the water pipes freezes, the pipes break. Which of the following conclusions can be drawn from this information?<br>I. when water freezes, its mass increases<br>II. density of ice is less than that of water<br>III. when water freezes, the distance between water molecules increases<br>A. I-II B. I-III C. II-III D. only III E. I-II-III | 23.3 | 66.7 | 80.0 |
| Item 11. A closed jar with ice cubes in it has been placed on a scale. What will happen when ice cubes melt?<br>A. needle of scale will deflect to left<br>B. needle of scale will deflect to right<br>C. volume of water will be higher than that of ice<br>D. temperature will be below $O^0C$<br>E. temperature of the jar will increase | 44.2 | 64.3 | 78.4 |
| Item 14: Which one of the followings increases if the mass of a pure substance increases under constant temperature and pressure?<br>I. number of molecules per unit volume<br>II. total number of molecules<br>III. volume<br>A. only I B. only II C. only III D. II-III E. I-II-III | 53.3 | 79.2 | 93.3 |

A Multiple Regression Analysis was conducted to evaluate how well the reasoning abilities predicted students' achievement in matter concepts. The linear combination of reasoning abilities was significantly related to students' achievement $F(5, 84)=2.83$, $p=0.021$. The sample correlation coefficient was 0.38, indicating that approximately 14 % of variance of the achievement scores can be accounted for by the linear combination of reasoning abilities. The results of multiple regression analysis are displayed in Table 4. According to Table 4, there was a statistically significant positive relationship between controlling variables and achievement scores. However, the coefficients were not statistically significant for other reasoning abilities, indicating that these variables do not contribute significantly to the model being considered.

**Table 4.** The results of multiple regression analysis.

| | Beta | T | *p* |
|---|---|---|---|
| CONT | 0.280 | 2.679 | 0.009 |
| PROP | 0.003 | 0.026 | 0.979 |
| PROB | 0.048 | 0.457 | 0.649 |
| CORR | 0.002 | 0.014 | 0.989 |
| COMB | 0.215 | 1.969 | 0.052 |

## Discussion

The key aspect of matter is the appreciation that it is the general term for the material things around us; it is defined as whatever occupies space and can be perceived by our senses. Liu & Lesniak (2004) proposed that matter is a fundamental domain concept in chemistry, since chemistry is a science of matter and its transformations. The progression of students' conceptions of matter determines their mastery of principles and theories of physical and chemical changes. In other words, the students are expected to acquire a satisfactory understanding of physical and chemical changes, changes of state, as well as solubility and ionization to comprehend the processes of matter and the particulate model.

The results of the present study revealed that there was a significant effect of grade level on students' achievement. $11^{th}$ grade students had the highest mean score on the test indicating higher achievement, while $8^{th}$ grade students had the lowest score. At this point it should be noted that students' cognitive level may have influence on students' achievement in matter concept. The development of a concept is subject to maturation levels. There is a developmental process in the formation of a concept, parallel to cognitive development. When a word has been learned by the child, its development is barely starting; the word at first is a generalization of the most primitive type; as the child's intellect develops, it is replaced by generalizations of a higher type which lead to the formation of true concepts (Vygotsky, 1986).

Intellectual development influences children's understanding of scientific concepts. Krnel, Glazar & Watson (2003) proposed that as the cognitive level of students increases, their success on the concept test increases. The researchers pointed out that as students grow older and have more experience of the world, they shift from using mixed criteria (extensive and intensive) for classifying objects and substances, to using mainly intensive criteria. As they gain more experience, their focus shifts from the extensive properties of objects which may change from object to object. Therefore, they become aware of intrinsic properties of matter such as color, and state of matter, that are independent of the form in which matter is presented.

The results of the present study are consistent with the findings of the study by Krnel et al. (2003). The Matter Concept Test administered in the present study consisted of examples from daily life as well as some items measuring students' achievement on matter concept emphasized in science courses. It was found that higher grade level students had a better construction of matter concept by means of their experience on the world. Furthermore, student responses indicated that as the grade level increases, their ability to distinguish between intensive properties that characterize matter and extensive properties that characterize objects. This differentiation is seen as a key process to construct stable and scientific concepts.

Another study by Stavy (1990) showed that very young children understand what the weight of an object is and know that a large body of a certain material is heavier than a smaller body of the same material. However, when children were asked about density which is an intensive property of matter, they responded as if they had been asked about weight, which is an extensive property of matter. These terms are not sufficiently well defined in the child's mind and as long as they are not consciously differentiated the child can be affected by them according to the situation. Consistent with the research results of Stavy (1990), the explanation of state of matter according to the arrangement of these particles has not appeared in early grade level students. The children adapt the particle theory to their own conception according to which solids weigh more than gases. The particulate theory is not internalized, and most of the students do not acquire a satisfactory understanding of this theory although this topic is emphasized at school.

Besides, the Matter Concept Test used in the current study required students to construct a coherent body of scientific knowledge instead of just memorizing facts and definitions. Therefore, it was expected that students who learned matter concepts meaningfully, identifying real life applications of what they know, and relationships among the concepts such as density, volume, and mass, get higher scores on the test. However, apart from students' cognitive level, the amount of relevant information presented, the way of its presentation, and students' prior knowledge may have influence on their understanding. For instance, Novick & Nussbaum (1981) proposed that as the amount of relevant information presented to students increases, their understanding of basic aspects of matter concepts increases. Older students spent more hours in chemistry course per week in school.

It should be also taken into consideration that 11$^{th}$ grade students in Turkey prepare for the university entrance examination consisting of questions, most of which deal with the matter concept. Furthermore, the results showed that 8$^{th}$ grade students have a better understanding on solubility and ionization, solid-liquid equilibrium and electrical conductivity. Eighth grade students also take a national examination focusing mainly on solubility and ionization, solid-liquid equilibrium, electrical conductivity. These topics are extensively practised during the instruction in that grade to meet the requirements of the examinations.

In this study the role of reasoning ability in student achievement was considered as well as cognition. Recent researches have provided evidence that formal reasoning ability is a significant predictor of academic success in chemistry concepts (BouJaoude & Giuliano, 1994). Consistent with this research finding, the linear combination of reasoning abilities was significantly related to students' achievement. Both reasoning ability and experience with concepts account for the understanding of chemistry concepts. Eleventh grade students appeared to be the most successful in controlling variables and combinatorial reasoning. In addition, although it was not statistically significant, they had the highest mean scores on TOLT items measuring other reasoning abilities. The limited quality of reasoning ability found in younger students could influence their achievement in MCT.

To develop the formation of the matter concept for early grade students, appropriate curriculum materials and instructional strategies should be utilized (Abraham et al., 1994). In this study, achievement scores in MCT were positively correlated with controlling variables. However, the results indicated that other reasoning abilities were not significant determinants of academic success. Other cognitive factors such as prior knowledge may play a more important role than proportional, probabilistic, correlational, and combinatorial reasoning in explaining the observed difference in student performance. Also, factors such as home and school environment, peer and teacher influences, socio-economic variations, family demands, and other student characteristics such as attitudes, interests, and motivational beliefs may account more in explaining the variations among student performance for the population of interest.

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# High school students' understanding of titrations and related acid-base phenomena

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**Abstract:** Acid-base titrations are common laboratory activities carried out in high school chemistry courses. Using a series of qualitative and computer-based tasks, this study examined sixteen American students' understanding of titrations. The findings indicated that students had considerable difficulty with acid-base chemistry, were unable to describe accurately acid-base concepts, such as pH, neutralization, strength, and the theoretical descriptions of acids and bases. Further, most students could not relate the concepts to actual solutions. Student difficulties stemmed from a lack of understanding of some underlying chemistry, such as the nature of chemical change and the particulate nature of matter. A number of factors were identified as contributing to these difficulties, including the overstuffed nature of introductory chemistry itself, the emphasis during instruction on solving numerical problems, and the dominant role played by the textbook. The conceptual density of acid-base chemistry, the confusing nature of acid-base terminology and the lack of agreement about what material should be included in the chemistry curriculum were identified as being problematic. [*Chem. Educ. Res. Pract.*, 2006, **7** (1), 32-45]

**Keywords:** Acid-base models, titration, pH, neutralization, student conceptions

## Introduction

Acid-base titrations are common experiments carried out by students in introductory chemistry classes. The topic has been a regular component of introductory chemistry curricula for decades, and receives wide coverage in introductory texts and related laboratory manuals (Dorin, 1987; Wilbraham et al., 1996; Dingrando et al., 2002). The most frequently conducted titrations involve the neutralization of strong acids with strong bases, with students being required to calculate the concentration of unknowns using this method. Some introductory texts (Dingrando et al., 2002) extend the topic to include details of titration curves. *A framework for high school science education* (Aldridge, 1996) suggested that students in grade 11 should be able to use the pH scale to investigate changes in pH that occur during titrations. The treatment of titration curves in introductory chemistry classes is usually non-mathematical, and they are most often included as a means of determining the most appropriate indicators to use in particular titrations.

That students have difficulty learning chemistry has been well documented (Gabel and Bunce, 1994), and has been attributed to a variety of factors such as, the abstractness of the subject (Herron, 1975), the complexity of the calculations involved, the remoteness of the language used (Glassman, 1967) and the different representational levels that chemists use

(Gabel, et al., 1987; Nakhleh and Kracjik, 1994). These difficulties carry into all areas of chemistry and an increasing number of studies have focused on student difficulties with the concepts of acid-base chemistry. The causes of student difficulties with acid-base chemistry have been ascribed to the existence of many alternative conceptions or misconceptions (Hand and Treagust, 1988; Hand, 1989; Schmidt, 1997; Sheppard, 1997; Demerouti et al., 2004; Demircioglu, 2005), a poor understanding of the particulate nature of matter (Nakhleh and Kracjik, 1993; Nakhleh, 1994; Smith and Metz, 1996), difficulties with the use of different models used in acid–base chemistry (Carr, 1984; Schmidt, 1995; Vidyapati and Seetharamappa, 1995; Sheppard, 1997; Furio-Mas et al., 2005; Kousathana, et al., 2005) and confusion between acid–base terminology and everyday words (Schmidt, 1991, 1995).

Some of the previous research has focused on particular acid-base concepts such as neutralization and pH. Cros et al. (1986, 1988) noted that college students tended to retain a descriptive definition of pH despite instruction that emphasized its more quantitative aspects. Ross and Munby (1991) noted that high school students demonstrated a good qualitative understanding of pH, while in contrast, Nakhleh (1990), in a more in-depth study, noted that high school students had relatively poor qualitative understanding of pH. Schmidt (1995) reported that students consider the products of neutralization reactions to always have a pH of 7 and he described neutralization as a 'hidden persuader'. Given these reported issues, it seems likely that students will have difficulty with understanding what is happening to the values of pH during a titration. This study documents high school chemistry students' attempts to explain what is happening during a titration and focuses on students' understanding of several related acid-base concepts such as acid, base, neutralization, pH, along with the use of various acid-base models.

## Method

### *Subjects*

Sixteen students from three introductory high school chemistry classes were interviewed for the study. All students were either 16 or 17 years old and were in grades 10 or 11. The students attended a school in the North-Eastern United States, and followed their state chemistry curriculum. As is the common practice in the USA, introductory chemistry is taught as a single-year course usually in the $10^{th}$ or $11^{th}$ grade (Sheppard and Robbins, 2005). A small fraction of students complete a second year of chemistry, though such courses are invariably college level courses and involve a detailed mathematical treatment of acid-base equilibria. The students in this study had all successfully completed biology in the year before taking chemistry. They were taught by the same chemistry teacher, and received a traditional lecture-based instruction with a weekly double period of laboratory work. The introductory chemistry curriculum required students to be familiar with both the Arrhenius and Brønsted-Lowry acid-base models, though not the Lewis model, with examination questions being set that required students to distinguish between acids and bases from both perspectives. As part of their chemistry instruction the students had carried out two acid-base titrations while completing their unit on acids and bases.

### *Procedure*

The study used a variety of qualitative research techniques to determine students' understanding of acid-base ideas. In 'interview about events' techniques students are questioned about their understanding of events or phenomena using practical situations. Students are then questioned about the phenomena and are asked to explain it. The technique has been used extensively in science education research (Osborne and Cosgrove, 1983). The ‘Prediction-Observation-Explanation’ or POE technique, probes understanding using three separate, but related tasks (White and Gunstone, 1992). Given a situation or event, such as the effect of bases on indicators, students are asked first to predict the outcome of the event and to give an account for their reasoning. Next, they perform the task and make observations, before finally explaining the outcome and reconciling any differences between their predictions and the actual outcome of the event. The technique is particularly useful for eliciting students’ ideas, and is used to measure their ability to apply knowledge. That students hold ideas about phenomena and use these ideas to determine what observations to make, highlights the theory dependent nature of POEs (Gunstone and Champagne, 1990). The POE technique has also been used successfully in a number of studies (see for example, Woods and Thorley, 1993) . The technique is straightforward and students often react positively, though it is important that students should commit themselves to a prediction before performing a task. Reconciling discrepancies between predictions and the outcome of the tasks can be difficult for many students (White and Gunstone, 1992). The third technique uses drawings, which allow students to show understanding that may be hidden from other procedures. For instance, students’ drawings of solutions can reveal more information about their views on the particulate nature of matter, the role and nature of the solute and solvent than could be obtained from verbal or written data (Nakhleh, 1994). In the procedure, students are asked to draw what they see or think that they will see in a given event. The technique may be applied to macroscopic objects or to non-visible objects such as atoms and ions, where its use is particularly powerful. The technique has been used in a number of studies (Yarroch, 1985; Ben Zvi, et al., 1987; Lythcott, 1990; Nakhleh et al., 2005).

**Table 1.** Interview tasks.

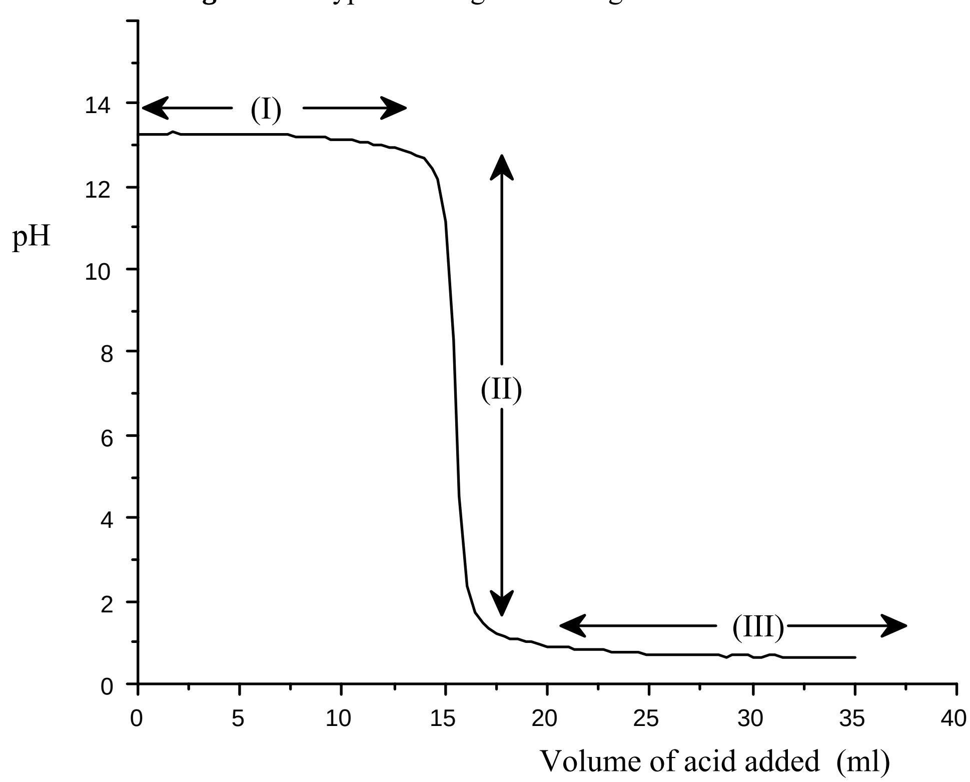
| Task | Activity | Purpose/Rationale |
|---|---|---|
| 1. Introductory pH event | Students were shown beakers with colorless solutions marked ‘pH 3’,’pH 5’ and ‘pH 11’, and were asked to explain their sub-microscopic composition using drawings. | Elicit ideas about pH, concentration, strength, acid and base. |
| 2. Neutralization | A small amount of acid was mixed with an equal amount of base,<br>a) with no indicator present,<br>b) with phenolphthalein indicator present. | Elicit ideas about acid-base reactions, neutralization and pH. |
| 3. Questions about the models | Using the descriptions from the two previous tasks, students were asked to explain their understanding of pH and neutralization and the different acid-base models. | To determine which theoretical description the students utilized. To show how the various concepts were inter-related, and as a template for further questioning. |
| 4. Acid-base titration | A titration was conducted using a pH electrode interfaced to a computer. Students were asked to predict and explain what would happen to the pH as the titration was conducted. After the titration, the students were asked to account for differences between their predictions and the outcome. | To determine students’ ideas about pH, acid, base, neutralization, and to determine which theoretical perspective the students would use when explaining the titration curve. |

The tasks used in this study are outlined in Table 1 and were designed to provide an overlap of the concepts in different contexts to provide triangulation of the data. For example, the students' ideas about pH and the representations they used to describe acids and bases were elicited from all tasks. The tasks were completed outside the classroom, in two sessions with Tasks 1, 2 and 3 (Interview-about-events and drawings) carried out together, while Task 4 (POE and drawings) was completed approximately one week later. The interviews lasted approximately 30 minutes each. Data collected from the first set of tasks were used to direct questions in the second interview. Students' responses were audio-taped and transcribed, and a number of drawings and predictions were elicited. Profiles for each student were then compiled that detailed each student's ideas about the acid-base concepts.

In Task 4 (POE and drawings techniques) a pH curve was produced by titrating 15mL of 0.1 M NaOH with 0.1 M HCl. The pH changes during the titration were monitored using a pH electrode interfaced to a computer, with the titration curve being produced in real time on the computer screen as a function of volume of acid added. While all the students had completed a unit on acids and bases and had performed titrations using indicators, they had not performed a titration in which pH changes were monitored. In Task 4, the students were required to sketch the shape of the pH curve they expected to obtain, and to explain, using their knowledge of acid-base chemistry, the reasoning behind their predictions. After making their predictions, the titration was run, and the students were asked to describe aloud what was happening. The students were then asked to compare their predictions with the actual curve, and to try to account for any differences.

A typical strong acid-strong base titration curve is shown in Figure 1. The curve has been split into three parts. The students were asked to describe and explain what they thought was happening in each of these sections.

**Figure 1.** A typical strong acid/strong base titration curve.



## Results and discussion

### *Student ideas about pH in tasks 1-3*

An overview of students' ideas about qualitative and quantitative aspects of the term 'pH' is shown in Table 2. Students were all familiar with the term pH, though three maintained the view that pH applied only to acids. Only one student was not fully familiar with the numerical pH values associated with acids, bases and neutral substances. The most common description of pH was that it either measured the 'strength' of an acid or base or the amount of acid or base present. In each case the students described strength as how powerful or reactive a substance was. All students described the pH scale as inverse, with more acidic solutions having lower values, but few students understood the logarithmic nature of pH.

**Table 2.** Summary of students' ideas about pH.

| Aspect | Number of Students |
|---|---|
| Familiarity with the term '*pH*' | 16 |
| Qualitative aspects of pH: | |
| • Distinguishes acids and bases | 13 |
| • Measures acidity only | 3 |
| • Measures 'strength' | 6 |
| • Involves ions | 4 |
| • Indicator changed color at pH 7 | 14 |
| Quantitative aspects of pH: | |
| • Numerical values given | 15 |
| • Inverse nature of scale | 5 |
| • Logarithmic nature of pH | 6 |
| Numerical definition of pH: | |
| • Defined as –log [$H^+$ ] | 2 |
| • Includes concentration term | 4 |
| • Includes logarithm term | 3 |
| • Includes amount of acid | 1 |

Several students gave quantitative descriptions of pH, with four students associating it with concentration and six describing it as logarithmic. However, only two students defined pH as pH = –log [$H^+$ ] and only one of these was able to explain correctly the hundred fold difference in $H^+$ concentration between the pH 3 and pH 5 solutions, despite all students having had instruction that had emphasized the use of the equation, including several simple calculations of pH values from $H^+$ concentrations. For most students pH was a linear scale and they applied this logic to answer questions that related pH to other acid-base phenomena, such as neutralization. Only four students mentioned ions in their descriptions of pH and all the students had considerable difficulty explaining how the pH values related to the actual substances in terms of the particles present. The profiles of the individual students showed that there was little consistency between student ideas with respect to the quantitative and numerical aspects of pH and their qualitative ideas.

Another interesting feature was that all the students in Task 2 suggested that the indicator would change color when the solution became neutral. For many of the students all indicators changed color at the same pH value and this was invariably at pH 7.

So why is pH so poorly understood? Kolb (1978, 1979) described the potential pitfalls to learning about pH as being due to the inverse and logarithmic nature of the scale. Hawkes (1994) has argued that texts and teachers are misleading or inaccurate in their presentation of the concept of pH in that they fail to describe the approximate nature of the scale by omitting descriptions of the activity of the hydrogen ion. Introductory chemistry texts tend to concentrate on the solution of numerical problems rather than on understanding the concept of pH. This, Hawkes suggests, leads to numerical answers to pH calculations that differ substantially from experimental reality. The treatment of pH by texts is also unsympathetic to any difficulties that students might have with the concept. For example, in the teacher's edition of the Wilbraham et al. chemistry text (1996), teachers are advised that, "*For students who have no concept of logarithms, explain that pH is found by taking the negative of the power (exponent) of the hydrogen ion concentration and expressing it as a whole number*." (p. 541) Students, who have no concept of logarithm, can have no adequate conception of pH at this level. The Wilbraham text contains the implicit assumption that telling somehow equals knowing or understanding, a belief that permeates much introductory chemistry.

The findings of the present study confirm this. Though several students defined pH as being "–log $[H^+]$" or were able to determine correctly the relationship between pH values and the hydrogen ion concentration of a solution, only one student could relate the concept of pH accurately to an actual solution. That students can perform numerical calculations in chemistry, without the requisite conceptual understanding has been widely described in the literature (see for instance, Nurrenbern and Pickering, 1987; Lythcott, 1990; Sawrey, 1990) and this seems to be the case with pH.

The findings of this study show that students do not generally understand that pH: 1) is a measure of concentration; 2) is not a measure of 'strength' nor of 'powerfulness'; and 3) is a logarithmic, not a linear scale. This, of course, has important implications for teachers, textbook writers and chemistry curriculum developers.

***Student ideas about neutralization from tasks 1-3***

Students in the study were all familiar with the term '*neutralization'* and all described it as some form of interaction between an acid and a base. Two students believed that acids were inherently more 'powerful' than bases and would have a greater influence in the process. Most students suggested that substances with pH values of 7 were neutral. Six students described the process of neutralization as the physical mixing of an acid with a base and named no products, drew no equations, and represented the process diagrammatically with unreacted chemical species. Ten students labeled neutralization as a chemical reaction, six gave considerable detail, identifying the reacting species, naming the products as water and salt, and explaining it as a chemical interaction symbolically in equations. Three students described the formation of new products by the addition of an acid species to a base species, but did not identify the products, nor could they represent the process with an equation. Their representations of sub-microscopic events simply showed base particles attached to acid particles. A summary of the students' ideas about neutralization is shown in Table 3.

**Table 3.** Summary of students' ideas about neutralization.

| Aspect | Number of Students |
|---|---|
| Familiarity with the term '*neutralization'* | 16 |
| Substances with pH 7 are neutral | 15 |
| Neutralization as interaction between acid + base | 16 |
| Interaction as | |
| • Physical mixing | 6 |
| • Chemical reaction | 10 |
| Interaction between | |
| • Unspecified chemicals/molecules | 10 |
| • Ions or charged particles | 5 |
| • Hydrogen/hydroxide particles | 5 |
| Products of neutralization | |
| Acidic product | 2 |
| Neutral product | 13 |
| Conditions for neutral product | |
| • Equal amounts of acid and base | 9 |
| • Equal 'strength' of acid and base | 3 |
| • Equal 'concentration' of acid and base | 1 |

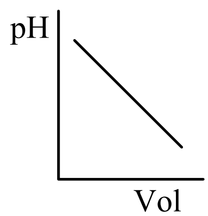
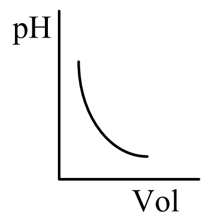
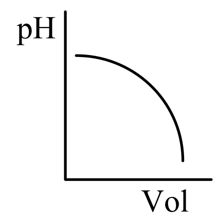
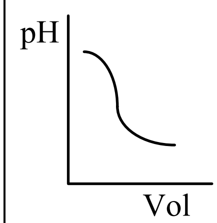
Several studies have highlighted the difficulties that students have with the concept of chemical change (Andersson, 1986, 1990; Hesse and Anderson, 1992). The Andersson studies classified student explanations of chemical change into five categories: a) its just like that; b) displacement, in which the products are displaced reactants, for example two substances simply mixed; c) modification, in which the products are modified forms of the reactants, for example sawdust made from wood; d) transmutation, in which an entirely new substance is formed, for example gold from lead; and e) chemical interaction, which is the scientifically accepted view. Student descriptions of neutralization all fell into categories of the Andersson classification scheme, with majority falling into the displacement and modification categories.

Many students described neutralization as a simple mixing of acid and base, with no interaction between the particles, and with the neutrality of the product being determined by the relative numbers of particles. From this perspective, the product of a neutralization reaction still contained the acid particles that had not interacted, corresponding to a displacement view of chemical reactions. Other students described neutralization as a process of dominance of acids over bases. The acids, being inherently more powerful than bases, simply dominated the bases. Few students described neutralization as a chemical interaction. All these findings have important implications, as even after instruction students do not understand some fundamental ideas about neutralization and chemical change, despite being familiar with much of the related terminology. Clearly, given student difficulties with such fundamental ideas, it would be interesting to examine what they thought was happening during a titration.

***Student predictions of pH changes during a titration: task 4***

The predictions made by the students about the pH changes during a titration are shown in Table 4 and their responses were categorized into four general shapes: concave, convex, linear and S-shaped.

**Table 4.** Student predictions of the titration curve.

| Shape | Linear | Concave | Convex | Step |
|---|---|---|---|---|
| Prediction |  |  |  |  |
| Number of students | 8 | 4 | 2 | 2 |
| Variations | 2 students:<br>pH stopped at 7.<br>1 student:<br>pH went level at 1. | | 1 student drew 2 lines | |

All students predicted that the addition of acid would cause the pH to fall, with the majority of the students predicting an immediate and rapid decline in pH. The reasons given were generally that as acids have low pH values and bases have high pH values, adding an acid would naturally lower the pH value. For example, one student who predicted a linear decline as the acid was added

**Student:** *"... it's forming an acid... bases have a higher number and acids have a lower number, so the pH value will fall..."*
**Interviewer:** "*So what do you think the pH is measuring?*"
**Student:** *"... the amount of acid present..."*
**Interviewer** : *"Could you draw what you would expect to be in the container when, say, 10 mL of acid have been added to the 15 mL of base?"*
**Student:** *"... I'll try (draws un-reacted $H^+$ and $OH^-$ ions)"*

This was a typical response. Of the students who predicted an S-shaped curve, one student simply recalled the shape from reading the textbook and was unable to explain the shape. Only one student gave an acceptable explanation for the S-shape.

***Student explanations for the pH changes during the titration***

After making their predictions the titration was carried out. Student explanations for the shapes of sections I-III of the titration curve revealed important non-scientific alternative ideas about neutralization, pH and the nature of chemical reactions and are summarized in Table 5.

**Table 5.** Student explanations of the sections of the titration curve.

| Explanation | Number of Students |
|---|---|
| Section I | |
| Approximately level section of curve due to: | |
| • no reaction | 4 |
| • reaction not yet started | 7 |
| • base dominating acid | 1 |
| • base particles outnumber acid particles | 1 |
| • immediate reaction leaving excess $OH^-$ ions | 3 |
| Section II | |
| Sudden change in pH due to: | |
| • reaction suddenly occurring | 5 |
| • acid dominating | 2 |
| • acid particles outnumbering base particles | 4 |
| • $[OH^-] \approx [H^+]$, adding acid causes large changes in $[H^+]$ | 3 |
| • no explanation | 2 |
| • indicator would change color at pH 7 | 11 |
| • indicator would change color at pH less than 3 | 4 |
| Section III | |
| Approximately level section of curve due to: | |
| • reaction has finished | 4 |
| • acid dominates | 1 |
| • acid particles outnumber base particles | 8 |
| • $[H^+] \gg [OH^-]$ | 3 |

In Section I, most students were very surprised to see that the pH value remained approximately constant as the acid was added and several questioned whether the equipment was functioning properly. To account for the non-changing value of pH about half of the students explained that despite the acid having been added, the reaction had not yet started. A further quarter of the students suggested that no reaction was occurring. One student considered the neutralization to be a battle of dominance between the acid and base, while another described the pH as constant due to there being more base particles present than acid particles. Only three students suggested that the acid and base were actually reacting during the first part of the titration.

The sudden drop in pH value near the endpoint in Section II drew audible gasps of surprise from many students. To account for the sudden drop in pH, approximately one third of the students described the reaction as suddenly starting to occur. One quarter of the students described the acid particles as outnumbering the base, while two students suggested that the acid was simply dominating the base. Only three students correctly explained that the concentrations of acid and base were approximately equal, so that on adding more acid, there would be a large change in $[H^+]$ and consequently in pH. Only one student invoked the logarithmic nature of pH to explain dramatic change in pH. When asked about where the indicator would change color the common answer was at pH 7 though a quarter of the students thought that it would not change until the solution had become acidic i.e. in section III of the graph.

Half the students described the leveling of the pH in Section III, as resulting from an excess of acid particles, and each of these students described a physical mixing of acid with base and not a chemical reaction. A further quarter of the students described the reaction as being finished. Only three students described an increased concentration of $H^+$ ions resulting from the reaction and the removal of virtually all the $OH^-$ ions.

Overall, seven students described a time-dependent nature for the interaction of an acid with a base to account for the shape of the curve, while five students described the process as being due to one type of particle outnumbering another with no interaction. Two students described a dominance effect with the acid being inherently "stronger" than the base and only two students described a chemical reaction that removed the $OH^-$ ions and left an excess of $H^+$ ions.

The students' ideas about neutralization and chemical change described in the Task 4 titration were different from those described in the previous tasks, and they appear to have been spontaneous attempts to explain what was for them a discrepant event. These inventions indicate a lack of coherent understanding of the nature of chemical interactions, neutralization and pH. Notably, the use of computers interfaced to pH probes, generally known as microcomputer-based labs (MBLs) provided an efficient tool for probing students' understanding of neutralization and pH. Previous research with MBLs has largely focused on investigating their use in instructional settings. This research suggests that MBLs, with their real time display of results and almost immediate feedback, when used with prediction - observation - explanation (POE) techniques, can provide a powerful tool for probing student conceptual understanding of a variety of topics. Student understanding of other areas of chemistry could be similarly investigated.

## Conclusions and implications

The topic of acids and bases is conceptually dense and requires an integrated understanding of many areas of introductory chemistry, such as the particulate nature of matter, molecular kinetic theory, the nature and composition of solutions, atomic structure, ionization, ionic and covalent bonding, symbols, formulae and equations, equilibria and collision theory. This study has indicated that, when conducting a titration, students' conceptual knowledge of acids and bases lacks both coherency and predictive accuracy and that many students have considerable difficulty understanding the underlying chemistry.

A contributing factor to the conceptual density of the topic, and consequently to well-documented student difficulties, is the tendency of introductory texts to be inclusive of all acid-base phenomena rather than being selective (Carr, 1984; Drechsler and Schmidt, 2005; Furio-Mas et al., 2005). Students are typically presented with an account of the properties or operational definitions of acids and bases, followed by the conceptual definitions, acid-base strength, neutralization, titrations, pH, indicators, acid-base equilibrium and buffers. Included in this coverage is a significant amount of complicated, confusing and sometimes conflicting terminology (Schmidt, 1997; Drechsler and Schmidt, 2005) and large numbers of numerical problems. Zumdahl (1990), for instance, has condensed the material into one chapter of 30 pages, while Dorin (1987), takes three chapters and 67 pages for the same material. In both cases, the 'coverage' is encyclopedic in nature

Analyzing the presentation of acids and bases in textbooks, de Vos and Pilot (2002) portrayed a complex and multi-layered topic that, like many areas of chemistry, resulted from the historical development of the content itself. In their analysis they noted that acid-base chemistry contained material from six different layers or contexts and that much of the reason for the conceptual complexity of acid-base chemistry was that the different layers had simply been added to previous layers without any restructuring of the content. In the USA, the topic of acids and bases is typically allocated three weeks of time in introductory chemistry and is studied towards the end of the academic year, (see for example, Nakhleh, 1990), as it requires the prior 'coverage' of many related topics.

Further increasing the conceptual density of the topic are the ways that various models of acid-base chemistry are introduced. Following their historical development, the Arrhenius model is presented first, then Brønsted-Lowry and finally, though not in as much detail, the Lewis model. The issue of which acid-base models to include in introductory chemistry has long been controversial and debate about which models to introduce at which level of chemistry has been ongoing since they were introduced in the 1920s and is still a contentious issue (see for instance, Hall, 1930; Briscoe, 1940; Johnson, 1940; Alyea, 1941; Luder, 1948; Logan, 1949; DeFord, 1950; Devor, 1954; Carr, 1984; Kaufmann, 1988; Hawkes, 1992; Rayner-Canham, 1994). Proponents of the Arrhenius model note that it is simple (Johnson, 1940), that it accounts for most acid-base phenomena encountered in introductory chemistry (Hall, 1940), and that it should be included in introductory courses for historical reasons (Briscoe, 1940). Proponents of the Brønsted-Lowry model note that the Arrhenius model is very limited (Hammett, 1940; Hawkes, 1992), especially for bases, only applies to aqueous solutions (Naiman, 1948) and that the Brønsted-Lowry theory is useful for explaining other areas of science such as respiration (Devor, 1954). Proponents of the Lewis theory note its more generalized approach, but few advocate its use in introductory chemistry (Luder et al., 1943; Drago, 1974).

Ausubel noted that "*the best way to organize information after it is understood is not always the best way to organize it so that it will be understood in the first place*" (quoted in Bodner, 1992; p 189) and curriculum writers, teachers and textbook writers should heed this advice. It suggests that instructional materials that build on what students already know, rather than on the encyclopedic coverage of what scientists have discovered will be more fruitful. Given the amount of material typically included in the unit on acid-base chemistry, coupled with the inadequate time allocated to the topic almost guarantees a transmission/reception style mode of instruction with an emphasis on 'covering' information in lectures.

A recommendation from this study is that curriculum developers, textbook writers and teachers heed the calls from science education researchers to reduce the quantity of material in introductory chemistry, particularly in the area of acid-base chemistry. The sheer quantity of material introduced; the short time in which it is introduced; the convoluted and vague terminology used to describe acid-base phenomena coupled with the need to relate the material to what students already know, inevitably leads to superficial, short-term learning with little conceptual understanding. Acid-base chemistry provides a wealth of valuable information about the nature of the discipline of chemistry and how chemical ideas develop and progress historically and as such it should be a springboard and not a barrier to further learning.

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# Textbook inflation: thirty-five years of Brown's general chemistry textbook

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**Abstract**: Today's general chemistry textbooks have grown to considerable size and cost, with a dazzling array of photos, illustrations, tables, insets and worked problems that compete for attention with the actual text. This letter examines the evolution of one particular textbook – Brown, LeMay, Bursten, and Burdge's '*Chemistry: the central science*' – and raises some questions about the current state of the general chemistry textbook. [*Chem. Educ. Res. Pract.*, 2006, **7** (1), 46-48]

**Keywords:** First-year undergraduate/general, textbooks/reference books

When I started as an undergraduate at Cumberland College, I used Brown and LeMay's *Chemistry: the central science*, 3rd edition. I thought the book had a good balance of written material and illustrations, was of a manageable size at well under 2 kg, and was reasonably priced at around $50 dollars (if memory serves). The most recent edition of this book has swelled to over 1152 pages, weighs around 2.5 kg, and costs around $140. This 'elephantiasis' of the general chemistry textbook (Cohen, 1986) has also occurred with the organic chemistry textbook (Kerber, 1988). Previous articles have examined the evolution of textbooks from 1789 to 1939 (Kaufmann, 2002) and during the 20th Century (Bailar, 1993). Here, I want to look at the evolution of one particular textbook and raise some questions about these developments.

Table 1 presents some details about the various editions, chosen because they were the ones on my shelves. Note that the first book listed is not part of the series. It is included for two reasons: it was published the year I was born, and it serves as a good reference point for the edition that I used and its successors. Notice that the 1968 text has only 688 pages, weighs just over a kg, and each chapter is of the order of 20 pages (all the books listed have about 25 chapters). I focused specifically on the 'Electronic structure of atoms' and 'Chemical kinetics' chapters because these had the same title throughout all the editions.

As the years progress, a new edition appears every three years. Do we really need a new edition so often when we have only just become accustomed to the last one? The number of pages per figure shrinks from about 2.5 pages/figure in the 1968 edition to as low as 1.4 pages/figure in the 2003 edition. One chapter has increased to 50 pages with 29 figures (Chapter 14, 2000 edition). Given the fact that the number of class hours devoted to a general chemistry course, and particularly to a given chapter, is probably about the same as 20 years ago, is all this material really necessary?

**Table 1.** Features from Brown's general chemistry textbooks.

| *Title, Author(s)* | *Edition, year* | *Total pages* | *Dimensions (cm.), weight (kg)*[a] | *Illustrations, photos, ancillaries* | *Electronic structure of atoms* | *Chemical kinetics* |
|---|---|---|---|---|---|---|
| *General Chemistry*[b] Theodore L. Brown | 2nd 1968 | 688 | 24×18×3 1.1 | gray, brown, no photos | Ch. 6 6 figs. 15 pages | Ch. 13 9 figs. 24 pages |
| *Chemistry: The Central Science* Theodore L. Brown H. Eugene LeMay Jr. | 3rd 1985 | 942 | 26×20×5 1.8 | gray, blue, b/w & a few color photos | Ch. 5 19 figs. 25 pages | Ch. 13 15 figs. 34 pages |
| *Chemistry: The Central Science* Theodore L. Brown H. Eugene LeMay Jr. Bruce E. Bursten | 5th 1991 | 1118 | 26×21×5 1.8 | multicolor illustrations, all color photos, software, video | Ch. 6 32 figs. 44 pages | Ch. 14 21 figs. 41 pages |
| *Chemistry: The Central Science* Theodore L. Brown H. Eugene LeMay Jr. Bruce E. Bursten | 6th 1994 | 1112 | 26×21×4 1.8 | multicolor illustrations, all color photos, laserdisc | Ch. 6 28 figs. 41 pages | Ch. 14 22 figs. 46 pages |
| *Chemistry: The Central Science* Theodore L. Brown H. Eugene LeMay Jr. Bruce E. Bursten | 7th 1997 | 1086 | 26×21×4 1.8 | multicolor illustrations, all color photos, online center, CD-ROM | Ch. 6 29 figs. 40 pages | Ch. 14 27 figs. 48 pages |
| *Chemistry: The Central Science* Theodore L. Brown H. Eugene LeMay Jr. Bruce E. Bursten | 8th 2000 | 1120 | 26×21×4 1.8 | multicolor illustrations, all color photos, course management | Ch. 6 29 figs. 40 pages | Ch. 14 29 figs. 50 pages |
| *Chemistry: The Central Science* Theodore L. Brown, H. Eugene LeMay Jr. Bruce E. Bursten Julia R. Burdge | 9th 2003 | 1152 | 27×22×4 2.5 | multicolor illustrations, all color photos, 22 ancillaries | Ch. 6 28 figs. 38 pages | Ch. 14 28 figs. 50 pages |

[a] These values are approximate.
[b] This book is from a different series than the other editions.

The 1968 edition has no photos, and the 1985 edition still has two-tone illustrations. Earlier editions have simple illustrations and a few black and white or color photos interspersed in the text. In the later editions, more illustrations, photos, and examples are crammed into the chapter so that some pages have more 'extra' material than text. Sometimes in a given two pages, one sees a sample problem worked, a table or illustration, a couple of photos, or perhaps a special topics inset. Do we really need all this detail? I find that this makes it very difficult to follow the thoughts presented in the actual text. Is this trend a response to the supposed preferences of the current generation of college students: their shorter attention span, their marked preference for image over text, their preference for screen over book?

I have also listed when different supporting materials became available. Software and videos became available with the fifth edition (1991), online and CD-ROM resources appeared with the seventh edition (1997), and course management software is offered in the eighth edition (2000). The ninth edition (2003) boasts the availability of 22 different ancillaries. Who has time to utilize all of these extra materials? Is the general chemistry textbook market driven by actual need or by profit?

If you have not done so already, I encourage you to ask some of these questions of your chemistry textbook publishers. Perhaps if we question what is really driving this process, we can curtail the current trend of bigger, more expensive general chemistry texts with more bells and whistles that may begin to appear every two years or dare I say it, every year!

## References

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