The Impact of Visualisation on the Quality of Chemistry Knowledge

Margareta Vrtačnik, Vesna Ferk and Danica Dolničar
University of Ljubljana, Faculty of Science and Engineering, Department of Chemical Education and Informatics, Vegova 4, Ljubljana, Slovenia
Phone: +386 61 214 326, Fax: +386 61 125 8684
margareta.vrtacnik@guest.arnes.si, vesna.ferk@uni-lj.si, danica.dolnicar@uni-lj.si
AND
Nataša Zupančič-Brouwer
University of Amsterdam, Department of Chemistry,
Nieuwe Achtergracht 166, NL - 1018 WV Amsterdam, The Netherlands
nbrouwer@chem.uva.nl
AND
Mateja Sajovec
Osnovna šola Simona Jenka Kranj
Ulica XXXI. Divizije 7A, Kranj, Slovenia
mateja.sajovec@guest.arnes.si

Keywords: spatial ability, visualisation of chemical structures and processes

Edited by: [Enter Editor name]
Received: [Enter date] **Revised:** [Enter date] **Accepted:** [Enter date]

The most important result of the long-term project entitled Computer literacy is that the majority of Slovenian primary and secondary schools are now equipped with multimedia computers and with LCD projectors. However, these computerised classrooms should not be used only for teaching computer science and informatics; they should also serve for teaching and learning other subjects e.g. chemistry, physics, languages, etc. Internet offers chemistry teachers previously unavailable possibilities for bridging the gap between concrete and abstract chemical concepts and processes. Research on the spatial ability of students and the quality of knowledge show that well developed spatial abilities enable better results when solving complex chemical problems, especially when dealing with 2-D representation of 3-D chemical structures. In this article we discuss how chemistry teachers can use specialized Internet websites for visualising chemical structures and processes on the macro- and microscopic level, and correlate properties of molecules with their structure. We also present results which demonstrate the effects of different visualisation elements on the quality of chemical knowledge.

1 Introduction

The ancient Chinese knew that one picture can symbolise the meaning of ten thousands words, and modern neuro-psychological studies have proved this is possible. A human being can remember 20% of what has been read, 30% of what has been heard, 40% of what has been seen, 55% of what has been told, 60% of the content after personal involvement in a subject, and 90% if all the elements are combined [1].

The pioneer work in the field of visual methods has been done by Jan Amos Komensky in his Orbis sensualium pictus (1657). His basic idea is that teachers should present everything through pictures, thus trying to visualise the subject-matter presented at school. Modern technology offers numerous possibilities to achieve these goals, especially through websites which offer various possibilities for making chemistry classes more attractive, thus helping the student to bridge the gap between concrete and abstract notions of chemical concepts and processes.

The significance of the visualisation of abstract knowledge structures can be linked with Gibson's theses of ecological visual perception, which state that mental conditions depend on the interactions between the entities and the objects from the environment. The objects can be either concrete, direct observations of phenomena or processes at a macroscopic level, or visualised microscopic explanations of processes, or their symbol presentation, using chemistry knowledge. In all these cases of perception the underlining idea is that visualisation supports cognitive processes [2].

The research so far indicates that a well developed spatial ability can have a significant impact on solving chemical problems [3, 4, 5, 6]. The correlation between visualisation and understanding is particularly strong when solving problem-based tasks, or those which require memorisation, but less so for algorithmic tasks. In chemistry there are some difficult areas, e.g. visualising three dimensional objects from a two-dimensional presentation. Even more difficult is to visualise objects from another perspective, or visualising a picture of an object after rotation, reflection, inversions, etc. In such cases, visual presentation can greatly help overcome these problems [7, 8, 9, 10, 11, 12]. There are different opinions as to whether spatial ability is inherited or acquired, however, numerous studies indicate that spatial ability can be improved by appropriate methods or teaching strategies [13, 14, 15, 16, 17].

2 Visualisation elements and the Internet in view of chemistry curricula for primary and secondary schools

The need for more extensive use of visualisation tools has been highlighted in the new chemistry curriculum for Slovenian schools. The Internet, which can provide quick access to various useful visual elements, can play an important role. In order to help Slovene chemistry teachers to access the relevant websites more easily, a special website, KemInfo (Slovenian Chemical Information Network) was designed at our Department. It offers numerous links to other relevant websites; including a special module on the visualisation of chemical structures and processes, organised according to relevant curricular chemistry topics. These have been analysed for primary and secondary schools and after extensive Internet searches we found a number of visualisation elements, which could be used for supporting presentations of chemistry themes. The summary of this search is listed below:

- images; visualisation at the macroscopic or microscopic level.
- films; visualisation at the macroscopic or microscopic level.
- process animations; visualisation at a macroscopic or microscopic level.
- molecular models; microscopic visualisation of structures.
- symbol presentation of molecules and reactions; symbol visualisation.
- schemes; reaction schemes for symbol visualisation; concept schemes for visualisation of the relations between concepts and concept groups.
- graphs, tables; visualisation of the relationships between data.
- knowledge test; visualisation at the macroscopic or microscopic or symbol levels.

The KemInfo website (http://www.keminfo.uni-lj.si) includes numerous links to other related web pages which offer either visual elements or complete teaching units.

The following symbols are used to denote links:
- symbol for molecules and reactions
- molecular models
- tables
- graphs
- teaching units
- experiments
- images
- films, animation
- task items
- schemes

For accessing some web pages we need additional web browser programs (e.g. CHIME, RASMOL, VRML, FLASH). These allow the simple visualisation of molecular structures in different formats, or show an animated image.

3 The impact of multimedia visualisation on student knowledge

In spite of the rich assortment of multimedia packages for chemistry, very little has been published regarding the impact of multimedia on the knowledge and motivation of students, let alone the cost-effectiveness of these products.

In the masters thesis by M. Sajovec [18], the impact of multimedia on cognitive, motivational and motoric development of students was studied. Based on the results of the study the evaluation criteria for assessing multimedia packages for chemistry teaching were set up. The research included 50 third year secondary-school students in 1996/97, who were divided into the experimental group (26 students: 15 males and 11 females) and the control group (24 students: 8 males and 16 females). Both groups were pre-tested. The pre-test consisted of six multiple choice questions and open-answer questions to check understanding of the following topics:

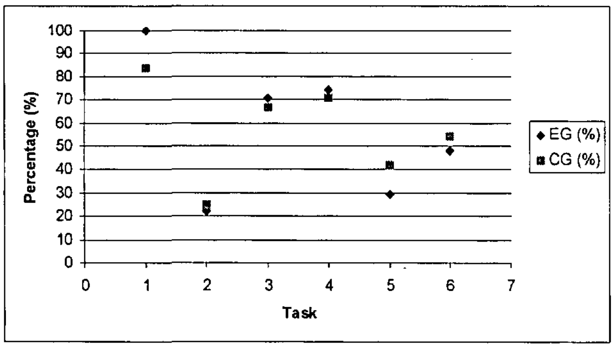
- matter and building blocks of matter,
- light,
- electromagnetic radiation spectrum,
- interactions between light and substances (absorption and in emission),
- photosynthesis, and
- radical halogenation of alkanes.

The students from the experimental group worked in pairs, using the CD ROM "Light and Chemical Change" [19], which was developed at our department and implemented in Toolbook computer based training (CBT) software package (Asymetrix). This teaching unit was designed with an interdisciplinary approach, integrating chemical, biological and physical concepts which are related to the phenomena of photosynthesis, and describing interaction of light with matter on the macro- and microscopic levels. The topics were designed as four interrelated segments:

- Oxygen, the life-supporting gas
- Light phase of photosynthesis
- Interaction of light with matter
- Example of a simple photochemical reaction - bromination of hydrocarbons

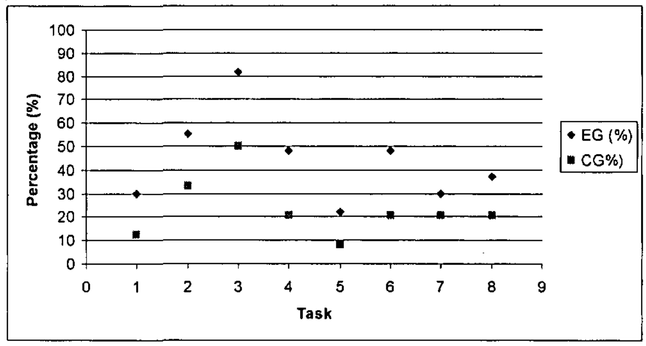
After studying with the CD ROM, the students had three hours available for solving the tasks. They did not use any additional literature for consolidating their knowledge. Students from the control group had several course books available, including a 1st year biology course-book, a 4th year physics book, and a 3rd year chemistry course-book. The topics from these course-books were first presented by the teacher in three one hour periods. After a week, both groups took a common test. The test had a similar concept structure to the pre-test, the difference being that greater emphasis was placed on understanding the concepts at the microscopic level. The results of the pre-test are shown in Figure 1 and the final test results in Figure 2. The comparison of both graphs shows that the performance of the two groups prior to the test (i.e. before working with the CD ROM and the teacher presentation) was equal. Even the distribution of points achieved is similar, while the results of the final test show significant differences in favour of the experimental group which can be ascribed to the visualisation elements included in the CD ROM.

Figure 1: Correct answers from the pre-test by both groups



Legend: EG (=experimental group), CG(= control group)

Figure 2: Correct answers from the final test by both groups



Legend: EG (=experimental group), CG(= control group)

To illustrate the impact of visualisation on understanding the concepts and the use of knowledge, the analysis of some final-test items is given below: Each item is presented with key visualisation elements from the CD ROM, textual description, and graphic presentation of student performance of both groups.

Task 4

Visualisation elements: spectra, animation of the absorption (Figure 3, Figure 4)

Question

The graph below presents the absorption spectrum of chlorophyl. In which wave-length range of the visible spectrum will chlorophyl absorb the light? Will chlorophyl absorb the light in the UV part of the spectrum? Does chlorophyl absorb green light?

Figure 3: Visualisation elements – spectra, animation

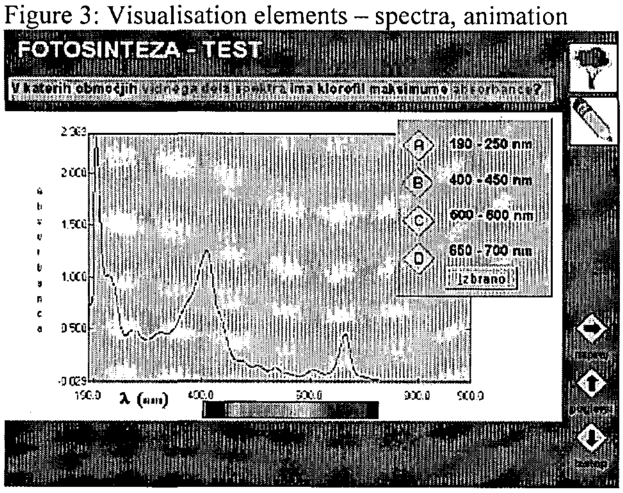
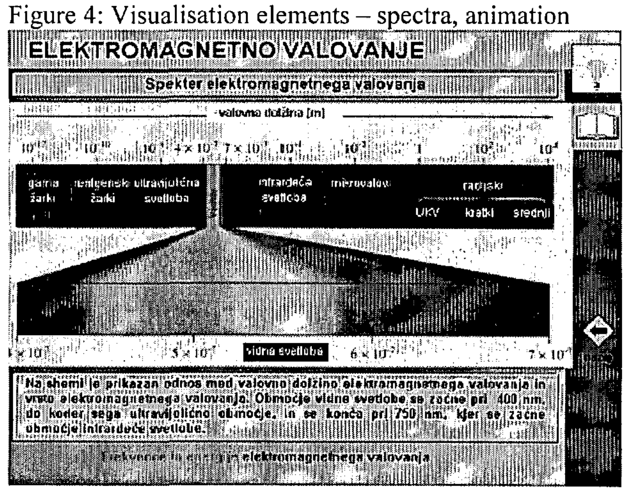
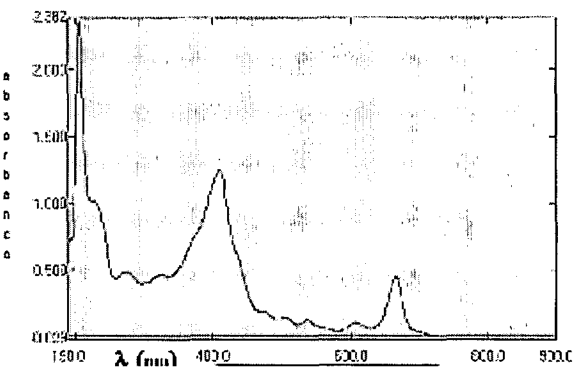


Figure 4: Visualisation elements – spectra, animation

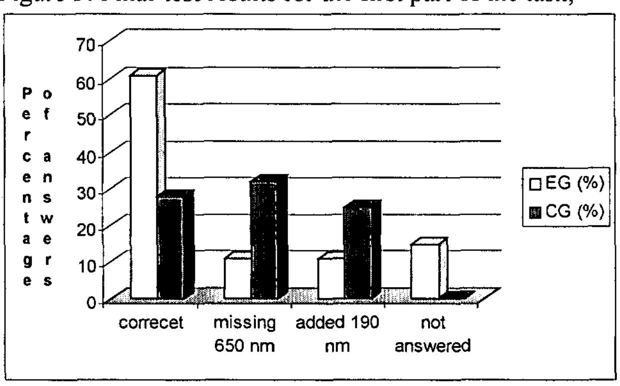




Results

The results presented in Figure 5 indicate that visual presentation of the chlorophyl spectrum and the written explanation about absorption on the CD ROM have contributed significantly to a better understanding of the phenomenon, and that students were able to apply their knowledge in solving the question about the absorption maximums of chlorophyl in the visible spectrum. As a result, 60% of students from the experimental group gave correct answers while only 28% from the control group answered correctly. There were only 10% wrong answers from the experimental group related to the question of the absorption maximum at 650 nm, while there were 30% wrong answers in the control group. In addition, 14% more students from the control group thought that chlorophyl would absorb light at 190 nm, (which is already in the UV range).

Figure 5: Final-test results for the first part of the task,



Legend: EG (=experimental group), CG(= control group)

Task 5

Visualisation elements – microscopic level

Absorption of light quantum, geometrical change of the molecule and explanation of the phenomenon (Figure 6, Figure 7, Figure 8)

Question

Select a combination of correct answers

a) Upon interaction with light, the substance will be transformed into an electron-excited state, regardless of the wave-length or the energy of the light.

b) Light energy will be absorbed by outer electrons.

c) Molecules will remain in an excited state for an unlimited period of time.

d) After the transformation into the excited state the molecular geometry will change.

e) Compared with the initial state of the molecules, the reactivity of excited molecules will not change.

f) Interaction with the light can lead to homolytic cleavage between the atoms of the molecule.

g) Excited molecules of the substance can return into their initial state by emitting a photon (light quantum).

Figure 6: Visualisation elements – microscopic level

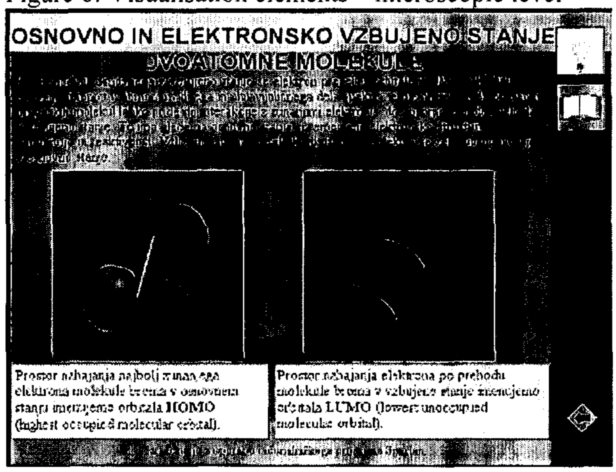


Figure 7: Visualisation elements – microscopic level

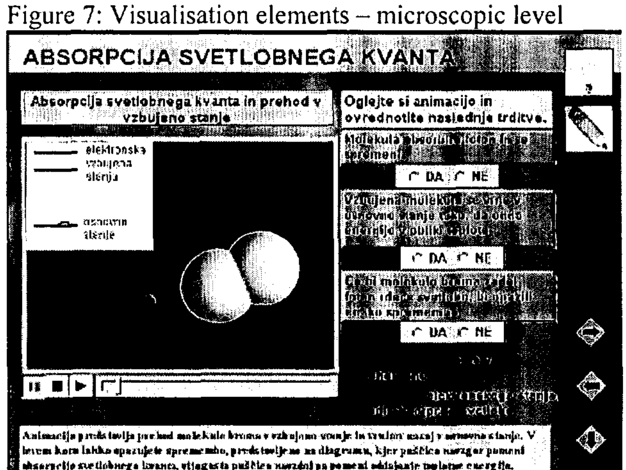


Figure 8: Visualisation elements – microscopic level

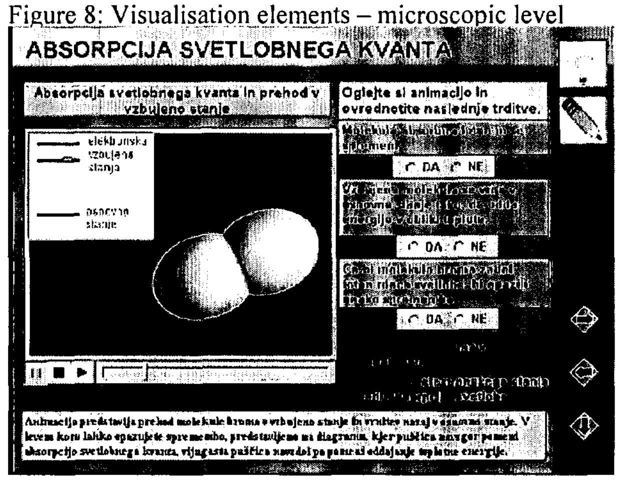


Figure 9: Percent distribution of the correct combination of answers (C) and incorrect answers (IC) by EG and CG

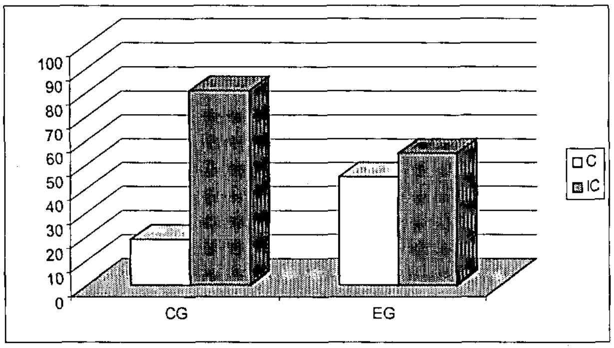
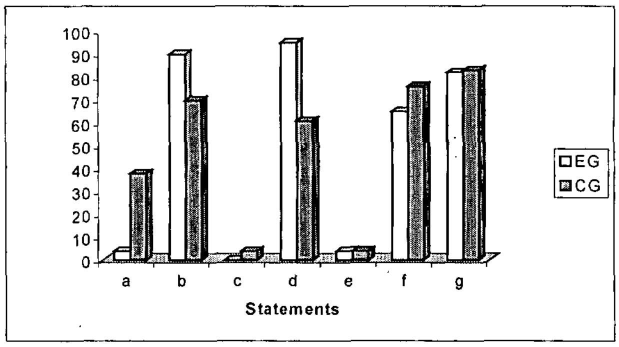


Figure 10: Distribution of answers by EG and CG



Results

The overall performance in solving Task 5, which was basically a rather difficult task, was rather poor for both groups. However, there is a noticeable difference between the two groups: 45% of students from the experimental group made a correct combination of statements while the result of the control group was only 19% (Figure 9).

Correct combinations for Task 5 are: b, d, f and g (Figure 10). A more detailed analysis of the results shows that the experimental group achieved better results since 20% more students selected (b) as a correct answer, while more than 35% of students from the control group selected a wrong statement (a). This indicates that students who saw the simulation of light absorption using the CD ROM better understood the concept. The majority of students, regardless of the group, correctly answered that molecules do not remain in the excited state for an unlimited period of time (statement c). The experimental group was again better in observing that the molecular geometry changes upon transformation into the excited state (statement d) which is indicated by a 35% better performance of the experimental group compared with the control group.
Similarly, the majority of students from both groups knew that the reactivity of molecules in the excited state is changed (statement e), however, there were 11% more students from the control group who knew that after the interaction between light and matter a homolytic bond cleavage between the atoms may occur (statement f). It should be noted that in the multimedia teaching unit the concept of homolytic cleavage was not used. In answers related to the statement that molecules from the excited state can return into their initial state by emitting a photon, the performance of both groups was similar (statement g).

Task 6

Visualisation elements – animation of the reaction mechanism in the bromation of cyclohexane (Figure 11, Figure 12)

Questions

Read the description and answer:

The bromation of cyclohexane proceeds according to the radical mechanism.

- *The first stage is the initiation of the reaction which runs due to the presence of light. Which of the molecules will absorb the light? Draw the reaction scheme for this stage.*
- *During the next stage the reaction expands. What processes will occur during this stage? Draw the reaction schemes.*
- *During the third stage the reaction is completed. Which processes run during this stage? Draw the reaction schemes.*

Figure 11: Visualisation elements – animation

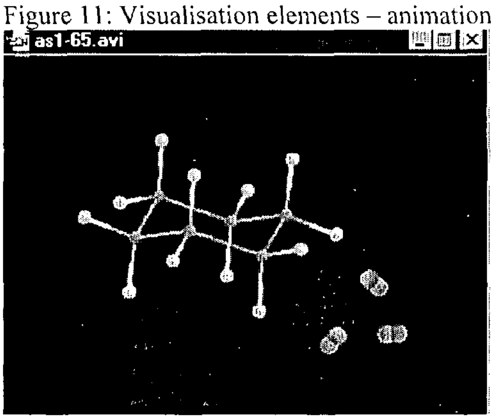
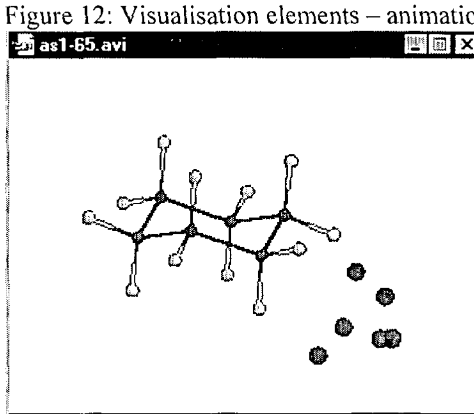
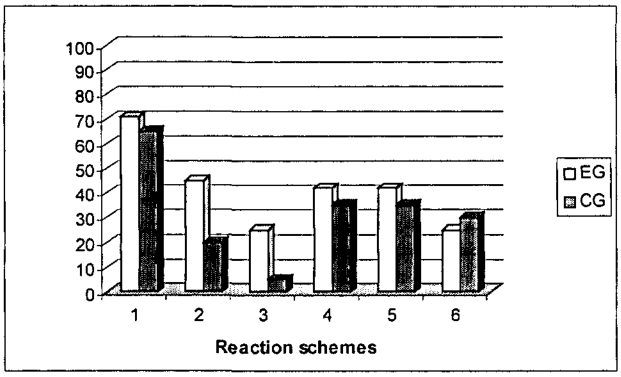


Figure 12: Visualisation elements – animation



Results

Figure 13: Performance of students in drawing the reaction schemes



As can be seen from the graph in Figure 13, only 8% of the students from the experimental group were better at drawing the first reaction scheme. In drawing the second reaction scheme (expansion of the reaction) the performance of the experimental group was significantly better (25%) compared with the control group, while in the third part, i.e. drawing the reaction schemes for the completion of the reaction, the differences between the two groups become smaller again. However, in the control group there were 12% more students who did not even try to accomplish this task.

On average, the performance of the experimental group was 20.5% better than the control group. The experimental group was doing much better at solving both, difficult and easy tasks. It was also noted that the experimental group achieved much better results in the experimental test compared with the marks which the students achieved during regular chemistry courses.

We are aware that the results should not be over generalised, yet they do indicate that there is a positive impact on the motivation and quality of knowledge if various visual elements are integrated into chemistry teaching. Some differences should be noted, however: the evaluation of the task showed that some students found it difficult to use the CD ROM unit on their own, and expressed a desire that a teacher be present to direct them, particularly when dealing with the animation of microscopic processes.

4 Conclusions

Visualisation skills are very important for an easier understanding of abstract science concepts. The Internet offers manifold visualisation support and visual elements can be easily integrated into teaching, which can help students enormously when it comes to understanding difficult chemical concepts. The KemInfo website which has been used by chemistry teachers in Slovenia, has proved to be very supportive in preparing teaching units with integration of visualisation elements.

5 References

[1] Collin, R., Goll, L., 1993, Umetnost učenja, Tangram, Ljubljana.

[2] Vrtačnik, M., 1999, Vizualizacija v kemijskem izobraževanju, Kemija v šoli, 11,1,2-8.

[3] Baker, S.R., Talley, L.H., 1972, The relationship of visualization skills to achievement in freshman chemistry, Journal of Chemical Education, 49, 11, 775-777.

[4] Baker, S.R., Talley, L.H., 1974, Visualization skills as a component of aptitude for chemistry: a construction validation study, Journal of Research in Science Teaching, 11, 2, 95-97.

[5] Carter, C. S., La Russa, M. A., Bodner, G. M., 1987, A study of two measures of spatial ability as predictors of success in different levels of general chemistry, Journal of Research in Science Teaching, 24, 7, 645-657.

[6] Keen, E. N., Fredman, M., Rochford, K., 1988, Relationships between the academic attainments of medical students and their performance on a test requiring the visual synthesis of anatomical sections, South African Journal of Science, 84, 205-208.

[7] French, J. W., 1951, Description of aptitude and achievement in tests in terms of rotated factors, Psychometric Monographs, 5.

[8] Lohman, D. F., 1979, Spatial ability, A review and re-analysis of correlation literature, Technical Report 8, Stanford University, Stanford.

[9] McGree, M., 1979, Human spatial abilities, psychometric studies and environmental, genetic, hormonal, and neurological influences, Psychological Bulletin, 86, 889-918.

[10] Eliot, J., Hauptman, A., 1981, Different dimensions of spatial ability, Studies in Science Education, 8, 45-66.

[11] Seddon, G. M., Moore, R. G., 1986, An unexpected effect in use of models for teaching the visualization of rotation in molecular structures, European Journal of Science Education, 8, 1, 79-86.

[12] Tuckey, H. P., Selvaratnam, M., Bradley, J. D., 1991, Identification and rectification of student difficulties concerning three-dimensional structures, rotation and reflection, Journal of Chemical Education, 68, 6, 460-464.

[13] Saunderson, A., 1973, The effect of special training programme on spatial ability test performance, Journal of College Science Teaching, 5, 15-23.

[14] De Bono, E., 1976, Teaching thinking, Template Smith, London.

[15] Lord, T. R., 1985, Enhancing the visuo – spatial aptitude of students, Journal of Research in Science Teaching, 22, 5, 395-406.

[16] Rochford, K., 1987, Underachievement of spatially handicapped chemistry students in an academic support programme at U.C.T. in 1986, Paper presented to staff of the Department of Education, Cornell University, Ithaca.

[17] Tuckey, H. P., Selvaratnam, M., 1993, Studies involving three-dimensional visualization skills in chemistry: A review, Studies in Science Education, 21, 99-121.

[18] Sajovec, M., 1998, Evaluation of Application of Multimedia in Chemical Education, Master Thesis, University of Ljubljana, Faculty of Science and Engineering, Department of Chemical Education and Informatics, Ljubljana.

[19] Vrtačnik, M., Zupančič-Brouwer, N., Dolničar, D., Orel, M., 1997, Svetloba in kemijska sprememba (Light and Chemical Change): interactive multimedia teaching unit, Zavod R Slovenije za šolstvo, Ljubljana.