VIRTUAL LABORATORY AS AN ELEMENT OF VISUALIZATION WHEN TEACHING CHEMICAL CONTENTS IN SCIENCE CLASS

Nataša Rizman Herga
Primary school Ormož, Hardek 5, 2270 Ormož, Slovenia
natasa_herga@yahoo.com

Milena Ivanuš Grmek
Faculty of Education, University of Maribor, Koroška 160, 2000 Maribor, Slovenia
natasa_herga@yahoo.com

Dejan Dinevski
Faculty of Education, University of Maribor, Koroška 160, 2000 Maribor, Slovenia
natasa_herga@yahoo.com

ABSTRACT
Using a variety of visualization tools for teaching and learning science and chemistry is necessary because pupils better understand chemical phenomena and formulate appropriate mental models. The purpose of the presented study was to determine the importance of a virtual laboratory as a visualization element when addressing chemical contents within science classes. Pupils from five different schools who were attending the seventh grade (N = 109), participated in the survey. The pupils were divided into experimental and control groups. We carried out a teaching experiment in order to assess the effectiveness of using a virtual laboratory. In addition, we asked ourselves two questions: whether the dynamic visualization enabled by the use of a virtual laboratory has a positive effect on the learning outcomes of pupils, and how successful are the pupils when solving tasks that involve visualization elements. The results from the didactic experiment showed, that in terms of knowledge acquisition, the use of a virtual laboratory was more effective than classes without the use of dynamic visualization elements.
Key words: primary school, science, virtual laboratory, dynamic visualization, knowledge

INTRODUCTION
Science teaching in Primary schools (9 year olds) is based on the understanding of physical, chemical, and biological contents. The starting-point for realizing these objectives during the teaching and learning of science is experimental and problem research-based learning. Most of the scientific concepts and their connections, especially chemical because of their triple nature (macroscopic, microscopic, and symbolic levels), can be illustrated or deduced from experimental work (Glažar, Devetak, Strgar & Naji, 2006). Experiments show us the actualities during experimental work. Explanations of scienctific concepts, particularly chemical, present no observable cases within the macroscopic world and are therefore difficult for pupils because they are abstract. Abstract interpretations of experimental observations correlate with the sub-micro level, ending-up with abstract records of events performed during the experiments (Devetak, 2006; Devetak & Glažar, 2007). The complexity of teaching and learning science concepts is reflected in the natures of chemical concepts, which can be described on three levels. The first concrete and actual level is the macroscopic level; the second is the actual phenomenon explaining the submicroscopic level; and the third level is symbolic, which encompasses a range of symbols that are easier to interpret (Devetak, 2012). For science and chemistry it is characteristic to perceive the physical world of matter, phenomena, and processes at the macroscopic level, but for their interpretation and prediction one should use the language of the submicroscopic world (Vrtačnik et al., 2003; Devetak et al., 2009). All three levels should meaningfully overlap during the learning process so that, within the long-term, the pupils' memories develop appropriate mental models that reflect adequate levels of chemical literacy (Devetak & Glažar 2007; Devetak, 2012).

Studies (Devetak et al., 2009; Johnstone, 1982; Williamson & Abraham, 1995; Papageorgiu & Johnson, 2005; Gregorius et al., 2010; deBerg, 2012; Rizman Herga & Dinevski, 2012) have shown that pupils have difficulties describing macro-phenomenon, and thus its interpretation at the submicroscopic level, which is the basis of understanding chemical concepts. Johnstone (1982) was the first to systematically indicate the meaning of the submicroscopic level of scientific concept for better understanding of chemical phenomena. The gaps between the three perceptual levels, as shown in Figure 1, could be overcome to a greater extent by the use of visualization elements (Vrtačnik et al., 2003; Barke & Wirbs, 2002; Dori & Belcher, 2005; Barak et al., 2007; Ferk et al., 2007; Johnstone, 1991).

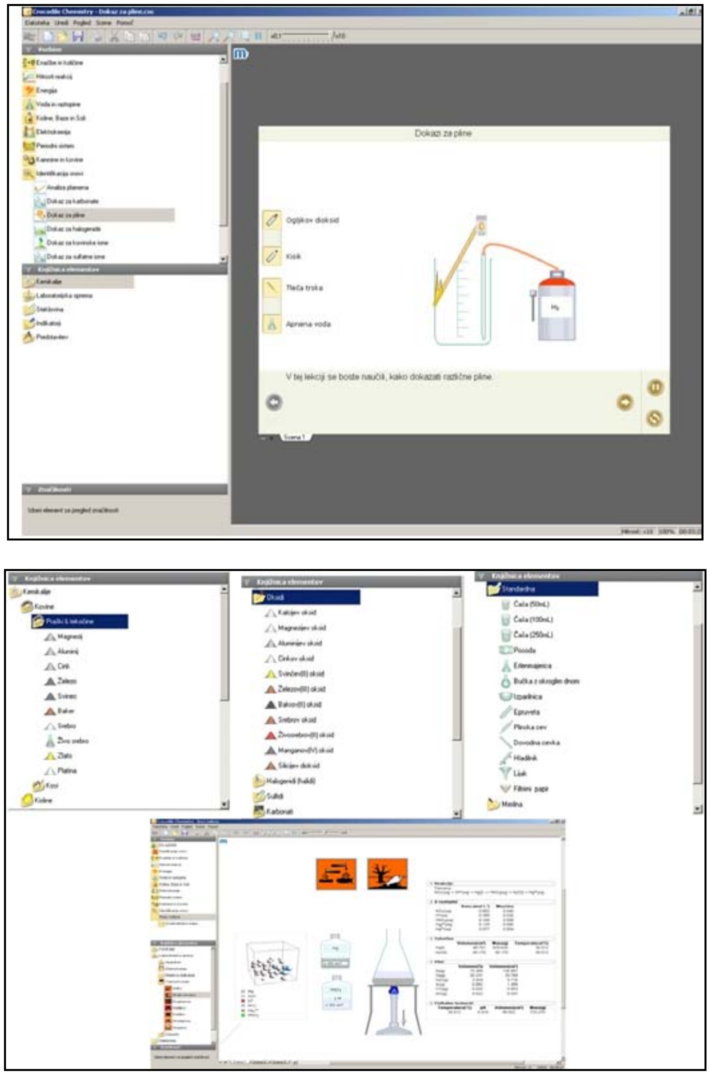


Figure 1: Three levels of scientific concepts' presentation, and the role of virtual laboratory

The visualization of science education is used in its widest sense; from physical models to a variety of images, multimedia and interactive animations, conveying virtual reality (Devetak, 2012). All these modern visualization approaches, enabled due to the rapid development of information - communication technology, have become an increasingly important tool of modern science lessons. Visualization methods and representations of science can be viewed as metaphors, analogies of models or theoretical constructs represented by different symbols, developed within chemisty to explain the real world. Combinations of different visualization elements can be designed in units within which macro, submicro-, and the symbolic components of the multimedia phenomena are intertwined(Devetak, 2012). Some multimedia researchers believe that this contributes to a better understanding of concepts compared to the classical interpretation (Gregorius et al., 2010; Vrtačnik, 1999; Sanger, 2000; Foti & Ring, 2008).

The formation of mental models at the submicroscopic level presents issues for pupils. This is especially true for those models that are dynamic, thus requiring the help of a medium which enables animations of the submicroscopical world of particles. The fact that these animations are statistically more appropriate than static submicro presentations, was demonstrated by the research of Williams and Abraham (1995).

When teaching and learning science, or teaching in general, we should also take into account pupils' different styles of perception. The style of perception is indicated by a perception channel – a sense that an individual takes advantage of when interpreting internal presentations of sensory impressions from the environment (MarentičPožarnik, 2000). Experimentations within schools should be a support for understanding concepts because of their powerful visualization effects, where pupils with visual styles of perception benefit most. Pupils with kinaesthetic styles of perception will enjoy the laboratory work, and thus develop experimental skills.

A multimedia interactive unit that connects all three levels of the chemical concept on a computer screen or interactive whiteboard, is a virtual laboratory. Virtual laboratories can replace real laboratory work which, for economical or other reasons, cannot be implemented.

The Purpose of this Research, Research Questions and Hypotheses

Virtual laboratories are modern visualization elements with which we bridge the gap between the macro and micro worlds of teaching and learning scientific and chemical concepts. They enable us to implement virtual laboratory work where pupils not only learn about changes at the macroscopic level but also at the dynamic submicroscopic level, leading to a better understanding of the subject matter. With this in mind, we designed a teaching experiment with the aim of verifying the effectiveness of a virtual laboratory in terms of chemical content knowledge by pupils during science classes in the 7th grade of a primary school. We were interested in the effects of classes executed by virtual laboratories, on pupils' knowledge. In doing so, we set the following hypotheses:

H1: We assumed that the experimental group of pupils, in comparison to the other pupils of the control group, would acquire more knowledge of chemical content by the end of the experiment.
H2: We assumed that the experimental group of pupils, in comparison to the pupils of the control group, would solve tasks involving visual elements more successfully after the experiment.

METHODOLOGY

Research method

In order to study the impact of classes executed by virtual laboratories regarding the units "Substances, their properties and changes" and "Pure substances and compounds" within the case-study, we used the experimental method of traditionally empirical-analytical educational research.

Experimental model

We designed a single-factor experiment with classes as compared groups. The research work was conducted by experimental (EG) and control groups (CG). In the classroom with a virtual laboratory, we used the Crocodile Clips Chemistry program. Lessons with the virtual laboratory were performed by an experimental group. The experimental factor had two modalities:

- teaching science according to the standardized curriculum using the approach by teachers in an everyday classroom (CG),
- teaching science according to the standardized method but where the teacher implements a virtual laboratory within the traditional approach (EG).

The study of the effectiveness of both modalities regarding the experimental factor was based on definitions of the following factors:
- factors before the experiment, relating to the pupils as individuals,
- factors relating to the group as a whole,
- indicators of the chemical contents'effects after science within virtual laboratories.

The didactic experiment took place from early March 2011 to the end of May 2011.

Indicators of the effect of the teaching experiment

In order to ensure the internal validity of the experiment (the possibility of attributing the discovered differences in effectiveness regarding these two approaches to the teaching of science and not to any existing initial differences between the compared groups) ,we studied the effects of conditions for controlling certain factors before the introduction of the experiment, relating to the pupils as individuals (pupils'genders, their grades in science before the experiment), and those factors relating to the group as a whole (age, curriculum).

In order to ensure content validity (exhaustive identification and verification of actual performance), we studied the effectiveness of the experiment after teaching the themes "Substances, their properties and changes" and "Pure substances and compounds" from the science knowledge point of view (chemical part), expressed as:
- the total score on the science test and
- the result of science knowledge testing with tasks that had visualization elements incorporated.

Defining the sample
The didactic experiment included 7th grade pupils from five different primary schools. The study involved 109 pupils (N = 109). The pupils were divided into experimental (EG) and control groups (CG). 56.9% of the pupils participated in the experimental group and 43.1% in the control group. A select group of pupils represented, in the context of statistical hypothesis testing, a simple coincidental sample from the hypothetical population. The didactic experiment was conducted within science classes and encompassed the chemical contents of the subject.

Data collection procedures
Data were collected by testing pupils' knowledge of subject matter according to a test created by the authors. Furthermore we carried out a rational and empirical validation of the test. Rational validation was based on assessing the appropriateness of the content and design of the test. For empirical validation we used the factor analysis solution, namely the percentage of explained variation by the first common factor (% ex. var. F1). Given that the first factor explains 30.3% of the variance and is above the limit of the criterion for the lower limit (20%), we estimated that the examination was valid. In order to determine the reliability of the examination we used Cronbach's alpha coefficient (α = 0.710). This confirmed whether it was a reliable instrument for assessing knowledge. The objectivity of the knowledge testing was provided by detailed instructions. Many questions on the test were closed-ended. The results for both groups were evaluated by the same teacher according to the same criteria.

In February 2011 we formed the experimental and control groups, and determined the school at which the experiment would eventually be carried out. Following the implementation of the didactic experiment we tested pupils' knowledge by assessing the learning progress of one group compared to the other. The tests were corrected and graded according to the instructions and scale of points.

Knowledge testing
Knowledge testing after the experiment consisted of 14 tasks (maximum 41 points). The test included tasks on the levels of understanding and use of knowledge. The exam consisted of tasks with one correct answer, tasks that required completing, matching tasks, and open-ended tasks. Visualization elements were included within tasks 2, 3, 8, 10, and 11 (see Appendix 1). In these tasks, which we analysed separately, the pupils could achieve 13 possible points.

The tests were corrected and graded according to the instructions and scale of points.
Task samples can be found in Appendix 1.

Data-processing procedures
The data was processed using the SPSS (Statistical Package for the Social Sciences). For the analysis of metric characteristics we used factor analysis and the Cronbach's alpha coefficient (α). The non-parametric test (χ2-test)was used for analysing the differences between the groups before the experiment. After the experiment we used the parametric test (t-test). In this paper, the results of the experiments listed the differences between the groups and the arithmetic means of the pupils' performances in individual visualization tasks.

RESULTS
Statistically important differences between the groups (EG and CG) were tested by the χ^2 – test. The structures of the pupils according to gender were similar in both groups (χ^2 = 0.02; P = 0.887). In addition the groups did not vary according to their marks in their science classes (χ^2 = 3.048; P = 0.384).

a) Pupils' Achievements in the total score regarding knowledge testing after the experiment
After carrying out the experiment we analysed the pupils' knowledge using a test. We analysed the total points score.

Table 1: Results from the t-test regarding the differences between the experimental (EG) and control (CG) groups in the total score on knowledge testing after the experiment.

GROUP	Numerous n	Arithmetic mean $\bar{x}$	Standard deviation	Test of homogeneity of variances		Test of the arithmetic mean difference	
EG	62	32.19	4.62	F	P	t	P
CG	47	23.02	6.20	1.957	0.165	8.850	0.000

The assumption of homogeneity of variance (F = 1.957 P = 0.165) was justified.

As shown by the outcome of the t-test (testing knowledge after the experiment), the experimental group's pupils ($\bar{x}$ = 32. 19) achieved higher scores than the control group's pupils ($\bar{x}$ = 23. 02). We could see that those pupils who had learned the subject-matter with the help of a virtual laboratory had gained more knowledge in comparison with those pupils who had been taught using no additional explanations at the submicroscopic level.

The difference in the arithmetic mean between the pupils in the experimental and control groups was statistically significant (t = 8.850, P = 0.000). This research **confirmed the hypothesis (H1)** in which we assumed that the experimental group's pupils would have gained more knowledge of chemical concepts at the end of the experiment than the control group's pupils.

b) Individual accomplishments for tasks, including the visualization elements

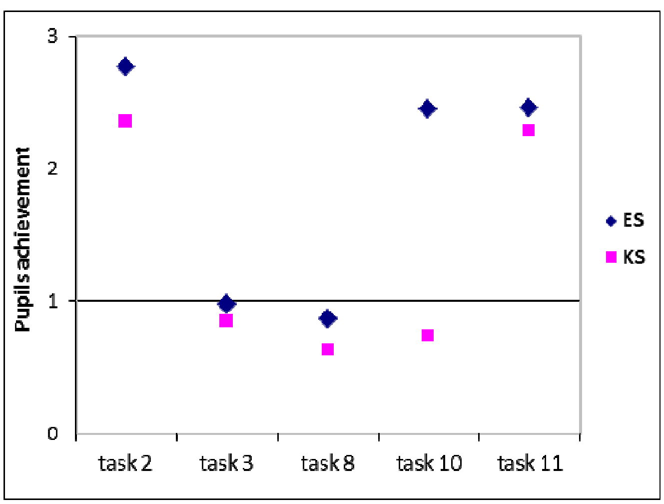
Table 2 presents the results of the t-tests regarding the differences between the pupils of the experimental and control groups according to the total scores in those tasks that included visualization elements.

Table 2: Results of t-tests regarding the differences between the experimental group's pupils (EG) and control group's pupils (CG) according to the total scores after the experiment

GROUP	Numerous N	Arithmetic mean $\bar{x}$	Standard deviation	Test of homogeneity of variances		Test of the arithmetic mean difference	
EG	62	9.54	2.19	F	P	t	P
CG	47	6.89	2.03	1.434	0.234	6.455	0.000

The assumption regarding homogeneity variance (F = 1.434 P = 0.234) was justified.
The results of the t-tests showed statistically significant differences (P = 0.000) amongst the pupils of the experimental group ($\bar{x}$= 9.54) and the control group ($\bar{x}$= 6.89) when accomplishing tasks that included visualization elements. Those pupils from the experimental group who learned about the chemical content through a virtual laboratory, had an advantage over the pupils in the control group,regarding these tasks. This research confirmed the hypothesis (H2) in which we assumed that the experimental group's pupils would better solve those tasks that included visualization elements, compared to the pupils of the control group, after the experiment.

Analysis of the pupils' achievements in various tasks with visualization elements is clearly shown in Graph 1. This graph shows that the experimental group of pupils was more successful in all five tasks compared to the pupils of the control group.



Graph 1: The arithmetic means of pupils' accomplishments (EG and CG) on the various levels of tasks regarding the testing chemical content, after the experiment.

The detected differences are statistically shown regarding their possible importance, by the results in Table 3.

Table 3: Results of t-test between the experimental (EG) and control groups (CG) regarding accomplishments using individual visualization tasks

	GROUP	Numerous n	Arithmetic mean $\bar{x}$	Standard deviation	Test of homogeneity of variances		Test of homogeneity of regression coefficients	
Test 2	EG	62	2.77	0.66	F	P	t	P
	CG	47	2.36	1.13	26.018	0.000	2.227	0.029
Test 3	EG	62	0.98	0.12	F	P	t	P
	CG	47	0.85	0.35	36.463	0.000	2.418	0.019
Test 8	EG	62	0.87	0.33	F	P	t	P
	CG	47	0.63	0.48	34.432	0.000	2.809	0.006
Test 10	EG	62	2.45	1.62	F	P	t	P
	CG	47	0.74	0.89	28.394	0.000	6.983	0.000
Test 11	EG	62	2.46	0.67	F	P	t	P
	CG	47	2.29	0.97	6.622	0.011	1.024	0.309

The assumption regarding homogeneity variances in all cases (F = 26,018, P = 0.000, F = 36,463, P = 0.000, F = 34,432, P = 0.000, F = 28,394, P = 0.000 and F = 6622, P = 0.011) was incon clusive.
The results of the t-tests showed that, between the experimental and control groups, when solving the second task (P = 0.029), the third task (P = 0019), the eighth tasks (P = 0006), and the tenth task (P = 0.000), there are statistically significant differences. In the eleventh task, which included visualization elements, the arithmetical mean for accomplishments between the groups was statistically insignificant (0.309).

DISCUSSION AND IMPLICATIONS FOR EDUCATION

In chemistry and natural sciences, in general, experimental laboratory work is one of the most effective methods for acquiring knowledge, which complements other methods and forms of active learning. Experimental work is one of the active forms of teaching, during which pupils learn experimental approaches: from the designing of experiments, the collection; analysis; and presentation of data, independent implementation, and integration with theoretical knowledge and pre-knowledge (Glažar et al., 2006; Pickering, 1993; Hofstein & Lunetta, 2004; Vrtačnik et al., 2011; Logar et al., 2011). Basically, experimental work can be divided into real and virtual. Classical experimental work is the best known form of practical work and is most commonly used when teaching science and chemistry in elementary schools. Pupils are trained in manual skills, develop their abilities to describe chemical changes, learn about the physical and chemical properties of substances, develop abilities to work safely within the school laboratory, consolidate and complement their knowledge and skills, and develop an experimental approach as a form of research work etc. We often ascribe the motivational aspect in order to justify practical work within schools. However, motivation is only one of the reasons why we decide to practise experimental work. We must be aware that experiments are an economic category; the practical execution of an experiment having its own price (Vrtačnik et al., 2005) and that the number of experiments carried out within schools are usually limited for security reasons due to the lack of adequate infrastructure and equipment, limitations of time and space, and also the lack of precision when carrying out laboratory work. As proven, pupils want laboratory work to be instigated more frequently within classical teaching (Šorgo & Špernjak, 2007).

Virtual laboratory practise is held within a virtual world, and a virtual lab brings many advantages. They can perform dangerous experiments without endangering themselves or others. Simulators are affordable. Once developed, they can function at no extra cost as many times as required. The results are always the same. A virtual laboratory provides independent or collaborative work, which is not necessarily related only to school time, school laboratory or available chemicals and laboratory facilities. Educational software for primary and secondary schools is available as a virtual chemistry laboratory called 'Chemistry Crocodile Clips' (see Appendix 2). This program also enables pupils to work independently or in groups, where the interface gradually leads them step by step through the virtual experiment.

Pupils or teachers have ready-made collections of experiments at their disposal. They can also use gadgets, glassware, or set a chemical experiment from the beginning. The program has the ability to modify existing experiments. Pupils or teachers can adapt an existing experiment by changing various parameters such as temperature, weight, concentration etc.

A booklet of elements features the extensive equipment available for chemical laboratories and also more than a hundred different chemicals, with which they can carry out experiments, including those that are too dangerous for school laboratories. It is adjusted for working on interactive whiteboards. When using virtual laboratories, the uninteresting and boring parts of the experiments can be removed. It helps pupils achieve higher cognitive levels of analyses, syntheses, and evaluations(Kirscher & Huisman, 1998; Abdulwahed & Nagy, 2009). Studies into the effectiveness of virtual laboratories during e-learning have shown that pupils prefer to use computerized tools whilst learning, and not textbooks(Sun et al., 2008; Rajendran et al., 2010).

Before carrying out this didactic experiment, we set two main hypotheses.
The first hypothesis in which we assumed that the experimental group of pupils compared to the pupils of the control group would gain more knowledge of chemical content, was confirmed. Teaching chemical contents according to the standardized science curriculum, where the teaching approach involved the use of a virtual laboratory, proved to be more successful compared to those classes where the dynamic visualization was excluded from the teaching of science. The differences in the total points scored on the knowledge test was statistically significant.

We can conclude, that the use of a virtual laboratory can affect the formation of mental models at the submicroscopic level. These dynamic models and animations, which are enabled by a virtual laboratory, when compared with the static submicro presentations, proved to be more appropriate for the understanding of chemical concepts, as proven in the study by Williams and Abraham (1995). Devetak and co-authors (2010) noted that even a limited manipulation of models statistically improves pupils' understanding of specific subject matter, such as the building-blocks of solid matter - crystals. Using a virtual laboratory clearly helps pupils to achieve higher cognitive levels (Rizman Herga & Dinevski, 2012; Kirscher &Huisman,.1998; Abdulwahed & Nagy, 2009).
The second hypothesis in which we assumed that the experimental group of pupils would be more successful in solving the tasks after the experiment compared to the pupils of the control group, was confirmed. When teaching and learning we should take into account the different styles of perception that can be achieved by using a virtual laboratory. Pupils in the experimental group better solved statistically those tasks involving the visual element which we specifically analysed in this study. These pupils did not simply verify the performances of visual type pupils, as these tasks also required spatial visualization skills by pupils. As demonstrated by the results from the study, pupils using the virtual laboratory better developed their spatial - visualization skills compared to the pupils who did not have this option. Similar results were obtained in the study of Boats and Engida (2001).

The revised syllabuses for science in Slovenia fairly quickly (from 11 years onwards) incorporates the introduction of particles. It is important that, during this tested primary school period, pupils form appropriate mental models in order in order to deal with any problems throughout subsequent science education. The understanding of science and chemical concepts also depends on visualization. In order to properly integrate new concepts, pupils need a variety of visualization elements. Alongside the development of modern information - communication technologies in this area, virtual laboratories play an important role. Using virtual laboratories for teaching science and chemistry has several strong advantages: 1) they enable experimental work that would otherwise be impossible due to economical, spatial, time, and other reasons. This is contrary to didactic recommendations, as experimental work is one of the most effective methods for acquiring knowledge. 2) they enable visualization at the macroscopic, submicroscopic, and symbolic levels, and 3) provide dynamic presentations of the submicro world of particles. 4) this then contributes to a better understanding of the chemical content. 5) their use of advanced information and communication technology is familiar to pupils, and serves as a powerful motivational tool.

Advanced information and communication technologies are increasingly coming to the forefront and we will need to change the methods of teaching. The presented findings regarding virtual laboratories empirically verifies the need for educational strategy changes regarding science and chemistry didactics.

ACKNOWLEDGMENTS
This research is supported by Fundation Dr. Antona Trstenjaka, Slovenia.

REFERENCES

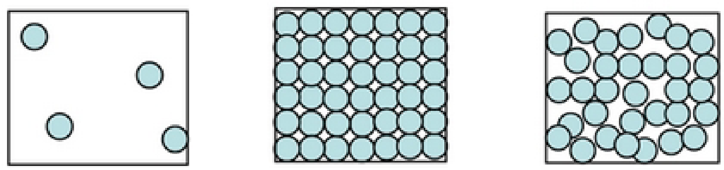
Abdulwahed, M., Nagy, Z. (2009). Applying Kolb's Experiential Learning Cycle for Laboratory Education. *Journal of Engineering Education,* 98(3), 283-293.

Barak, M., Harward, J., Kocur, G., Lerman, S. (2007). Transforming an introductory programming course: from lectures to active learning via wireless laptops. *Journal of Science Education and Technology,* 16(4).
Barke, H. D. & Engida, T. (2001). Structural Chemistry and Spatial Ability in Different Cultures. *Chemistry Education: Research and Practice in Europe*, 2, 227-239.
Barke, H., D. & Wirbs, H. (2002). Structural units and chemical formulae. *Chemistry Education: Research and Practice in Europe,* 3(2), 185-200.
deBerg, K. (2012). Student-generated Submicro Diagrams: A Useful Tool for Teaching and Learning Chemical Equations and Stoichiometry. *Chemistry Education Research and Practice*, 11 (3), 8-16.
Devetak I. (2006). Eksperiment kot osnova oblikovanja celostnega razumevanja naravoslovnega pojava (pp. 130-136). In Strgar, J. & Naji, M. (Eds.): *Naravoslovje v teoriji in šolski praksi*. Zavod Republike Slovenije za šolstvo.
Devetak, I. & Glažar. S. A. (2006). Razumevanja kemijskih pojmov na submikroskopski ravni in sposobnost vizualizacije pri dijakih, starih 16 let (pp. 9-36).In I. Devetak (Ed.): *Elementi vizualizacije pri pouku naravoslovja*. Ljubljana: Pedagoška fakulteta Univerze v Ljubljani.
Devetak, I. (2012). *Zagotavljanje kakovostnega znanja naravoslovja s pomočjo submikroreprezentacij*. Ljubljana: Pedagoška fakulteta Univerze v Ljubljani.
Devetak, I., Hajzeri, M., Glažar, S. A. & Vogrinc, J. (2010). The Influence of Different Models on 15-years-old Students' Understanding of the Solid State of Matter. *Acta Chimica Slovenica*, 57, 904-911.
Devetak, I., Vogrinc, J., Glažar S. A. (2009). Assesing 16-YearOld Students' Understanding of Aqueous Solution at Submicroscopic Level. *Research in Science Education*, 39(2), 157-179.
Dori, Y., J. & Belcher, J., W. (2005). How does technology-enabled active learning affect students' understanding of scientific concepts? *The Journal of the Learning Sciences,* 14(2), 243-279.
Ferk Savec, V. & Vrtačnik, M. (2007). Povezovanje eksperimentalnih opažanj z razlago na ravni delcev pri bodočih učiteljih kemije (pp. 37-56). In I. Devetak (Ed.): *Elementi vizualizacije pri pouku naravoslovja*. Ljubljana: Pedagoška fakulteta Univerze v Ljubljani.
Foti, S. & Ring, G. (2008). Using a Simulation-Based Learning Environment to Enhance Learning and Instruction in a Middle School Science Classroom. *Journal of Computers in Matematics and Science Teaching*, 27 (1), 103-120.
Glažar, S. A., & Devetak I. (2006). Eksperimentalno delo kot del poučevanja in učenja naravoslovja (pp. 121-129). In Strgar, J. & Naji, M. (Eds.): *Naravoslovje v teoriji in šolski praksi*. Zavod Republike Slovenije za šolstvo.
Gregorius, R., Santosb, R., Danob, J. B. & Gutierrezb, J. J. (2010). Can Animations Effectively Substitute for Traditional Teaching Methods? *Chemistry Education: Research and Practice*, 11 (4), 253-261.
Hofstein, A., & Lunetta, V. (2004). The Laboratory in science education: fundations for the twenty-first century. *Science Education,* 88(1), 28-54.
Johnstone, A. H. (1982). Macro and microchemistry. *The school Science Review,* 64, 377-379.
Johnstone, A., H. (1991). »Why is science difficult to learn: Things are seldom what they seem«. *Journal of Computer Assisted Learning,* 7, 75-83.
Johnstone, A., H. (1991). »Why is science difficult to learn: Things are seldom what they seem«. *Journal of Computer Assisted Learning,* 7, 75-83.
Kirscher, P. & Huisman, P. (1998). Dry Laboratories in Science Education:Computer-based Practical Work. *International Journal of Science Education,* 20 (6), 665-682.
Logar, A. & Ferk Savec, V. (2011). Students' hands-on experimental work vs lecture demonstration in teaching elementary school chemistry. *Acta Chimica Slovenica,* 58, 866-875.
Marentič Požarnik, B. (2000). Psihologija učenja in pouka. Ljubljana: DZS.
Papageorgiu, G. & Johnson, P. Do particle ideas help or hinder pupils' understanding of phenomena? *International Journal of Science Education*, 27 (11): 1299-1317.
Pickering, M. (1993). The teaching laboratory through history. *Journal of Chemical Education,* 70(9), 699-700.
Rajendran, L., Veilumuthu, R., Divya, J. (2010). A study on the effectiveness of virtual lab in E-learning. *International Journal on Computer Science and Engineering,* 2 (6), 2173-2175.
Rizman Herga, N. & Dinevski, D. (2012). Virtual Laboratory in Chemistry – Experimental Study of Understanding, Reproduction and Application of Acquired Knowledge of Subject's Chemical Content. *Organizacija*, 45 (3), 108-116.
Sanger, M., J. (2000). Using particulate drawings to determine and improve students' conceptions of pure substances and mixtures. *Journal of Chemical Education*, 77(6), 762-766.
Šorgo, A. & Špernjak, A. (2007). Profesorice bi morale bit zgoraj brez ali kaj spremeniti v pouku biologije. *Vzgoja in izobraževanje*, 38 (5), 37-40.
Sun, K., Lin, Y., Yu, C. (2008). A study on learning effect among different learning styles in a Web-based lab of science for elementary school students. *Computers & Education,* 50(4), 1411-1422.
Vrtačnik, M. (1999). Vizualizacija v kemijskem izobraževanju, *Kemija v šoli*, 11 (1), 2-8.

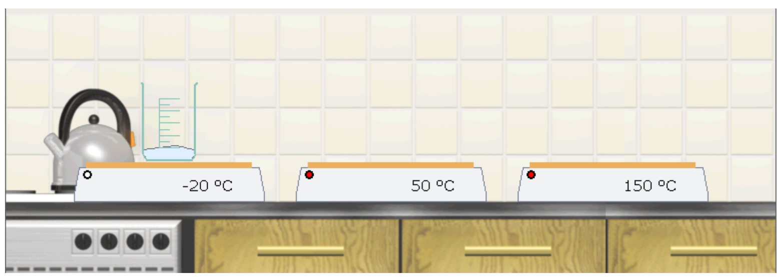
Vrtačnik, M., Ferk, V., Fir, M., Dolničar, D., Renič, V., Potisk, B., & Pozdered, N. (2003). *Dinamična vizualizacija naravoslovnih pojmov s poskusi in modeli.* Ljubljana: Naravoslovnotehniška fakulteta Univerze v Ljubljani.
Vrtačnik, M., Glažar, S. A., Ferk, V., Pahor, V., Keuc, Z. & Sodja, V. (2005). Kako uspešneje poučevati in učiti se kemijo? Ljubljana: Fakulteta za kemijo in kemijsko tehnologijo.
Williamson, V., M., Abraham, M., R. (1995). The effect of computer animation on particulate mental models of college chemistry student. *Journal of Research in Science Teaching,* 32(5), 521-534.
Williamson, V., M., Abraham, M., R. (1995). The effect of computer animation on particulate mental models of college chemistry student. *Journal of Research in Science Teaching,* 32(5), 521-534.

APPENDIX 1
Sample items from the test

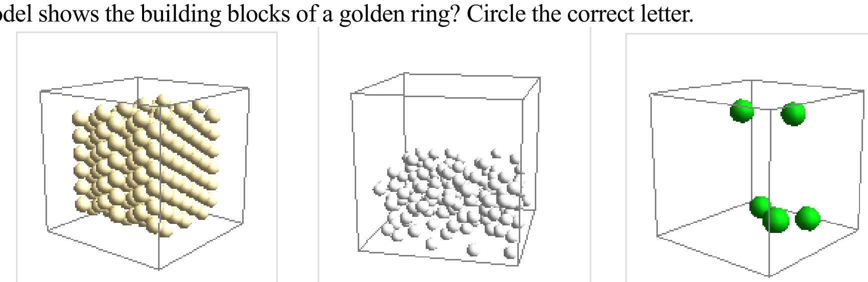
2. How does the structure of water change from ice to water vapor? Use lines to connect boxes with heaters so that the aggregatic state complies with the temperature shown by the heater!



__/3



3. Which model shows the building blocks of a golden ring? Circle the correct letter.



A B C

__/1

8. This sketch shows the process of:

A chromatography
B decanting
C distillation
D filtering
E separation by a funnel

__/1