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Virtual Laboratory in the Role of Dynamic Visualisation for Better Understanding of Chemistry in Primary School

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Understanding chemistry includes the ability to think on three levels: the macroscopic level, the symbolic level, and the level of particles – sub-microscopic level. Pupils have the most difficulty when trying to understand the sub-microscopic level because it is outside their range of experience. A virtual laboratory enables a simultaneous demonstration of all three levels of a chemical concept along with dynamic visualisation at the submicroscopic level. This study presents the effective usage of a virtual laboratory that can overcome the gap between the previously-mentioned conceptual levels. We carried out a didactic experiment to test the effectiveness of a virtual laboratory that enables dynamic visualisation. The experiment involved seventh-grade pupils (N = 109) from five different primary schools in Slovenia. We asked ourselves the question as to whether the learning outcomes of pupils are better when they use a virtual laboratory rather than in science classes without a virtual laboratory where dynamic visualisation at the sub-microscopic and sub-micro levels are only explained by means of static demonstrations. A virtual laboratory has many significant advantages. The results of the didactic experiment showed that, in terms of knowledge acquisition, using a virtual laboratory is better than science classes without visualisation elements.

Keywords: virtual laboratory, submicro animations, primary school, chemistry, knowledge, dynamic visualisation

INTRODUCTION

The most effective basic method when acquiring chemistry knowledge is the experimental and laboratory work. Allowing students and pupils to 'experience' science through various forms of carefully designed practical work including experimentation, is often claimed to support their learning and motivate their engagement whilst fulfilling specific curriculum requirements. Students can only perceive changes on the macroscopic level by 'hands-on' experimental work. Students' abilities to use the macroscopic, sub-microscopic, and symbolic

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representations are essential for understanding several chemistry concepts and phenomena. Studies indicate that students experience difficulty in understanding the sub-microscopic system of representations because these representations are abstract and cannot be experienced. These problems can be overcome with the use of a virtual laboratory that integrates all three levels of representations. This article deals with a study about a didactic experiment from the pupils' points of view after using a virtual laboratory.

State of the literature

- An understanding of chemistry includes the ability to think on three levels: macroscopic, symbolic, and the level of particles. It is important that pupils and students understand and know how to connect the concepts with all three demonstration levels, which is difficult for many.
- The gap between the visualisation levels can be, to a greater extent, overcome by the usage of visualisation elements. They have become more accessible with the development of computer technology.
- The use of visual representations such as computerised molecular models help translate abstract ideas into concrete ones, helping students understand chemical concepts.

Contribution of this paper to the literature

- This research proposes an effective technology - enchanced teaching strategy to improve student learning of chemical concepts in primary school.
- The usages of virtual laboratories in chemistry classes provide specific advantages and the ability to present teaching matter at the macroscopic, symbolic, and dynamic sub-microscopic levels. Simultaneously connected all three levels of the chemical concept have a positive impact on students' learning outcomes at the primary level of education.
- Virtual laboratory in the role of dynamic visualisation increase knowledge and promote effective learning of chemistry.

Levels of Representation regarding science concepts and the virtual laboratory

Many sciences, especially chemistry concepts, are abstract and do not have detectable examples within the macroscopic world. This is why concepts such as atoms, electrons, compounds, elements, and molecules, etc. are difficult for students to understand as they are unable to mentally connect them with the appropriate mental model. Pupils at around the age of twelve when they first encounter the world of particulate matter, begin to learn about the interactions between them, and are expected to understand the explanation of a macro phenomenon on a sub-microscopic level (Harrison and Treagust 2002).

Cognitive psychologists assume that an understanding of chemistry includes the ability to think on three levels: macroscopic, symbolic, and the level of particles (Johnstone 1991). Primary pupils, high school, and university students have the most difficulty understanding the sub-microscopic level – level of particles, because it is beyond their experiences. When learning chemistry, it is important that pupils and students understand and know how to connect the concepts with all three demonstration levels (macroscopic, symbolic, and sub-microscopic), which is difficult for many. The gap between the visualisation levels can be, to a greater extent, overcome by the usage of visualisation elements (Barke and Wirbs 2002). Visualisation elements such as molecules, atoms, ions, and crystal network structures have become more accessible with the development of computer technology.

Real-world experiments and virtual experiments

In chemistry, and natural sciences in general, experimental and laboratory work is one of the more effective methods for acquiring knowledge. Experimental work can be divided into real and virtual. Classical experimental work is the best-known method of practical work and is more commonly used when teaching science and chemistry in primary schools. Pupils train using their manual skills, developing their abilities to describe chemical changes, learn about the physical and chemical properties of matter, developing safety at work abilities within the school laboratory, strengthening and complementing their knowledge, abilities, and skills, and developing an experimental approach as a form of research work. However, logistical constraints (more especially relating to the funding of school science) place significant limitations on the abilities of schools to support high quality practical experiences. The number of experiments carried out in schools and universities is usually limited due to safety reasons, lack of adequate infrastructure, equipment, due to limitations of time and space, and also due to poor precision in the implementation of experimental exercises (Sokoutis 2003).

All this can be avoided by experimenting with a virtual laboratory. Virtual laboratory exercises are held in the virtual world. A virtual laboratory brings many advantages. You can perform dangerous experiments without endangering yourselves or others. Simulations are affordable. Once developed, they can be done at no extra cost as many times as you would like. The results are always the same. A virtual laboratory allows for independent or collaborative work which is not necessarily only related to the lesson, school laboratory or available chemicals, and laboratory equipment. The usages of virtual laboratories in science classes, especially in chemistry classes, provide specific advantages and the ability to present teaching matter at the macroscopic, symbolic, and sub-microscopic levels. There is not a clear advantage for virtual experiments over the real-world experiments. Some researchers suggest that virtual experiments used with hand-on experiments in real-world may provide the best experience (Martinez-Jimenez et al., 2003; Georgiou et al., 2008; Domingues et al., 2010).

Visual presentation modes and the virtual laboratory

Many studies (Hartley 1988; Baker 1991; Lelouche, 1998) have shown the usefulness of computers during science education: as an interactive communication means permitting access to all kinds of information (texts, images, different types of data, graphics, etc.).

The majority of computer usage researchers when investigating science came across better results, and improved attitudes towards science if they performed computer-based classes. (Dori and Barnea 1997; Chu and Leung 2003; Kocijancic and O'Sullivan 2004; Keller 2005; Rajendran et al. 2010; Barak and Dori 2011). Multimedia display of an experiment helps pupils achieve higher cognitive levels such as the evaluation, analysis, and synthesis of knowledge (Kirscher and Huisman 1998). Correspondingly, Barak and Dori (2005) found that the use of visual representations such as computerised molecular models enhanced students' visualisation abilities, conceptual understanding, and modelling skills. The same was also argued by Khan (2011). Furthermore, animations of the sub-microscopic world of particles are far more suitable than the static sub-micro representations (Williamson & Abraham, 1995; Russell et al., 1997; Sanger et al., 2000; Yang et al., 2003). Schnotz and Rasch (2005) claimed that animation may carry a potential for misconceptions, since in most cases they are a simplified version of a phenomenon.

Crocodile Clips Chemistry

Virtual chemical laboratories offer a new form of education. The aim of virtual reality is to provide a realistic simulation of chemical processes, so that pupils are actively involved in the learning process and remember more due to their own active participation.

Crocodile Clips develop educational software for primary and secondary schools. Crocodile Clips' products are recommend by teachers worldwide as innovative approaches to learning. A new generation of educational tools is represented by Yenka. Virtual Chemical Laboratory Crocodile Clips Chemistry provides a secure demonstration of experiments. The program can serve as a teacher's tool for showing experiments during a frontal method of teaching. It is adapted for working on an interactive whiteboard. This program also allows pupils to work independently or in groups, where an interface gradually leads them step by step through the virtual experiment. Pupils or teachers can find ready-made collections of experiments (Figure 1). One may also use equipment, glassware, and chemicals to compose an experiment. The program has the ability to modify existing experiments. Pupils or teachers can adapt the existing experiment by changing different parameters such as temperature, mass, and the concentration of elements. One can discover over one hundred different chemicals that are too dangerous for the school laboratory.

Nevertheless, this application in comparison to virtual reality has some drawbacks such as: limitations in the interaction and navigation, and the unrealistic presentations of models.

Purpose of the study

The presented study researched the influence of a virtual laboratory on the chemical knowledge of 12 – 13 year old pupils attending science classes in Slovenia. The research was limited to two chemistry learning themes: Substances' properties and changes, and pure substances and compounds that seventh grade students learn and understand on the sub-microscopic level. According to the Slovenian educational system, the concept of pure substances and compounds and substances, their properties and changes, are introduced in grade 4 (age 9) of lower primary school at the macroscopic level and then upgraded until grade 7 (age 12), where the topic is then introduced at the sub-microscopic level. The responsibility of the teacher is to present these chemical learning themes at the sub-microscopic level.

On the sub-microscopic level, appropriate displays of atoms, ions or molecules can be seen with the use of virtual laboratory animations. Figure 2 shows the role of the virtual laboratory and its visualisation material that connects all three levels of interactive form. The display of changes on the dynamic sub-microscopic level and the use of visualisation elements can overcome the gap between macro and micro worlds, thus leading to a better understanding of the learning material. We can visualise submicro demonstrations with the help of a static 2D or 3D picture. We can demonstrate, with the help of animation, sub-micro presentations as dynamic or even

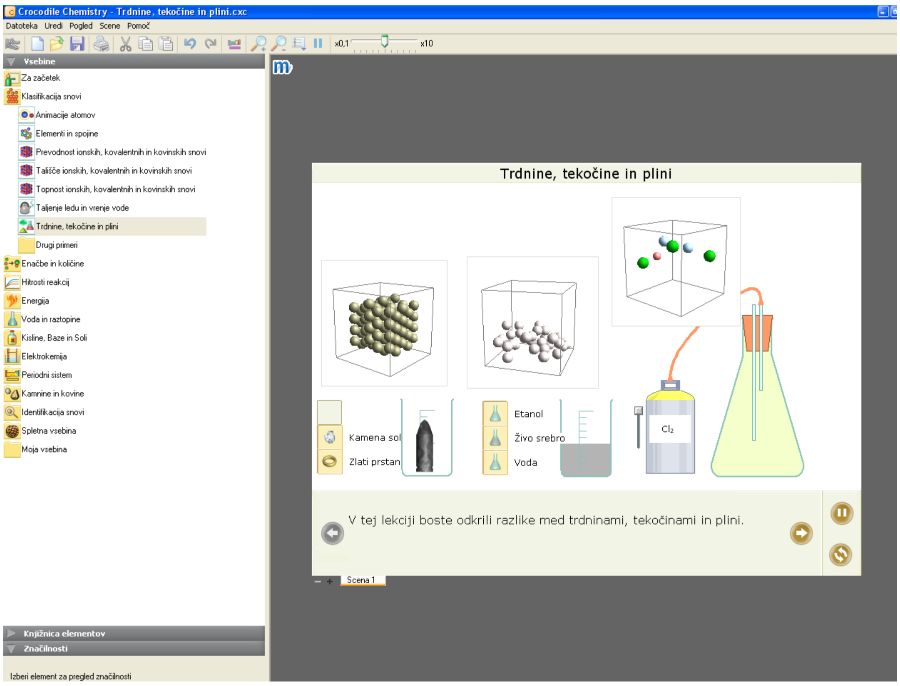

Figure 1. Solid, liquid, and gaseous aggregate state- an example of the content used in an experimental group's class

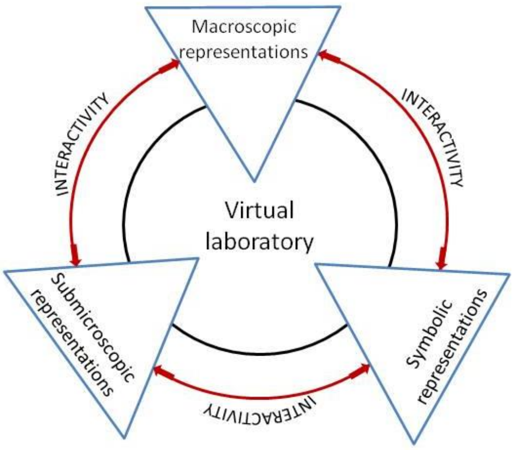

Figure 2. Three levels of science phenomena visualisation, and the role of a virtual laboratory as an interactive visualisation element

interactive where animations can be combined with videos and symbolic notes. On this basis, we designed a teaching experiment aimed at verifying the effectiveness of a virtual laboratory that enables a dynamic sub-micro demonstration in terms of pupils' science knowledge in the seventh grade.

Research hypothesis

H1: we assumed that experimental group students (EG) where the sub-micro level was presented dynamically with the help of a virtual laboratory, would have an advantage when compared to control group students (CG) in regard to knowledge of selected topics in chemical science

H2: we assumed that EG pupils compared to CG pupils would have an advantage according to the reproduction of knowledge

H3: we assumed that EG pupils compared to CG pupils would have an advantage according to understanding of the concepts

H4: we assumed that EC students/ EG students compared to CG students would have an advantage according to the use of chemical knowledge at science classes.

METHODOLOGY

Research method

In order to study the impact of classes' performances when using virtual laboratories, we used an experimental method from traditional empirical-analytical educational research. We were interested in the effects on pupils' knowledge, when the sub-micro level is presented dynamically with the help of a virtual laboratory. Knowledge is reflected on three levels: reproduction, comprehension, and the application of knowledge. An educational experiment was conducted during science classes that encompassed chemical contents that pupils learn in the seventh grade:

1. Substances, their properties and changes and
2. Pure substances and compounds.

Experimental model

We designed a one-factor experiment with parallel classes of compared groups (experimental (EG) and control groups (CG)) and one nonexperimental factor (previous socre). On the base of previous score we designed experimental and control group so that there were equal. Both groups of students were learning new material

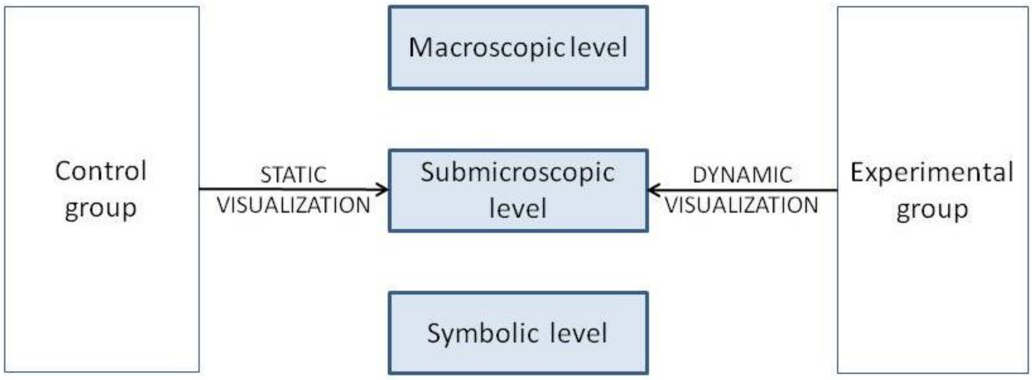

Figure 3. Schematic implementation of the survey in class

through practical, real, and experimental work. This was followed by describing the macro concept and its interpretation on the sub-microscopic level using symbolic illustrations. In doing so, teachers in the CG used 2D or 3D images in the textbook or used a computer to explain the sub-microscopic level of the concept (static visualization). The EG teachers used a virtual laboratory (dynamic visualization) for explanation (see Figure 3). A virtual laboratory enables laboratory work in virtual space and simultaneously the visualisation of the three levels, of which the sub-micro level is animated. In the classroom we used the Crocodile Clips Chemistry program within a virtual laboratory. This program is easy to use and accessible for home use, so that teachers can use it to prepare for their lessons at home. The experimental factor had two modalities:

- Teaching science according to the standardised curriculum using the approach as used by teachers in everyday classrooms where the sub-micro level of the experiment is explained with the help of static demonstrations; (CG),
- Teaching the subject according to the standardised curriculum where the sub-micro level is demonstrated with the help of animation (EG).

In order to ensure internal validity, we controlled the initial status of those factors relating to the pupils. All students, both the experimental and control groups, attended the 7th grade of primary school (average age was 11.4 years) and were taught the same learning contents according to the same curriculum. Statistically-significant differences between the compared groups (EG and CG) were identified using the $\chi2$ - test. The gender structure in both groups was quite similar ($\chi2 = 0.02$, $P = 0.887$). The groups were not differentiated according to their science final grades, and therefore this difference was statistically insignificant ($\chi2 = 3.048$, $P = 0.384$). These data ensured internal validity because we estimated both groups as being identical before the experiment. In order to minimise the probability of uncontrolled actions on the part of the teacher biasing either the control or experimental modality, materials for both groups were prepared up front, as was a unified worksheet for an hour of consolidation following the presentation of the thematic unit, together with instructions. The instructions contained: (1) content set, (2) operative objectives, (3) standards of knowledge, (4) instructions re the content of the virtual laboratory (for EG), (5) instructions for slideshows (for CG), (6) notes for teachers, and (7) the worksheet. Accordingly, the only difference in teaching materials and protocol between the control and experimental groups lay within the mode of visualization; namely, through static visualization (with the aid of electronic slides) in the CG, and dynamic visualization (with the aid of the virtual laboratory) for the pupils in the EG. 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

Table 1. Number (f) and percentage (f %) of participating pupils in the experimental (EG) and control (CG) groups, based on gender

GROUP	f	f%
EG	62	56.9
CG	47	43.1
TOTAL	109	100

compounds' from their science knowledge points of view (chemical part), expressed as:

- Their total scores in the science test, and
- Their results from science knowledge testing regarding the three levels of Bloom's taxonomy: knowledge, comprehension, and application of knowledge.

Defining the sample

109 pupils (N = 109) from five different school in the north-east of Slovenia were involved in this didactic experiment (Table 1). We included seventh grade pupils aged eleven and twelve. The model used during the didactic experiment was not a coincidental model. The pupils were divided into experimental (EG) and control groups (CG).

A select group of students represented, within the context of statistical hypothesis testing, a random sample from the hypothetical population.

Data collection procedures

Data were collected by testing students' knowledge after lessons. Furthermore, we carried out a rational and empirical validation of the tests. Rational validation was based on assessing the appropriateness of the content, and the design of the test. For empirical validation we used a factor analysis solution, namely the percentage of explained variations by the first common factor (% ex. var. F1). Given that the first factor explained 24.5% of the variance and was above the limit of the criterion for the lower limit (20%), we concluded that the examination was valid. In order to determine the reliability of the examination we used Cronbach's alpha coefficient ($\alpha = 0.832$). This confirmed that it was a reliable instrument for assessing knowledge after the experiment. The objectivity of the knowledge testing was provided by detailed instructions. The questions in the test were both closed-ended and open-ended. The results for both groups were evaluated by the same teacher according to the criteria.

In February 2011 we defined the experimental and control groups, and determined the school at which the experiment was eventually to be carried out. Implementation of the didactic experiment followed. The experiment was carried out by a teacher who taught chemistry in that particular school. Following the completion of the didactic experiment we tested the students' knowledge once more to detect their progress on learning, and compared one group with the other.

Knowledge testing

Knowledge testing after the experiment consisted of 14 tasks (maximum 42 points). The test was designed as a paper & pencil exam. The tasks (Table 2) were arranged into three categories in accordance with Bloom`s cognitive scale:

- Basic level of knowledge (B) – knowledge of facts, concepts and procedures: six tasks (tasks 2, 4, 6, 11, 13, 14).
- Higher level of knowledge (H) – comprehension of facts, concepts and procedures: three tasks (tasks 1, 3, 8).
- Advanced level of knowledge (A) – application, reasoning and argumentation: Five tasks (tasks 5, 7, 9, 10, 12,).

Table 2. Matrix diagram of the test

Task No.	No. of Points	Concepts	Listing in the Curriculum	Type of Task	Knowledge Category Basic-Higher-Advanced B	H	A
1	4	State of matter	Matter consists of particles	Gap fill		*	
2	3	State of matter	Matter consists of particles	Multiple choice	*		
3	1	Chemical reaction	Physical and chemical changes of matter	Free response		*	
4	3	Illustration of gaseous particles	Matter consists of particles	Schematic drawing	*		
5	2	Compound	Mixtures and pure substances	Multiple choice			*
6	1	Separation of substances from a mixture	Methods of separation of pure substances from a mixture	Free response	*		
7	2	Sugar, water, solution	Solutions	Gap fill			*
8	6	Pure substance, submicroscopic representation	Mixtures and pure substances	Gap fil		*	
9	4	Separation of substances from a mixture	Methods of separation of pure substances from a mixture	Gap fill			*
10	2	Physical change	Physical and chemical changes of matter	Multiple choice			*
11	3	Element and compound	Mixtures and pure substances	Multiple choice	*		
12	3	Chemical reaction	Physical and chemical changes of matter	Free response			
13	5	Physical and chemical change	Physical and chemical changes of matter	Gap fill	*		
14	3	Filtering	Physical and chemical changes of matter	Multiple choice	*		
42	**Points in Total**		Total:	Tasks	6	3	5
				Points	14	6	10
				Percentage	46.7	20.0	33.3

Performance evaluation was conducted according to the criteria, and a scale of achieved points.

Data processing procedures

The data was processed using the SPSS (Statistical Package for the Social Sciences) program, treated at the level of descriptive and inference statistics. We used factor analysis and the Cronbach's alpha coefficient (α) for analysing the metric characteristics. The non-parametric ($\chi2$ – test) was used for analysing the differences between the groups before the experiment. When analysing the differences between the groups after the experiment, we used the parametric t-test for independent samples.

RESULTS

After carrying out the experiment, we analysed the pupils' knowledge using a test. We analysed the total points scored. Table 3 displays the results of the t-test regarding the differences between experimental and control group.

The assumption of homogeneity of variance ($F = 1.957$ $P = 0.165$) was not violated. 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 gained more knowledge in comparison with those pupils who were taught using no additional explanation at the sub-microscopic level. The difference between the arithmetic 'means' for pupils in both groups was statistically significant (t = 8.850; P = 0.000). We can hereby confirm from the first hypothesis (H1) was upheld, namely that the experimental group of pupils would have an advantage over the control group, according to their knowledge of taught chemical content after the experiment.

Analysis of the differences between the experimental and control groups at their various levels of knowledge

Knowledge testing consisted of three levels of questions according to Bloom's taxonomy of objectives for the cognitive area: knowledge, comprehension, and application of knowledge. The chart below (Figure 4) shows the arithmetic 'means' for individual levels of knowledge when testing substance knowledge.

The graphical display shows that the line of the experimental group (EG) is above the line of the control group (CG). The line of the achieved results drops because there were more queries on the level of knowledge and fewer queries on the level of comprehension and the application of knowledge. Pupils were less successful dealing with these questions. Distinct differences were visible regarding comprehension, and the application of knowledge. Whether the detected differences are statistically important is shown by the results in Table 4.

a) Achievements for knowledge testing questions.

The results show that the assumption of homogeneity of variances was violated (F = 4. 866, P = 0. 030). This is why we used the Welch proximal method of variance analysis for testing differences. The results of the t-test showed statistically-significant differences between the experimental and control groups of students (t = 6.685; P = 0.000). On the reproduction of knowledge the experimental group's pupils had an advantage over the control group's pupils. We hereby confirm the second hypothesis (H2), that EG pupils would have an advantage over the CG pupils regarding the reproduction of knowledge after the experiment was finished.

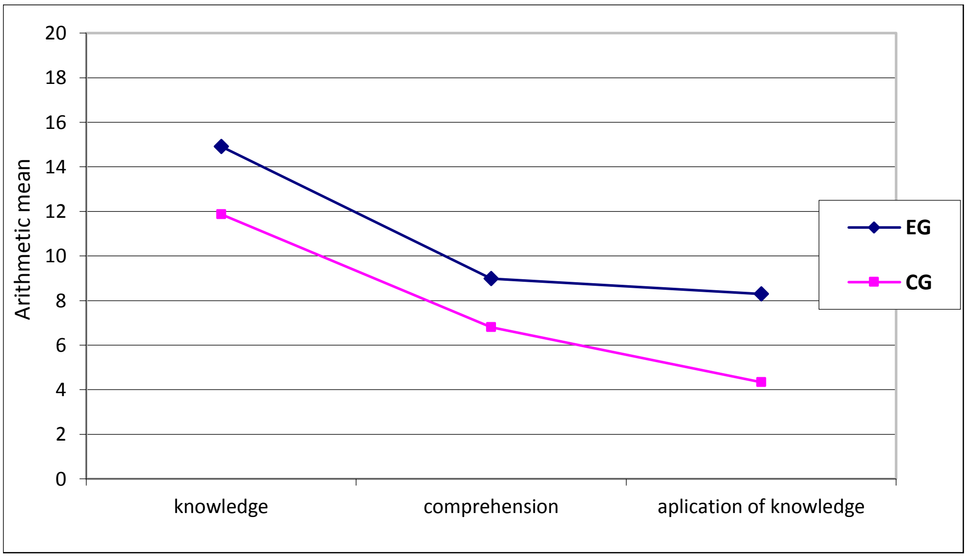

Figure 4. The arithmetic 'means' for the students' acomplishments (EG and CG) on the various levels of questions testing chemical content, after the experiment

Table 3. Results of the t-test regarding the differences between the experimental (EG) and control (CG) groups in their total scores on knowledge testing after the experiment

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

Table 4. Results of the t-test between the experimental (EG) and control groups (CG) regarding accomplishments concerning knowledge, comprehension, and application of knowledge questions

	GROUP	Numerous n	Arithmetic mean $\bar{x}$	Standard deviation	Test of homogeneity of variances		t -test	
KNOWLEDGE	EG	62	14.91	2.27	F	P	t	P
	CG	47	11.87	3.09	4.866	0.030	5.685	0.000
COMPREHENSION	EG	62	8.98	1.76	F	P	t	P
	CG	47	6.80	2.87	18.370	0.000	4.872	0.000
APPLICATION	EG	62	8.29	2.45	F	P	t	P
	CG	47	4.34	2.31	0.128	0.722	8.530	0.000

b) Achievements from comprehension testing

The assumption of homogeneity of variances (F = 18. 370, P = 0. 000) was violated .This is why we used the Welch proximal method of variance analysis when testing the differences. The results from the t-test (P = 0.000) showed that the experimental group's pupils ($\bar{x}$ = 8. 98) were better at knowledge testing questions than the control group's pupils ($\bar{x}$ = 6. 80) (knowledge testing after the experiment). At the level of conceptual understanding the pupils in the experimental group had an advantage over the control group's pupils. We hereby confirm the third hypothesis (H3), that the EG students would have an advantage over the CG students in regard to understanding the concepts after the experiment was finished.

c) Achievements for the application of knowledge-testing questions

Table 4 shows that the assumption of homogeneity of variances (F = 0. 128, P = 0. 722) was not violated. The results of the t-test showed that there was a statistically significant difference (P = 0.000) between the experimental group's pupils ($\bar{x}$ = 8. 29) and the control group's pupils ($\bar{x}$ = 4. 34). In terms of knowledge application the experimental group's pupils also had an advantage over the control group's pupils. We hereby confirm the fourth hypothesis (H4), that the EG students would have an advantage over the CG students when applying their knowledge after the experiment was finished.

DISCUSSION

In the presented study we identified statistically-significant effects within the area of chemistry knowledge on the experimental groups. Better results can be argued concerning the use of a virtual laboratory. The experimental groups' pupils were given the chance to participate in explaining concepts on all three levels: macroscopic, symbolic, and sub-microscopic levels (this level was animated). It is difficult for students to form dynamic mental models on the sub-microscopic level. Therefore the help of a certain media is necessary. The best media for this job is animation of the process (Rodrigez at al. 2001, Yang e tal. 2003) - an element that the experimental group had the privilege of experiencing. The advantages of using a virtual laboratory were proven during a chemistry analysis study. (Zimmerer et al.2003).

The control group's students were taught in classes based on the curriculum according to the traditional approach of teaching (teacher-led lectures, use of textbooks and experimental work) as used by the teacher in the classroom. Changes were shown at the macroscopic level and also at the symbolic and sub-microscopic level (the sub-micro level of the experiment is explained only with the help of static demonstrations). Using virtual laboratory represents an upgrading of traditional teaching (Chin 1999). Virtual laboratory simultaneously connects all three levels of chemical concept. Experiments can be performed as in the real world, whilst at the same time we can monitor changes on the macroscopic level and on the sub-micro animation of interactions. With one click on the mouse we can see the format of the concept using symbolic chemical language. In this respect the pupils in the experimental group had an advantage over the control group where the visualisation of the sub-micro world was not presented dynamically. Well-designed laboratories, on the basis of educational theory, can lead to better learning outcomes (Abdulwahed and Nagy 2009).

The number of experiments carried out in schools and universities is usually limited due to safety reasons, lack of adequate infrastructure, equipment, due to limitations of time and space, and also due to poor precision in the implementation of experimental exercises (Sokoutis 2003). Logistical constraints (more especially relating to funding) place significant limitations on the abilities of schools to provide and maintain high-quality science laboratory experiences and equipment (Lowe et al. 2012). The experimental group's pupils could do the experiments several times and did not have such limitations due to their virtual laboratory.

Other studies have shown that the use of animations and visualisations contributes to students' and pupils' conceptual understanding (Barak and Dori 2005), learning achievements (Dori et al. 2003; Dori and Belcher 2005; Abdulwahed and Nagy 2009; Zimmerer et al. 2003), spatial abilities (Barnea and Dori 2000), and motivation to learn science (Barak et al. 2011; Sun, Lin and Yu 2008). Sanger et al. (2000) compared the understanding of changes when heating water in an open can and cooling water in a closed can. They found statistically significant differences between the control (sub-micro level of the experiment is explained with the help of static presentations) and experimental group where the sub-micro level is presented with the help of animation. Yang et al. (2003) state that the students, who were present at lectures using animated demonstrations of chemical reactions, had significantly better understanding of electrochemistry than those students present at lectures with only stationary demonstrations. Dynamic animations may help students better understand the submicroscopic nature of matter. The positive results presented during our study and in the studies mentioned above, can be explained due to dynamic sub-microscopic presentations of scientific concepts to the experimental group's pupils.

CONCLUSION

Our basic empirical findings are:

At the primary level of science education and chemical contents we set-up the visualisation process in a virtual laboratory that simultaneously connected all three levels of the chemical concept (macro, sub-micro, and symbolic levels), and dynamically demonstrates the sub-micro world with the help of animations. We identified statistically-significant positive effects on science knowledge at the higher level of the experimental group. The consolidation of knowledge on the topics 'Substances, their properties and change' and 'pure substances and mixtures' was made by a virtual laboratory. Not only have we identified statistically-significant positive effects on the reproduction of knowledge; the pupils of the experimental group also achieved statistically-significant better results for their measurements of knowledge and understanding in the usage of the acquired knowledge, and so were successful in achieving higher cognitive objectives.

We can conclude that the use of a virtual laboratory can affect the formation of mental models at the sub-microscopic level. These dynamic models and animations, which are enabled by a virtual laboratory, when compared with the static sub-micro presentations, proved to be more appropriate for the understanding of chemical concepts. These studies, unlike ours, were not carried out at the primary level of education.

IMPLICATIONS FOR TEACHING

It is important that teachers teaching in primary schools, where the foundation of science skills in presenting and interpreting the subject matter are initially laid, involve all three levels (macroscopic, symbolic, and sub-microscopic) regarding chemical concepts, thereby offering pupils the best possible development of an appropriate mental model of science concepts. If in the process of acquiring scientific skills pupils' own active research is important, this should be put into practice in the chemistry classroom using laboratory experimental work. However, whilst teaching a specific topic, teachers should not forget that the classical laboratory work is used so that the pupils perceive the world only on the macroscopic level. It is therefore important that specific topics are reinforced by interpretations at the symbolic and sub-microscopic levels using dynamic visualisation. Otherwise, students will only remember some abstract knowledge- and such knowledge is short-term. The use of multi-media software and computer animations that illustrate those changes that the atoms, ions, and molecules undergo during chemical reactions can further reinforce the relationships between the observed changes and the changes at the particulate level (Ardac and Akaygun 2005, 2006; Tasker and Dalton 2006).

A virtual laboratory offers some important advantages and a new form of education. The aim of virtual reality is to provide realistic simulations of chemical processes, so that pupils and students are actively involved in the learning process, as they remember more through their own active participation. A virtual laboratory provides a safe environment without risk so that pupils and students would better understand the theory and concepts, and can thus repeat the experiments without risk. Therefore, we propose the use of virtual classroom laboratories 1) as a teaching tool during the phases of new topics, 2) as a combination of learning devices in the consolidation phase of learning materials, and 3) as a teaching tool with which students virtually prepare for the real practical work.

The role of the teacher is to plan work well-based on the pedagogical theory. Amongst the multitude of teaching tools that are available for teaching and learning chemistry, what matters is the teachers' autonomy to select pupil-adjusted tools for their learning styles and abilities, that are in accordance with the curriculum. If he/she does not, then the side-effects are negative results. Animations may carry a potential for misconceptions since in most cases they are simplified versions of a phenomenon (Schnotz and Rasch 2005).

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 verify the need for educational strategy changes regarding science and chemistry didactics.

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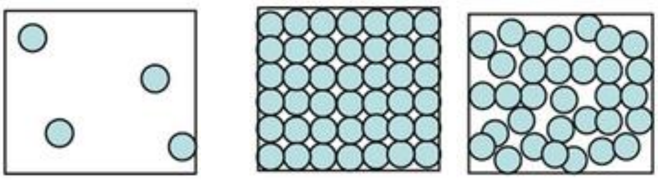
APPENDIX

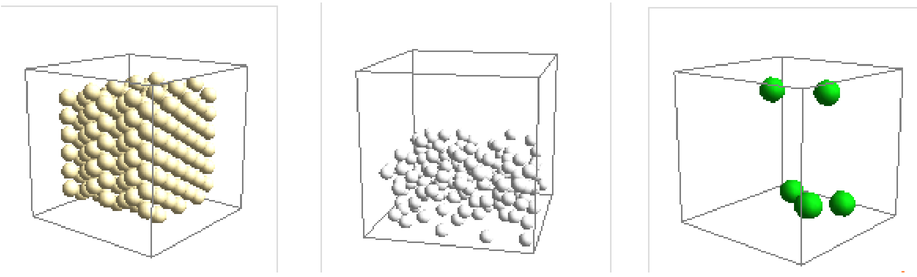
Sample items from the test

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.



__/1

8. This sketch shows the process of:

A) Chromatography
B) Decanting
C) Distillation
D) Filtering
E) Separation by a funnel

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APPENDIX 2

Virtual laboratory screens