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DYNAMIC VISUALIZATION IN THE VIRTUAL LABORATORY ENHANCES THE FUNDAMENTAL UNDERSTANDING OF CHEMICAL CONCEPTS

Nataša Rizman Herga,
Saša A. Glažar,
Dejan Dinevski

Abstract. *In natural science education it is important that the macroscopic, submicroscopic and symbolic levels are interconnected in a student's mind. Primary school children have the greatest difficulty in understanding the sub-microscopic, which is outside their experiential framework. This research examines the classroom application of the virtual laboratory in integrating macroscopic, submicroscopic and symbolic aspects of chemistry. Pupils of the seventh grade, aged between 12 and 13 years (N = 225), participated in the didactic experiment that was conducted in ten primary schools in Slovenia. The fundamental research question was whether pupils studying the same natural science content using the virtual laboratory performed better than those who did not.*
The results of the experiment revealed that in terms of knowledge acquisition the use of a virtual laboratory improved pupil performance in relation to those who did not use elements of dynamic visualisation in the classroom. In accordance with Bloom's cognitive scale, it was demonstrated that in relation to basic, higher and advanced levels of knowledge and comprehension, the use of the virtual laboratory positively influences pupils' understanding of selected concepts in chemistry.

Key words: *virtual laboratory, dynamic visualization, chemical concepts, submicroscopic level.*

Nataša Rizman Herga
Ormož Primary School, Ormož, Slovenia
Saša A. Glažar
University of Ljubljana, Slovenia
Dejan Dinevski
University of Maribor, Slovenia

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; indeed, they may only perceive changes at the macroscopic level by 'hands-on' experimental work. Pupils' abilities to use the macroscopic, submicroscopic and symbolic representations are essential for understanding related concepts and phenomena. In the teaching and learning of concepts in natural science, it is important to connect the macroscopic, submicroscopic and the symbolic levels in the minds of pupils (Johnstone, 1991; Devetak & Glažar, 2010; Chittleborough, 2014). The starting point for an understanding of concepts in chemistry is their macroscopic manifestation which we can perceive with our senses. An explanation of macroscopic observation and the interconnected concepts derives from an understanding of the submicroscopic and the fact that matter is built of particles. Macroscopic observations and submicroscopic representations can also be translated and understood symbolically, namely as the formulae of elements and compounds, the symbols and notation of chemical changes in the form of equations and other schematic and graphical presentations. At the same time, experimental work in the classroom is crucial in the perception of the macroscopic and exerts a strong impact on the motivation of pupils; accordingly, it plays an important integral part in the teaching and understanding chemistry. Through experiments pupils learn about the physical and chemical properties of substances, develop their skills of observation and description of chemical processes, enhance and strengthen their knowledge, as well as acquire manual dexterity and abilities to undertake safe experimentation, from which an investigative approach to research derives.

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Most concepts in chemistry are abstract, thus it is not possible to perceive them in the macroscopic world. To the pupil, such abstract concepts as atoms, electrons, elements, molecules and compounds, are more difficult to understand because a young mind is not always able to mentally connect them to an appropriate abstract model (Devetak & Glažar, 2007). Pupils encounter a world of particles at the age of twelve, when learning about such macroscopic phenomena as, for example, the interpretation of the physical states of matter (Harrison & Treagust, 2002).

Many researchers (Hartley, 1988; Baker, 1991; Lelouche, 1998) suggest that computers in natural science classrooms serve as interactive communication tools and provide access to various types of information, such as texts, graphic materials and the like. With the aid of a PC and a computer animation, concepts can also be displayed dynamically in two or three dimensions, or even in an interactive form in combination with videos and symbolic records. A great many researchers report findings which confirm that the use of computers in the science classroom results in better learning outcomes (Dori & Barnea, 1997; Chu & Leung, 2003; Dori et al., 2003; Zimmerer et al., 2003; Kocijancic & O'Sullivan 2004; Keller, 2005; Dori & Belcher, 2005; Abdulwahed & Nagy, 2009; Rajendran et al., 2010; Barak & Dori, 2011; Rizman-Herga & Dinevski, 2012). The study by Smith & Villarreal (2015), however, showed that the use of animations had no effect on the students' views on the movement of particles within the liquid.

The integration of visualizations during class stimulates pupils' conceptual comprehension (Barak & Dori, 2005), develops their spatial skills (Barnea & Dori, 2000), and positively influences their motivation for learning natural sciences (Barak et al., 2011; Sun et al., 2008). The use of multimedia software and computer animation, which demonstrate chemical changes on the particle level, engenders an understanding of chemical changes at the macroscopic level (Arcad & Akaygun, 2005, 2006; Tasker & Dalton, 2006; Dori & Belcher, 2005). 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).

Visualization is important in connecting the macroscopic, submicroscopic and symbolic (Barke & Wirbs, 2002), while the virtual laboratory is an appropriate tool in achieving visualization (Wu et al., 2001).

Figure 1 portrays the role of the virtual laboratory as an interactive element in connecting macroscopic changes with their explanation at the submicroscopic level and record at the symbolic level.

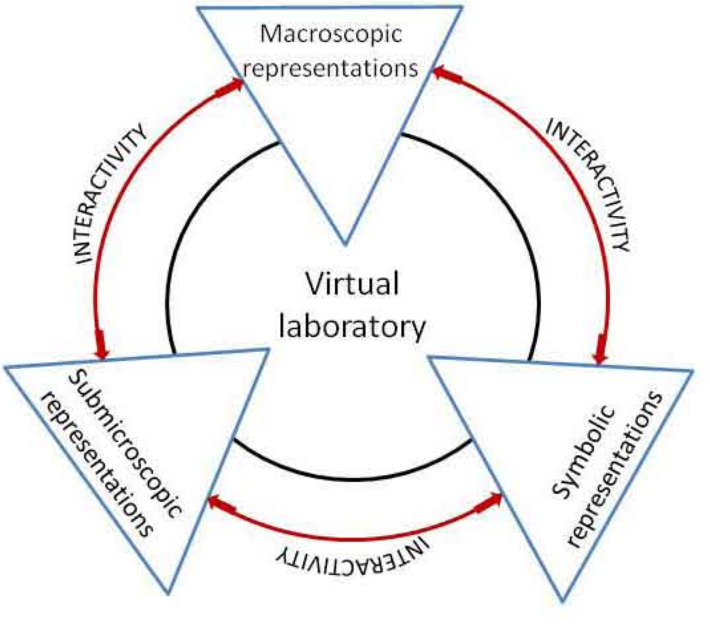

Figure 1: The role of the virtual laboratory as an interactive element in the visualization of three levels of a concept.

A series of issues and limitations, such as health and safety, lack of equipment, spatial as well as temporal restrictions, represent barriers to the undertaking of high-quality experimental work in schools. Such obstacles can be circumvented through the use of the virtual laboratory, and its great advantage over the physical one is that it enables the performance of expensive and dangerous experiments as well as the observation of those which occur too fast or too slow in the physical world. Pupils can observe or simulate chemical experiments that are difficult to implement in the classroom, which do not facilitate observation or reliable measurement, as well as include risks to health, or necessitate expensive supplies or equipment which are conventionally not at hand (Georgiou et. al., 2008). The use of computer simulations can be helpful in improving problem solving scores (Avramiotis & Tsaparlis, 2013). Despite the fact that virtual laboratories cannot fully replace actual experiments (Hawkins & Phelps, 2013) they are - if used appropriately - a very effective complementary tool (Georgiou et. al., 2008; Domingues et. al., 2010).

Research which has examined the efficiency of the virtual laboratory reveals it to be a suitable tool in e-learning (Rajendran et. al., 2010), with which chemistry pupils can prepare themselves for the actual practical work (Dalgarno et. al., 2009; Georgio et. al., 2008; Abdulwahed & Nagy, 2009; Rajendran et. al., 2010; Domingues et. al., 2010). The use of the virtual laboratory substantially contributes to an understanding of experimental work and the development of autonomy at work, together with a more appropriate analysis and interpretation of results.

Research Aim

The research examines the influence of the virtual laboratory on the quality of knowledge attained by pupils aged 12-13 (seventh grade of primary school) in Slovenia. The research was confined to two subject areas:

1) Matter, its characteristics and changes, and

2) Pure substances and mixtures.

Twelve-year-old pupils deal with these contents in the science classroom as part of the curriculum. The research protocol aimed to analyse how dynamic submicro particle animations of matter using the virtual laboratory affected the pupils' knowledge and understanding of selected concepts in chemistry and on the quality of knowledge.

Research Hypotheses

H_1: There is a statistically significant difference in the quality of knowledge of pupils who learn selected concepts using the virtual laboratory in relation to those who learn those same concepts through lecture style instruction.

H_2: There is a statistically significant difference in the ability to solve tasks which require the reproduction of knowledge among pupils who learn selected concepts using the virtual laboratory in relation to those who learn those same concepts through lecture style instruction.

H_3: There is a statistically significant difference in the ability to solve tasks which require an understanding of knowledge among the pupils who learn selected concepts using the virtual laboratory relative to those who learn those same concepts through lecture style instruction.

H_4: There is a statistically significant difference in the ability to solve tasks requiring the application of knowledge among pupils who learn selected concepts using the virtual laboratory relative to those who learn those same concepts through lecture style instruction.

Methodology of Research

Research Design

The experimental research was carried out. The research was of a pre-test and post-test design, involving an Experimental Group (EG) and a Control Group (CG) The effect of the use of the virtual laboratory on the pupils' knowledge was studied (see Figure 2).

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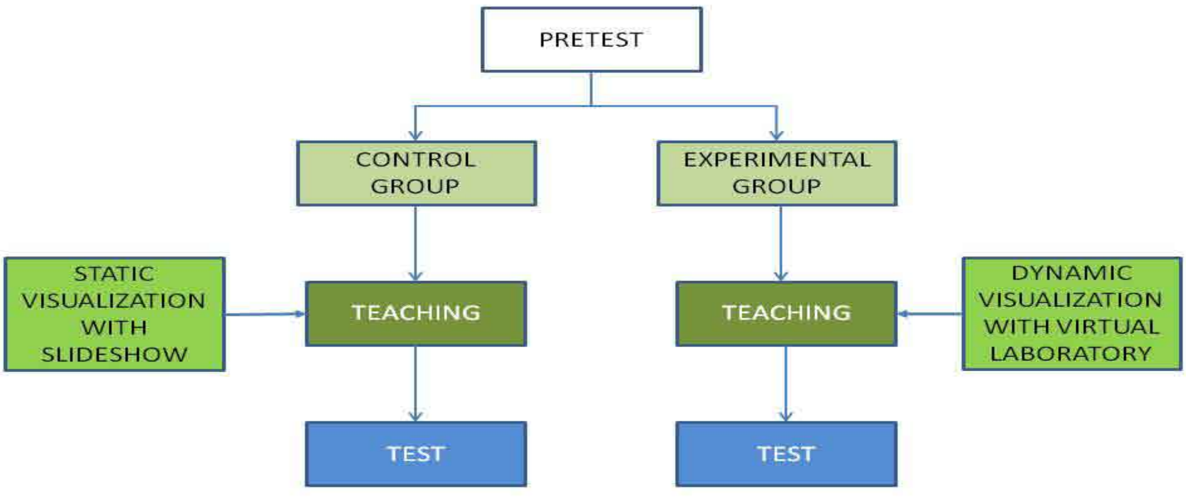


Figure 2: The implementation of the pedagogical experiment.

The experimental factor had two modalities: teaching the specific content following the established curriculum using the approach as used by teachers in everyday classrooms where the submicroscopic level of the experiment is explained with the help of static slideshows (CG), and teaching that same content where the submicroscopic level is demonstrated with virtual laboratory to enable the dynamic visualization of the content (EG). 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 for 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 (see Table 1).

Table 1. Contents with concepts included in the research.

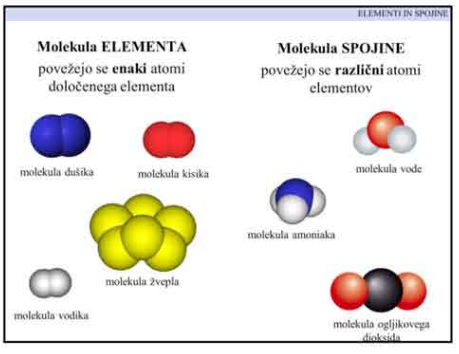
CONTENTS SET: LESSON UNITS:	Number of hours	Concepts	Experimenting		Visualization	
			CG	EG	CG	EG
Pure Substances Granular Mixtures	3	- pure substance - mixture - chemical element - compound	Actual	Actual and Virtual	Slideshow	Virtual Laboratory
Solutions	3	- solution - solvent - solute				
Methods of Separating Pure Substances from Mixtures	3	- filtration - crystallization - distillation - funnel separation - chromatography - sublimation				
Physical and Chemical Changes of State	3	- physical change - chemical change - chemical reaction - reactant - product - complete combustion - incomplete combustion				

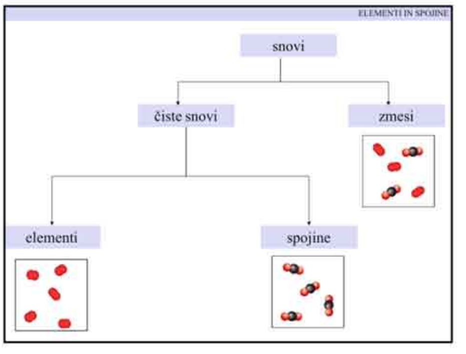
An example of the use of teaching materials in the control and experimental group

Lesson unit: Elements and compounds
Subject contents: Pure substances and mixtures

The objectives of the lesson unit are that a pupil (1) differentiates between pure substances and mixtures, (2) realises that pure substances are chemical elements and compounds, and (3) understands that chemical elements consist of a single type of atom, whilst in compounds atoms of several elements are held together by chemical bonds.

In addition to the conventional materials for the execution of a lesson, control group teachers also included prepared slides (Figures 3 and 4) which present only a part of the materials prepared for teachers. Through a slideshow (static visualization), the pupils differentiated between pure substances and mixtures in order to realise that pure substances are chemical elements and compounds. The slide (picture on the left) allowed the pupils to become familiar with the molecules of elements and compounds as well as to learn the difference based on what they saw (a molecule of an element consists of a single type of atom, whilst a molecule of a compound consists of different atoms).





Figures 3 and 4: An example of the teaching materials in the Slovene language provided to the control group: static visualization through slideshows.

Besides the aforementioned conventional materials used in the lesson, the teachers of the experimental group also included a virtual laboratory (Figure 5). Figure 5 is the static counterpart of the dynamic picture provided by the virtual laboratory.

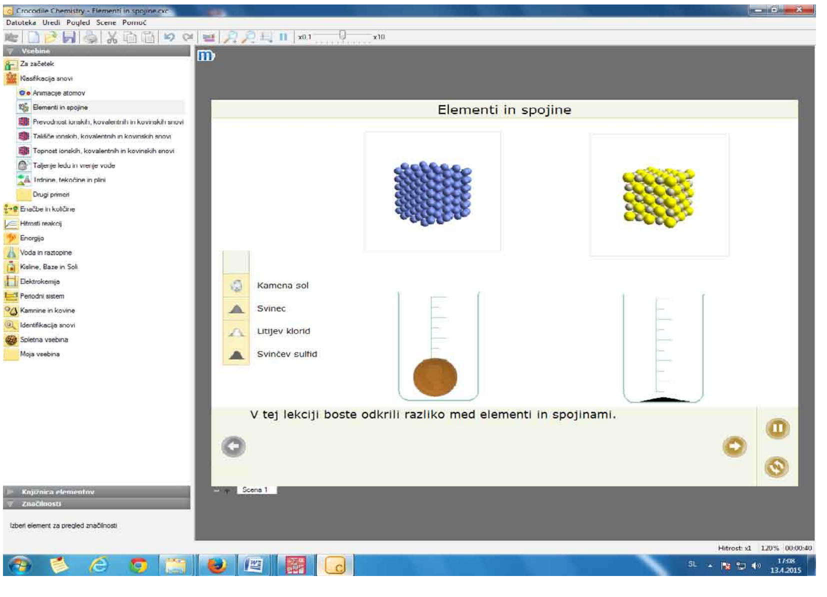


Figure 5: Dynamic visualization provided for the experimental group using a virtual laboratory.

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Virtual Laboratory

The *Crocodile Chemistry* virtual chemistry laboratory (Gorghiu et. al. 2009), which is an interactive simulation program that facilitates the safe presentation of experiments, was used in this research. The program serves a tool which can be used by the teacher to demonstrate experiments in front of a class, thus there are a range of pre-pared collections of experiments ready to use. Alternatively, the program can be used as an aid to actual physical classroom experiments utilising chemistry laboratory equipment and chemicals. *Crocodile Chemistry* features: (1) adjustable animations and simulations, (2) the possibility to display data using charts, (3) a large set of chemical elements and chemicals, and (4) the possibility for pupils to work independently. Animations can be viewed at the submicroscopic level, with appropriate displays of atoms or molecules.

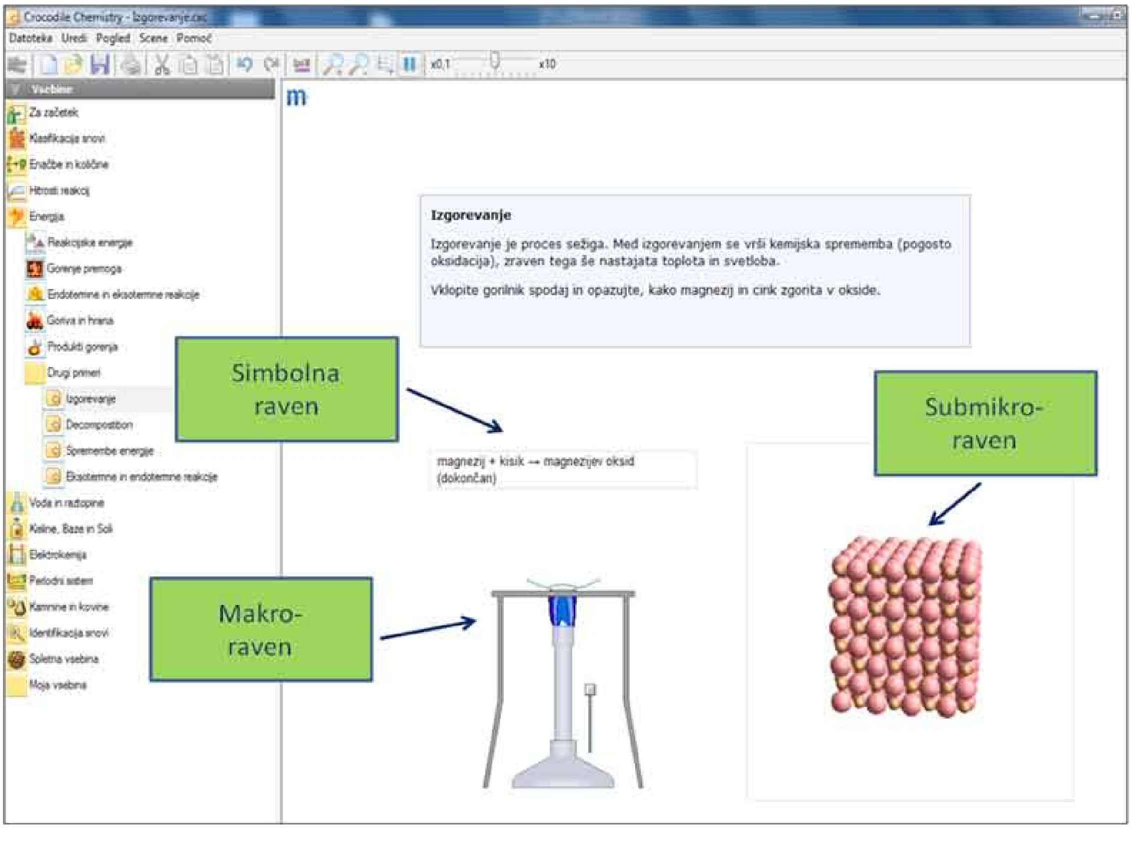

Figure 6: The *Crocodile Chemistry* virtual laboratory in the Slovene language, with a simultaneous presenta-tion of a chemical concept.

Figure 6 provides an example of the use of the virtual laboratory in an experiment in which magnesium is burned. Pupils can observe the experiment at the macroscopic level, while at the same time they can observe changes at the level of particles (submicroscopic level) in conjunction with those same conversions recorded through chemical equations (symbolic level). Thus, the virtual laboratory enables the integration of all three levels of a chemical concept into a homogenous entirety which provides meaning to the abstract concept. If this experiment was conducted solely in an actual laboratory, pupils would detect only those changes occurring at the macroscopic level. The teacher would then explain the changes at the submicroscopic particulate level as well as record the reaction symbolically using a chemical formula.

Prior to the implementation of the actual research program, teachers were introduced to the project and its purpose; this encompassed familiarisation with the step-by-step conduct of the program plan and the prepared materials, in order that they might equivalently and validly participate as executors of the study. By way of a pair of tests before and after the study period, the pre-trial and post-trial knowledge of pupils was measured and recorded for both the experimental and control groups. The comparability of pupils' knowledge of chemistry and natural science was first ascertained for all participating pupils in both the experimental and control groups to ensure the attribution of observed differences in efficiency of the two didactic approaches and thus the internal validity of the study itself.

Participants

The pedagogical experiment involved 225 seventh grade of primary school pupils (N = 225), with an average age of 11.4 years; these pupils were drawn from ten state primary schools in Slovenia.

At the level of inferential statistics, the given cohort represents a simple non-probability sample drawn from a hypothetical population of primary school pupils.

Table 2. The number (f) and percentage (f %) of pupils according to the group.

Group	f	f %
Control Group (CG)	81	36.0
Experimental Group (EG)	144	64.0
Total	225	100.0

Data Collection Procedure and Instruments

Prepared tests:

- Pre-test of each pupil's knowledge of natural science (6th grade chemistry pupils aged ~11) conducted in the 2012/13 school year by means of which the internal validity of the trial was established; and
- Post-test of each pupil's knowledge of natural science (7th grade chemistry pupils aged ~12) conducted in the 2013/14 school year upon conclusion of the trial.

The pre-test was designed as a paper & pencil exam. It consisted of 10 tasks for the evaluation of knowledge (yielding a possible maximum 13 points). Experts from the field of science education arranged items into three categories in accordance with Bloom's cognitive scale:

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

The post-test, following completion of the trial was likewise designed as a paper & pencil exam. It consisted of 15 tasks for the evaluation of knowledge (yielding a possible maximum 30 points). Again, the tasks were arranged according to the Bloom's cognitive scale into three categories:

1. Basic level of knowledge (B) – knowledge of facts, concepts and procedures: eight tasks (tasks 1, 2, 3, 4, 5, 11, 14 and 15).
2. Higher level of knowledge (H) – comprehension of facts, concepts and procedures: three tasks (tasks 8, 10, and 12).
3. Advanced level of knowledge (A) – application, reasoning and argumentation: four tasks (tasks 6, 7, 9 and 13).

Table 3. Matrix diagram of the post-test.

Task No.	No. of Points		Concepts	Listing in the Curriculum	Type of Task	Knowledge Category Basic-Higher-Advanced		
						B	H	A
1	1		Compounds	Mixtures and pure substances	Multiple choice	*		
2	1		State of matter	Matter consists of particles	Multiple choice	*		
3	2		Chemical reaction	Physical and chemical changes of matter	Free response	*		
4	1		Illustration of gaseous particles	Matter consists of particles	Schematic drawing	*		
5	3	1	Compound	Mixtures and pure substances	Multiple choice	*		
		1	Chemical change	Physical and chemical changes of matter	Multiple choice	*		
		1	Air	Mixtures and pure substances	Multiple choice	*		
6	3		Separation of substances from a mixture	Methods of separation of pure substances from a mixture	Free response			*
7	3		Sugar, water, solution	Solutions	Gap fill			*
8	1		Pure substance, submicroscopic representation	Mixtures and pure substances	Multiple choice		*	
9	2		Separation of substances from a mixture	Methods of separation of pure substances from a mixture	Gap fill			*
10	1		Physical change	Physical and chemical changes of matter	Multiple choice		*	
11	1		Element and compound	Mixtures and pure substances	Multiple choice	*		
12	4	1	Pure substance, submicroscopic representation	Mixtures and pure substances	Gap fill		*	
		1	Mixture, element, compound, submicroscopic representation	Mixtures and pure substances	Gap fill		*	
		1	Mixture, element, submicroscopic representation	Mixtures and pure substances	Gap fill		*	
		1	Mixture, compound, submicroscopic representation	Mixtures and pure substances	Gap fill		*	
13	2		Physical and chemical change	Physical and chemical changes of matter	Gap fill			*
14	1		Filtering	Physical and chemical changes of matter	Multiple choice	*		
15	4	1	Synthesis	Physical and chemical changes of matter	Gap fill	*		
		1	Synthesis, sulphur, iron	Physical and chemical changes of matter	Gap fill	*		
		1	Evaporation	Physical and chemical changes of matter	Gap fill	*		
		1	Physical change	Physical and chemical changes of matter	Gap fill	*		

Task No.	No. of Points	Concepts	Listing in the Curriculum	Type of Task	Knowledge Category Basic-Higher-Advanced		
					B	H	A
30	Points in Total		Total:	Tasks	13	6	4
				Points	14	6	10
				Percentage	46.7	20.0	33.3

A rational and empirical evaluation of the tests was undertaken based on an assessment as to the adequacy of the content and the form of the examination. The pre-test and the post-test results were reviewed and evaluated by two experts from the field of science education. A factor analysis was used in the empirical evaluation; namely, the percentage of variation is explained by the first common factor (% ex. var. F1). Given that the first factor explained 24.5% of variance, and was above the lower limit of the criteria (20%), it was concluded that the post-test was valid. Cronbach's alpha coefficient ($\alpha = 0.832$) was applied to ensure the reliability of the post-test, and it confirmed the reliability of the instrument used in the assessment of knowledge following completion of the study. The objectivity of the post-test was ensured through detailed instructions while the pre-test and the post-test results of the CG and EG were assessed by the same teacher using the prescribed criteria. The research was thus a didactic experiment conducted by the science teacher at the selected school, with the pupils of both (CG and EG) groups receiving the same written post-test.

Data Analysis

The SPSS (Statistical Package for the Social Sciences) program was used in analysis at the level of descriptive and inferential statistics. Data analysis encompassed the application of a factor analysis and Cronbach's alpha coefficient (α) for the analysis of metric characteristics, a nonparametric ($\chi 2$ – test) for the analysis of between the two groups by gender, and the independent t-test for the analysis of differences between the compared groups prior to the study protocol. A one-way analysis of covariance (ANCOVA) was used to analyse the differences between the CG and EG in the post test variables as dependent variables using the pre-test variables as covariates.

Results of Research

The evaluation of the pre-test of pupil knowledge prior to the study program revealed that there were no statistically significant differences ($t = 1.444$, $p = 0.501$) between the pupils in the experimental (EG) and control (CG) groups, thus pre-trial both were fairly equal from the perspective of knowledge. The sample of pupils in the experimental and the control groups did not significantly differ by gender ($\chi 2 = 0.676$, $p = 0.411$). These data ensured internal validity, through vindication as to the equivalency of the groups prior to the trial.

Table 4 displays the results of covariance analyses with regard to the total number of points attained in the post-test by experimental and the control group pupils.

Table 4. Results of the one-way analysis of covariance in the total number of points attained in tests as dependent variable using the pre-test scores variable as covariate undertaken by both the experimental (EG) and control (CG) groups.

Group	Number n	Mean $\bar{x}$	Standard deviation s	Test of homogeneity of variances		Test of homogeneity of regression coefficients		Test of mean differences	
				F	p	F	p	F	p
EG	144	22.35	4.114	2.150	0.144	0.003	0.953	61.060	0.000
CG	81	17.59	4.889						

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The assumption of the homogeneity of variances ($F = 2.150$, $p = 0.144$) and homogeneity of regression coefficients ($F = 0.003$, $p = 0.953$) are not violated. The mean differences between the test results of pupils in the experimental and control groups is statistically significant ($F = 61.060$, $p = 0.000$). Pupils in the experimental group ($\bar{x} = 22.35$) performed better in the post-test after the completion of the experiment than the pupils in the control group ($\bar{x} = 17.59$).

The first research hypothesis (H_1) is confirmed - there is a statistically significant difference in the knowledge among the pupils who learn selected concepts using the virtual laboratory relative to those who learn the same concepts through conventional lecture-style instruction. Teaching the specific content where submicroscopic level is presented dynamic with virtual laboratory affected on the pupils' understanding of selected concepts in chemistry and on the quality of knowledge.

Differences in individual levels of knowledge in the experimental and the control groups following the research program, which were determined in the post-test, were analysed. The arithmetic mean achievement per knowledge category, as ascertained through the post-test given to both control and experimental group pupils, is graphically presented below (Figure 4). The bar chart illustrates that the experimental group (EG) achieved better results across all three knowledge categories than the control group (CG).

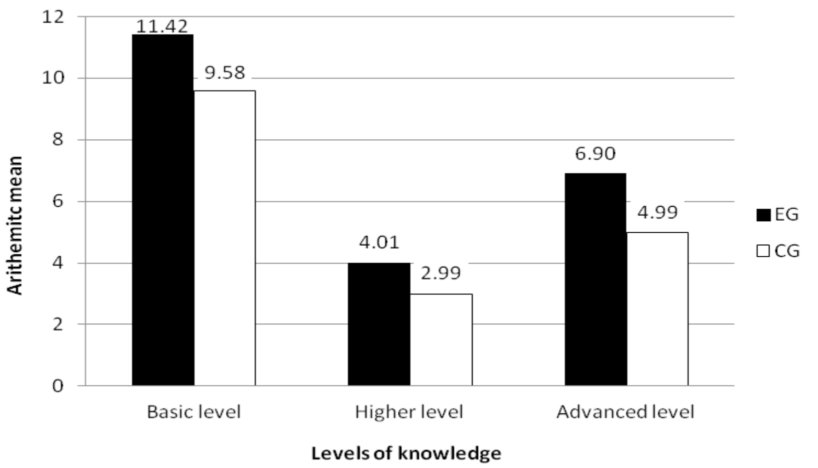

Figure 4: Mean post-test achievements of Experimental and Control Group pupils across all three knowledge categories (basic, higher, advanced).

Basic Level of Knowledge

Table 5 below reveals the one-way analysis of covariance in the test results of experimental (EG) and control (CG) group pupils in those tasks requiring a basic level of subject knowledge, i.e. the recalling of facts, concepts and procedures.

Table 5. Results of the one-way analysis of covariance in the number of points attained in tasks requiring a basic level of knowledge with respect to tests as dependent variable using the pre-test scores as covariate undertaken by both the experimental (EG) and control (CG) groups.

Group	Number n	Mean $\bar{x}$	Standard deviation s	Test of homogeneity of variances		Test of homogeneity of regression coefficients		Test of mean differences	
				F	p	F	p	F	p
EG	144	11.42	1.834	6.874	0.009	0.214	0.644	42.529	0.000
CG	81	9.58	2.323						

From Table 5 it can be seen that the hypothesis of homogeneity of the regression coefficients (F = 0.214, p = 0.644) is justified, but the homogeneity of variances isn't (p = 0.009).

Due to the fact that the hypothesis of homogeneity of variances isn't justified, interpretation of the test of mean differences (F = 42.529, p = 0.000) and thus statistical confirmation of research hypothesis H_2 is renounced. Analysis of the means nonetheless reveals that pupils in the experimental group (EG) did better than those in the control group (CG), which is in line with the basic hypothesis that pupils who learn selected concepts using the virtual laboratory did better than those who learned the same concepts through conventional lecture-style instruction.

Higher Level of Knowledge

Table 6 reveals the one-way analysis of covariance of the test results of pupils of the experimental (EG) and control (CG) groups in those tasks that required higher level of knowledge, i.e. comprehension of facts, concepts and procedures

Table 6. Results of the one-way analysis of covariance in the number of points attained in tasks requiring a higher level of knowledge with respect to tests as dependent variable using the pre-test scores as covariate undertaken by both the experimental (EG) and control (CG) groups.

Group	Number n	Mean $\bar{x}$	Standard deviation s	Test of homogeneity of variances		Test of homogeneity of regression coefficients		Test of mean differences	
				F	p	F	p	F	p
EG	144	4.01	1.746	8.608	0.004	0.070	0.791	19.282	0.000
CG	81	2.99	1.392						

From Table 6 it can be seen that the hypothesis of homogeneity of the regression coefficients (F = 0.070, p = 0.791) is justified, but the homogeneity of variances isn't (p = 0.004).

Due to the fact that the hypothesis of homogeneity of variances isn't justified, interpretation of the test of mean differences (F = 19.282, p = 0.000) and thus statistical confirmation of research hypothesis H_2 is renounced. Nonetheless, analysis of the means reveal that pupils in the experimental group (EG) did better than those in the control group (CG), which is in line with the hypothesis that pupils who learn selected concepts using the virtual laboratory perform better than those who learn the same concepts through conventional lecture-style instruction.

Advanced Level of Knowledge

Table 7 shows the one-way analysis of covariance of the test results attained by pupils in the experimental (EG) and control (CG) groups in those tasks that required an advanced level of subject knowledge, i.e. those involving application, reasoning and argumentation.

Table 7. Results of the one-way analysis of covariance in the number of points attained in tasks requiring an advanced level of knowledge with respect to tests as dependent variable using the pre-test scores as covariate undertaken by both the experimental (EG) and control (CG) groups.

Group	Number n	Mean $\bar{x}$	Standard deviation s	Test of homogeneity of variances		Test of homogeneity of regression coefficients		Test of mean differences	
				F	p	F	p	F	p
EG	144	6.90	2.262	0.000	0.990	0.246	0.620	36.884	0.000
CG	81	4.99	2.244						

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From Table 7 it can be seen that the assumption of homogeneity of the regression coefficients (F = 0.246, p = 0.620) is justified, as is the assumption on the homogeneity of variances (F = 0.000, p = 0.990).

The ascertained mean differences in the results of the control and experimental groups in relation to tasks requiring an advanced level of knowledge, and, accordingly, the application of that knowledge through reasoning and argumentation, is statistically significant (F = 36.884, p = 0.000). This confirms the fourth hypothesis (H_4) that in relation to the solution of tasks which require an advanced level of knowledge there is a statistically significant difference in the ability of pupils who learn selected concepts using the virtual laboratory over those who learn the same concepts through lecture-style instruction.

From the results of the research it follows that following the study period, pupils in both the control and experimental groups understood such concepts as elements, compounds, pure substances, mixtures, as well as physical and chemical change.

There are statistically significant differences at the level of $p < 0.001$ in relation to tasks involving schemes of the distribution of particles in substances as well as changes of state at the particle level, in which pupils in the experimental group were more able and knowledgeable than those in the control group.

Discussion

Through its integration of the macroscopic and submicroscopic, the virtual laboratory is a useful classroom tool which helps the pupils to learn selected concepts in chemistry and natural science. Indeed, animation is an eminently suitable medium for the explanation of macroscopic findings at the submicroscopic level (as already concluded by Rodrigues et al., 2001; Yang et al., 2003).

This research identified statistically-significant effects as regards knowledge of chemistry in relation to the experimental group (EG), and it can be argued that these improved results were consequential to the use of a virtual laboratory as an upgrade of traditional teaching (Chin, 1999). Pupils in the control group (CG) attended science classes performed in the context of traditional approaches to classroom teaching (in which the teacher leads the lesson with the aid of textbooks and various physical experiments); submicro levels of chemistry were explained solely through talk, chalk, books and the use of slideshows, i.e. static visualization. Accordingly, differences in teaching between the control and experimental groups existed in relation to both the macroscopic and submicroscopic, while by contrast, all three levels of a chemical concept - macroscopic, submicroscopic and formulaic - were integrated within the experimental group's lessons utilising the virtual laboratory. Real time chemistry experiments were carried out in the same way with all groups; however, in addition to observing changes at the macroscopic level, pupils in the experimental group using the virtual laboratory, were, through submicro level animations, able to further interpret what was transpiring as well as simultaneously upgrade their understanding at the formulaic level. In this regard, i.e. through their visualization of a dynamic presentation of the submicroscopic world, experimental group pupils had an advantage over their control group counterparts. The use of multi-media software and computer animations which illustrate the changes that atoms, ions and molecules undergo during a chemical reaction, can further reinforce the relationships between transformation observed with the naked eye and the latent changes undergone at the particulate level (Ardac & Akaygun, 2006; Tasker & Dalton, 2006; Rizman Herga & Dinevski, 2014). Also several studies generally report that using animations increased the quality of student's explanations and the level of their performance on assessments (Kelly & Jones, 2007; Özmen, 2011; Akaygun & Jones, 2013).

Other studies reveal that the use of animations and visualisations contribute to a pupil's conceptual understanding (Barak & Dori, 2005), learning achievements (Zimmerer et. al., 2003; Dori & Belcher, 2005; Abdulwahed & Nagy, 2009), spatial abilities (Barnea & Dori, 2000) and motivation to learn science (Barak & Dori, 2011; Sun et. al., 2008). Further to this, it has already been demonstrated that the use of a virtual laboratory has a positive impact on pupil learning outcomes in tertiary education (Chin, 1999; Abdulwahed & Nagy, 2009); our studies, however, pertain to learning outcomes in primary education.

Conclusions

The dynamic visualisation process afforded by a virtual laboratory simultaneously unite animate and integrate all three levels of a chemical concept (macro, sub-micro, and symbolic), thus it is able to interconnect them in the minds of primary school pupils. The classroom use of a virtual laboratory in primary science education yielded a statistically-significant positive impact on the knowledge of children and contributed to the consolidation of their understanding of such topics "matter, its characteristics and changes" and "pure substances and mixtures". Statistically-significant positive effects were not solely confined to the reproduction of knowledge; pupils in the experimental group also achieved significantly better results in relation to metrics of their knowledge and understanding in the application of acquired knowledge, thus they were successful in achieving higher cognitive objectives.

To demonstrate the submicro world dynamically with the aid of animation, the virtual laboratory simultaneously connects and integrates all three conceptual levels. Such visualization is both meaningful and substantive in the teaching and learning basic chemistry. Precise application of the virtual laboratory, with its animated presentations of the submicroscopic, enhances the fundamental understanding of chemical concepts.

The use of a virtual laboratory can affect the formation of mental models at the sub-microscopic level. The dynamic simulations and animations, which are enabled by a virtual laboratory, when compared with static submicro presentations, proved to be more appropriate in the understanding of chemical concepts.

A virtual laboratory offers some important advantages. The aim of virtual reality is to provide realistic simulations of chemical processes, so that pupils are actively involved in the learning process; indeed, through their own active participation they are able to remember more.

Consequently we propose the use of virtual classroom laboratories in the following ways:

i) as a teaching tool in the explanation of new topics,

ii) in combination with other tools in consolidating learning; and

iii) as an aid to pupils in their preparation for actual practical (lab) work.

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Nataša Rizman Herga	Primary School Ormož, Hardek 5, 2270 Ormož, Slovenia. E-mail: natasa_herga@yahoo.com
Saša A. Glažar	PhD., Professor, University of Ljubljana, Faculty of Education, Kardeljeva ploščad 16, 1000 Ljubljana, Slovenia. E-mail: sasa.glazar@guest.arnes.si
Dejan Dinevski	PhD., Associate Professor, University of Maribor, Faculty of Education, Koro ka cesta 160, 2000 Maribor & Faculty of Medicine, Taborska ulica 8, 2000 Maribor, Slovenia. E-mail: dejan.dinevski@uni-mb.si