The influence of 16-year-old students' gender, mental abilities, and motivation on their reading and drawing submicrorepresentations achievements

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Abstract: Submicrorepresentations are a powerful tool for identifying misconceptions of chemical concepts and for generating proper mental models of chemical phenomena in students' long term memory during chemical education. The main purpose of the study was to determine which independent variables (gender, formal reasoning abilities, visualization abilities and intrinsic motivation for learning chemistry) have the most influence on students' reading and drawing submicrorepresentations. 386 secondary school students (aged 16.3 years) participated in the study. The instruments used in the study were: test of Chemical Knowledge, Test of Logical Thinking, two tests of visualization abilities Patterns and Rotations, and Questionnaire on Intrinsic Motivation for Learning Science. The results show moderate, but statistically significant correlations between students' intrinsic motivation, formal reasoning abilities and chemical knowledge at submicroscopic level based on reading and drawing submicrorepresentations. Visualization abilities are not statistically significantly correlated with students' success on items that comprise reading or drawing submicrorepresentations. It can be also concluded that there is a statistically significant difference between male and female students in solving problems that include reading or drawing submicrorepresentations. Based on these statistical results and content analysis of the sample problems, several educational strategies can be implemented for students to develop adequate mental models of chemical concepts on all three levels of representations.

Key Words: secondary school students', submicrorepresentations, students' mental abilities, intrinsic motivation, misconceptions.

INTRODUCTION

Learning science is strongly connected with building knowledge through understanding and concepts linking in students' long-term memory by interpreting multi-modal representations of science phenomena (Ainsworth, 1999; Russell & McGuigan, 2001). Students who recognized relationships between different representations demonstrated better conceptual understanding than students who lacked this knowledge (Prain & Waldrip, 2006). Students should be also able to translate one representation into another one and co-ordinate their use in representing scientific knowledge (Ainsworth, 1999). Russell and McGuigan (2001) argued that learners need opportunities to generate various representations of a concept, and to recode these representations in different modes, as they refined and made more explicit their understanding. In the process of science learning, the teacher should therefore incorporate students' "rich pool of representational competence" in creating lessons so that they are motivating for students (diSessa, 2004, p. 298). diSessa (2004) also points out that the quality of the representation ought to be evaluated according to its purpose. Waldrip, Prain, and Carolan (2006) argue that, in order to maximize the effectiveness of designed representational environments, it is necessary to take into account the diversity of learner background knowledge, expectations, preferences, and interpretive skills.

Submicroscopic representations of chemical concepts

Representations of the chemical concepts could be defined on three levels (i.e. macro, submicro and symbolic level). Adequately merged, these representations can help students to develop a conceptual understanding of chemical phenomena. The *ITLS (Interdependence of Three Levels of Science concepts)* model shows these connections between different representations and the role of visualization methods used in the process of mental model construction of chemical phenomena that students ought to develop. The *ITLS* model draws on different educational theories, such as Paivio's dual coding theory, Mayer's SOI model of meaningful learning and Johnstone's model of information processing, cognitive theory of multimedia learning and Mayer's theory of effective illustrations (see for more details Author; Author).

Figure 1: Model representing Interdependence of Three Levels of Science concepts representations – ITLS model (Author).

To illustrate chemical concepts on the level of particles, submicrorepresentations *(SMR)* can be used and can be presented as static or dynamic modes of representations. Research shows (Bunce & Gabel, 2002; Tien, Teichert, & Rickey, 2007; Kelly & Jones, 2008) that those students who were exposed to *SMRs* during the educational process more adequately understand the nature of the particle interactions compared to those who learned the same concepts only by textbooks reading. Studies in the last two decades (Williamson & Abraham, 1995; Johnson, 1998; Chittleborough, Treagust, & Mocerino, 2002; Solsona, Izquierdo, & DeJong, 2003; Papageorgioua & Johnson, 2005; Stains & Talanquer, 2007; Tien et al, 2007; Kelly & Jones, 2008; Author) also show that students have many difficulties in understanding the submicro and symbolic levels of chemical concepts, and that previous knowledge of a specific topic has an influence on integrating new science concepts into students' mental structure. It is also important to emphasise that a lot of different factors influence students' achievement on different pictorial test questions (Halakova & Prokša, 2007; Sanger & Phelps, 2007; Stains & Talanquer, 2008) and that the students' knowledge evaluation part of the educational process needs further study. Research also shows that teachers use mostly the symbolic level of chemical concepts to teach chemistry (Williamson & Abraham, 1995;

Chittleborough et al., 2002). It is important to introduce different visualization abilities to illustrate abstract science concepts to the students at the beginning of science education - age 10 or 11 (Longden, Black, & Solomon, 1991) - thus also the application of submicrorepresentations (Papageorgioua & Johnson, 2005).

For the purpose of this paper some independent variables such as mental abilities (i.e. formal reasoning and visualization abilities) and intrinsic motivation were selected because, according to the research literature, these variables influence chemistry learning.

Students' mental abilities and chemistry learning

Piaget defined four stages of individuals' cognitive reasoning development: sensorimotor (from birth to about age 2), preoperational (begins about the time the child starts to talk to about age 7), concrete (about first grade to early adolescence) and formal operations (adolescence). Five modes of reasoning (i.e., controlling variables, proportional, correlational, probabilistic, and combinatorial reasoning) were defined and according to those modes subjects can be differentiated into three groups: concrete reasoners, transitional reasoners and formal reasoners (Tobin & Capie, 1981).

Thiele and Treagust (1994) report that students who cannot visualise chemical phenomena and/or do not have properly developed formal reasoning abilities cannot properly understand chemical concepts; thus those concepts are hard to understand, unattractive and pointless for them. According to some research results (Wu & Shah, 2003) the significant correlation between spatial ability and chemistry problem solving skills is based on general reasoning abilities or intelligence rather than on visuospatial thinking. Valanides (1996) reported that students aged 12 to 14 years show relatively low developed formal reasoning abilities. 64.6 % of these students show concrete operational abilities. The difference in their levels of formal reasoning abilities is not statistically significant. Similar results were obtained by Shemesh, Eckstein, & Lazarowitz, (1992). Statistically significant correlations were proven between formal reasoning abilities and students' chemical knowledge especially on submicro level (Haidar & Abraham, 1991; Williamson & Abraham, 1995)

It is important to emphasize that Yang, Andre, & Greenbowe (2003) concluded that students with low levels of visualization abilities show greater difficulties in understanding computer animations of chemical phenomena on particulate level. Research (Barke & Engida, 2001) also shows that girls have lower developed visualization abilities than boys, and they propose that students should use different models and visualization material very early in the science education process to stimulate development of visualization abilities. On the other hand, Wu and Shah (2003) reported no statistically significant correlations between students' achievements on the test with static *SMRs* and spatial abilities. They anticipated that the knowledge achievement is more dependent on students' prior knowledge and the general cognitive factor than on visualization abilities.

Students' motivation for chemistry learning

A negative relationship towards chemistry does not enable proper concept change and/or modification of students' mental model of chemical phenomena. Students often do not have a proper knowledge base that would make it possible to upgrade their knowledge of more and more abstract chemical concepts when they make progress on the educational vertical (Treagust, Harrison, & Venville, 1998).

Learning motivation is defined as a construct which includes different motivational elements (interests, goals, attributes, self-image, external enticements, etc.). Some of these form a more extrinsic stimulus for learning (e.g., learning for grades, praises, avoiding punishment, social acceptance, etc.), while others are manifested more intrinsically (i.e., learning for mastering, learning for knowledge) (Authors).

According to Ryan and Deci (2000), intrinsic motivation is an individual's inherent inclination from which stems his/her tendency to learn about particular areas of life regardless of the presence of external enticements. This construction encourages humans to '… assimilate, control, generate spontaneous interests and to research which makes it essential for the individual's social and cognitive development while on the other hand it represents the fundamental source of personal satisfaction and life energy.' (p. 70).

Highly intrinsically motivated students are more successful in learning new concepts and show better understanding of the learning matter (Stipek, 1998). Rennie (1990), on the basis of the research on science learning, also concluded that higher results in science are related to the learner's active engagement in learning tasks, to his/her positive attitude towards the subject and to a highly positive self-concept in science, which all imply the learner's intrinsic motivation to learn. This is especially important, since many writers (Anderman & Young, 1994; Zusho, Pintrich, & Coppola, 2003) report that the decrease in intrinsic motivation with years of schooling is particularly noticeable in mathematics and science and is at its peak in the period of early adolescence.

Keig and Rubba (1993) pointed out that motivation can be a potential source of variance on students' chemistry knowledge achievements. These claims were confirmed by Tuan et al. (2005). They reported that from 7 to 16% of variance on the science knowledge test could be explained by students' motivation. But on the other hand Nieswandt (2007) reported no statistically significant effect of students' affective variables (situational interest, attitudes towards chemistry and students chemistry-specific self-concept) on their understanding of grade 9 (age 15 to 16) chemistry concepts.

Chittleborough et al. (2002), according to their qualitative research, reported that students are not motivated for learning chemistry more that is necessary for passing the exam. Students' motivation for learning science and chemistry for that matter can be stimulated by using different visualization elements and analogies because this element of the lessons increases students' attention (Theile & Treagust, 1994).

Research (Anderman & Young, 1994) also shows that gender differences in motivation for science learning, in grades five through seven, are connected with achievements on the standardized test of science knowledge. It was also established that girls show lower interest in science, that science is boring for them, especially because they just have to learn everything by heart. Results also show that adolescent girls possess lower levels of self-confidence in demonstrating their science knowledge (Simpson & Oliver, 1990). On the other hand, Meece and Jones (1996) did not confirm these results; they established that there is no difference between girls and boys, in grades six to ten, regarding the interest in learning science and they also pointed out that gender influence on motivation and in its effect on the manifestation of science knowledge are more complex processes than other researchers try to show.

Purpose and research questions

According to the literature review the study of some independent variables that can influence chemistry learning was conducted. In this research the *SMRs* were used as a way for gathering students' chemical knowledge on the higher cognitive level. Submicrorepresentations were defined as tools for determining students' understanding of chemical concepts, and could be used mostly in two different ways. Firstly, students could read them and then use the information given by the specific *SMR* for solving the problem (reading *SMRs*), and secondly they could use the submicrorepresentations for presenting the solution of the science problem (drawing *SMRs*).

Regarding the purpose of this study four research questions can be addressed: (1) Are students' achievement scores significantly higher on problems that include reading *SMRs* than on those that include drawing them?, (2) Do male and female students achieve significantly different scores on problems that include reading and drawing *SMRs*?, (3) Do students with higher mental abilities (i.e. formal reasoning and visualization abilities) achieve significantly higher scores on problems that include drawing *SMRs* than on those that include reading them?, and (4) Do students with higher levels of intrinsic motivation score significantly higher on problems that include drawing *SMRs* than on those that include reading them?

Method

Participants

A total of 386 secondary school students (60.6 % females; 39.4 % males) participated in the study. On average, the students were 16.3 years old (M= 195.4 months; SD = 5.7 months). All students attended second year of the general type of secondary school (Gymnasium). The chemistry curriculum of the Gymnasium is common to all students. The students attended the fourth year of chemical education in the period that testing occurred (two years in higher primary school - age 13 and 14 and two years in secondary school - age 15 and 16). The sample included 5.5 % of the whole population of the students (N = 7033) in school year 2005/06, throughout Slovenia. Three schools were located in the larger towns (more than 100,000 residents) and three in smaller towns (between 35,000 and 100,000 residents). The sample represented a predominantly urban population with mixed socioeconomic status. Parents' basic educational background was diverse (3.1 % finished primary school; 45.1 % finished secondary school; 43.0 % finished university and 7.3 % finished other formal education) but only 11.6 % of parents had finished some kind of science or technology education.

Instruments

Students' abilities to read and draw the *SMRs* were measured using the diagnostic instrument for determining *Chemical Knowledge (CK)*. The instrument comprises 19 items. Eight items required reading and eleven items drawing *SMRs* in solving the chemistry problems considering the *ITLS* model. The *CK* includes four different contents: pure substances and mixtures (4 items), chemical reactions (6 items), water solutions (4 items) and electrolyte chemistry (5 items). The *CK* showed satisfactory measuring characteristics (i.e. internal consistency reliability - Cronbach's alpha was 0.80; discriminate indexes for every item between 0.21 and 0.80 were all statistically significant). Kortusis and skewness coefficients show normally distributed data (see Table 1). Students had 60 minutes to solve the *CK*. One sample item of each content of *CK* is introduced in Appendix 1.

To determine other independent variables, four different tests and a questionnaire were administered to the students: Test of Logical Thinking (*TOLT*), Rotations (*RO*), Patterns (*PA*), and Intrinsic Motivation for Learning Science questionnaire (*IMLS*).

The level of students' formal reasoning abilities was obtained with the *Test of Logical Thinking (TOLT)* (Tobin & Capie, 1981). The *TOLT* is a ten-item group paper-pencil test. The authors of the test reported a strong correlation ($r = 0.82$; $p < 0.0001$) between performance on tasks during Piagetian clinical interviews that are considered a traditionally preferable method in measuring individuals' formal reasoning abilities and the results on *TOLT*. The *TOLT* has high internal consistency reliability (Cronbach's alpha was 0.85). The test consists of two items designed to measure each of the five modes of reasoning (i.e., controlling variables, proportional, correlational, probabilistic, and combinatorial reasoning). The test scores from 0-1 points (concrete reasoners), 2-3 points (transitional reasoners) and 4-10 points (formal reasoners) were used as a basis for classifying the students. Students had 38 minutes to solve the test.

The students' visualization abilities were measured with two tests: *Patterns (PA)* and *Rotations (RO)* (Pogačnik, 1998; 2000). The *PA* measures students' speed of perception and the *RO* measures students' spatial relations abilities. Both tests were developed based on the Cattell-Horn theory of mental abilities. The *PA* is a 36 item group paper-pencil test. It requires individuals to find and mark exactly the same pattern among the four similar patterns on the right side of the paper to the one on the left part of the paper as quickly as possible. The *PA* has high internal consistency (Cronbach's alpha was 0.86). Correlations between some other instruments for determining individuals' perception abilities (*BTI-Or; BTI-Pr, Beta 6* and *4)* determine that the instrument's validity was higher and statistically significant. Students had 4.5 minutes to solve the test. The *RO* is a 90 item group paper-pencil test. The *RO* requires individuals to find and encircle those patterns on the right side of the paper that are just rotated in comparison with the left pattern. Individuals have to cross those patterns that are not just rotated in the plane but represent a different pattern. Cronbach's alpha for the *RO* was 0.94. Correlations between some other instruments for determining individuals' perception abilities (*BTI-Pr, Beta 4)* were also high and statistically significant. Students had 6 minutes to solve the test. The classifications of students into three groups with regard to their visualization abilities were performed according to the statistical equations. Into Group 1 (poor visualization abilities) were classified students that scored less than M - 1SD points, into Group 2 (average visualization abilities) those that scored between M - 1SD and M + 1SD points, and into Group 3 (superior visualization abilities) students that scored above M + 1SD points on the *PA* and *RO*.

The last independent variable, the intrinsic motivation for learning chemistry was measured by the *IMLS* questionnaire. There are many questionnaires to measure students' attitudes or interests in science and/or chemistry (e.g. Moore & Foy, 1997; Tuan et. al., 2005; Coll et al., 2002; Nieswandt, 2007). All these instruments show a rather general structure of students' attitudes towards science, but they lack the dimension with reference to the *ITLS* model and separately for different science school subjects. These questionnaires do not show enough specific characteristics regarding the research questions asked in this study and would need extensive revision for adapting the instrument to secondary level. For those reasons the new instrument for measuring intrinsic motivation, 125-item *IMLS (Intrinsic Motivation for Learning Science* questionnaire, was developed (Authors). The response to each item is on a five-point Likert-type scale ranging from 1 as strongly disagree to 5 as strongly agree. The internal consistency (Cronbach α) of *IMLS* was 0.78. Students had 20 minutes to complete the questionnaire. The classifications of students into three groups with regard to their intrinsic motivation for learning chemistry were performed according to the statistics. Into Group 1 (poor intrinsically motivated) were classified students that scored less than M - 1SD points, into Group 2 (average intrinsically motivated) those that scored between M - 1SD and M + 1SD points, and into Group 3 (superior intrinsically motivated) students that scored above M + 1SD points on the *IMLS*. Three sample items of each component of intrinsic motivation from the *IMLS* questionnaire are included in Appendix 2.

Research design

The research was a non-experimental, cross-sectional and descriptive study (Bryman, 2004).

The students had received no special teaching about using *SMRs* in the chemistry classroom. The chemical concepts comprised in the *CK* were not instructed using *SMRs* by the teachers that taught the students participating in the study.

CK and *IMLS* were designed specifically for this study. The *CK* was administered to two university chemistry and chemical education professors. Their responses provided scientifically correct answers and content validation for the instrument. The *IMLS* was distributed to two experts in science education and one in educational psychology. Their evaluation of the instrument confirmed that the *IMLS* measures students' intrinsic motivation for learning and their analysis provided validation for the questionnaire. The Slovene translation of the *TOLT* was used for the study. The test was separately translated into the Slovene language by one expert in chemistry and one expert in physics education. The translations were compared and possible modifications were made in preparing the third version of the test. The third expert translated the test back into English. The original and the translated version of the English test were compared and possible modifications were made in designing the final Slovene version of the *TOLT*. Four independent experts in chemistry, physics and mathematics education finally reviewed the test, and their responses provided content validation of the instrument.

After all the instruments had been developed or chosen in relation to the purpose of the study, a pilot study was conducted with 77 students. The *CK*, *TOLT* and *IMLS* were used in the pilot study. Taking into account the statistical analysis of the results obtained in the pilot study, the *SK* and *IMLS* were modified.

All instruments were applied on the research sample at the end of the second school year 2005/06 of the secondary school. The testing took students about 135 minutes on two separate days. Students solved the *IMLS* and *CK* in the first week and in the second one they solved the *TOLT, RO* and *PA*. The last testing was conducted by a trained psychologist. All instruments were applied in a group and under normal examination conditions.

Descriptive statistics were obtained for illustrating the *CK* characteristics. For determining differences in the means of *CK,* the paired-sample t-test was used. Pearsons' correlation coefficients for determining the correlation between knowledge of chemical concepts and other independent variables were calculated. The percentage of variance two variables share is referred to as the coefficient of determination. The coefficient of determination is calculated by square the correlation coefficient (r^2) value and then converted into percentage of variance by multiplying it by 100 (Pallant, 2005). In other words, the square of correlation coefficient (r^2) is the fraction of the variation in the values of independent variable that is explained by the least-squares regression of independent on dependent variable (Moore & McCabe, 1997).

In addition, the one-way between-groups analysis of variance (*ANOVA*) was conducted to explore the influence of reasoning abilities, visualization abilities and intrinsic motivation for learning chemistry on students' success in solving *CK* tasks. If the test of homogeneity of variances was statistically significant when comparing the means of the groups of students, the more robust test (Welch test) of equality of means was used.

The 5% cut off was used in presenting the most frequent misconceptions detected by analysing the students' sample problem solving achievements. The decision was made according to the statistical significance of results. It tells us something about the degree to which the result is "true" in the sense of being "representative of the population": 5% is customarily treated as a "border-line acceptable" error level (Moore & McCabe, 1997).

Results

The *CK* analysis shows secondary school students' average chemical knowledge of the tested basic chemical concepts (*Table 1*). Students achieved on average 49 % of all points possible on the *CK*.

Students were more successful in reading *SMRs* than drawing them. Students managed to get on average 56.5 % of all points on items that required reading the *SMRs*. On the other hand, students achieved on average 42.4 % of all points available on problems that required drawing the most suitable *SMRs*.

Table 1. Descriptive statistics for *CK*.

The paired samples t-test shows that students score statistically significantly higher in solving problems that require reading *SMRs* than in those that require drawing them (t (385) = 1.97, p = 0.048). More detailed presentation of students' achievements in solving specific sample problems (See Appendix 1) is presented in Chart 1.

Chart 1. Students' achievements at sample chemistry problems (PSM – Pure substances and mixtures; CR – Chemical reactions; EC – Electrolyte chemistry; and SC – Solution chemistry).

Some results of the detailed analysis of students' responses to the sample *SMRs* chemistry problems are presented below in the same order as in Chart 1.

Pure substances and mixtures (PSM Reading SMRs)

Results of the analysis of Problem 1 (See Appendix 1) show, that 34.8% of students incorrectly select the *SMRs* representing the mixture of two compounds (Chart 1). Some students correctly selected one of them, out of two possible solutions.

13.4% and 13.7% of students think that a mixture of molecules with the same atoms and molecules with different atoms, presented on *SMR* C and *SMR* E respectively, is also a mixture of two compounds. 9.6 % of students selected the *SMR* A as a correct answer. These results show that about 10% of students after three years of chemical education do not adequately understand the differences between a molecule of element and compound at the particulate level. There were other mistakes which were less frequent (less than 5% cases).

Chemical reaction (CR reading SMRs)

Results presented in Chart 1 show that 33.1% of students correctly solve Problem 2 (See Appendix 1). 40% of students selected the chemical equation representing the given *SMR*. More than 42% of students selected the incorrect chemical equation ($5A + 5B_2 \rightarrow 5A_2B_2 + 2A$). Those students do not understand the connection between the concept of chemical reaction on submicroscopic level and its symbolic representation and/or do not understand the basic roles of symbolic chemical language. More than 6% of the students also selected the equation $12A + 10B \rightarrow 6A_2B_2$. 36% of those students that were incorrect in selecting the equation did succeed in determining which reactant did not react completely. It is important to emphasize that 42.2% of students think that the reactant that does not react completely in the chemical reaction is written as a product into the chemical equation. 32 % of students wrote in elaborating their answer, that substance B was completely used in the reaction, and 24 % wrote vice versa, that substance A remains after the reaction. 22.5% of students elaborate their answer at the submicroscopic level (e.g. *»All atoms (A) were used in the reaction.«*) but almost 44% of the students elaborated their answer on the macroscopic level (e.g. *»Substance*

A didn't completely react.»; *»There is still substance A after the reaction.«; »Remains only substance A.«; »At the end there is no substance B only A.«*). It is also interesting to note out that 19.9% of students did not elaborate their answer. There were other mistakes which were less frequent (less than 5% cases).

Electrolyte chemistry (EC reading SMRs)

57.8% of students correctly assigned all three *SMRs* to the aqueous solution of base, acid and soluble salt in Problem 3 (See Appendix 1). 6.1% of students did not solve the problem and 33.1 % of them incorrectly assigned one or more *SMRs* to the correct aqueous solution. These students tried to answer the question by guessing the right answer so they didn't understand the submicroscopic properties of electrolyte. Other mistakes represent less than 5% of all cases.

Pure substances and mixtures (PSM drawing SMRs)

87.3% of students didn't draw the correct *SMRs* of all three states of water (Chart 1) in Problem 4 (See Appendix 1). Only 7.8% of students drew the *SMRs* correctly. Students were the most successful at drawing water in a gaseous state (65.2%) whilst only 7.8% of students correctly represented liquid water. 29.2% of students draw water molecules too far apart (Figure 2a) and 23.9% of them represent liquid water as a gas (large distances between the molecules). Students also didn't take into account that the distances between water molecules during freezing increases (ice has about 9 % lower density as liquid water), but they just adopted the general characteristic of substances that there are larger distances between particles in liquid than in solid state.

Figure 2. Incorrectly presented states of water; original students' drawing, where written on a line means: a liquid; b solid; c liquid and d gas.

26.7% of students present an ordered structure of water molecules in liquid (Figure 3.2a) and 6.1% of students draw ice on submicroscopic level with molecules too apart and not ordered (Figure 3.1b.). There were also other misconceptions (some are presented in Figure 3) which were less frequent (less than 5% cases).

Figure 3. *SMRs* of different states of water presenting different sizes of molecules and their organisation in a specific state of water; original students' drawing, written on a line means: 1 - a gas; b solid; c liquid and 2 - a liquid; b solid; c gas).

Chemical reaction (CR drawing SMRs)

Only 18.4% of students correctly presented the chemical reaction between chlorine and hydrogen molecules on submicroscopic level (See Chart 1). The Problem 5 (See Appendix 1) was three-parted. In the first part students had to write the *SMR* (18.4 % correct drawings and 75.2 incorrect), in the second part they had to present the drawn particles in a legend with their nemeses or formulas (39.1% sufficient legends and 55.3% with some sort of incorrectness) and in the third part students had to elaborate their solution of the problem.

34.3% of students did not take into account the different size of chlorine and hydrogen atoms and they just drew the *SMR* as shown in Figure 4.

Figure 4. The same size of hydrogen and chlorine atoms in the molecule of hydrogen chloride.

38% of students did not consider the correct number of product molecules according to the problem text, so they illustrated only two molecules of hydrogen chloride.

Analysis of the legend shows, that 27.2% of students who correctly presented the legend used symbols of elements to illustrate the drawn particles, but in only 2.7% of cases students used a correct name of the particle (e.g. hydrogen atom and chlorine atom). In average more than 27% of students just wrote the name (hydrogen – 28.2%; chlorine – 27.5%) of an element in the legend and not the name of the particles.

48.2% of the students elaborate their *SMR* using some part of submicroscopic level of chemical concepts: (e.g. *»In two molecules of each element are 4 atoms, and so 4 molecules of HCl are formed.« »HCl is composed from 1atom H and 1 atom Cl.«*). It is also important to take into account that 20.8% of students did not write any elaboration. There were other less frequent mistakes, less than 5% of all cases.

Solution chemistry (SC drawing SMRs)

7.6% of students otherwise drew the *SMR* correctly (See Problem 6 in Appendix 1), but made some mistake in the legend or vice versa. Only 2.9% of students correctly named the particles in the solution as bromide and potassium ions. Only 0.7% of students correctly solve both parts of the problem (see Chart 1).

The most frequent misconception (46.1% of students) of potassium bromide aqueous solution is that students draw molecules of the solute (Figure 5). Almost half of these students did not consider the different ionic (atomic) radius of the ions (atoms) and drew the solution (Figure 5).

Figure 5: *SMR* illustrating misconceptions of aqueous solution of potassium bromide.

10.7% of students did also not know that the mol ratio between potassium and bromide ions is 1:1, so they attribute usually two bromide ions to one potassium ion.

Only 2.9% of all students correctly named the particles presented in the *SMR* in the legend. Most (28.2%) students wrote the symbol of an element to represent the particle, or 13.5% of students also wrote the names of both elements.

There were other mistakes which represent less than 5% of all cases. For more detailed analysis see Authors (…).

Electrolyte chemistry (EC drawing SMRs)

For the correct solution to Problem 7 (See Appendix 1) students should take into consideration five variables (i.e. represented the same acid concentration; higher number of hydronium ions and conjugated base ions like on the given *SMR* but the number of each should be the same; and the complete dissociation should be represented). 35.3% of students represent the same number of acid molecules as on given *SMR*. 34.1% of them associate the acid strength with the concentration of acid molecules in the aqueous solution and 25.7% of them with the level of dissociation. The same number of hydronium ions and conjugated base ions was given only by 21.6% of the students. All variables were considered in the process of problem solving only by 10.3% of the students and 21.6% did not even attempt to draw the *SMR*.

The most frequent mistake (30.6%) was that students represented lower concentrations of the strongest acid. 20.8% of the students did not draw the hydronium and conjugated base ions, and 12.5% of the students represented also the water molecules. Other misconceptions are: (1) the same number of conjugate base ions as on *Scheme* 1 (11.8%) (Figure 6.1); (2) lower concentration of an acid as on *Scheme* 1 (11.5%) (Figure 6.1-6.4); (3) no conjugated base ions in the drawing, only hydronium ions (10.5%) (Figure 6.2-6.3); (4) the same number of hydronium ions as on *Scheme* 1 (9.8%) (Figure 6.3); (5) no hydronium ions (7.4%) (Figure 6.4) and (6) the same or less conjugated base ions as on *Scheme* 1 (6.6%) (Figure 6.1-6.4).

There were other mistakes which represent less than 5% of all cases and they are not presented at this point.

Figure 6: *SMR* illustrating misconceptions of an acid aqueous solution drawn by the students using the *Scheme 1*.

44.1% of students did not elaborate their *SMR*, 35.5% did try to discuss their decision connecting macroscopic and submicroscopic level of chemical concepts, but they show numerous misconceptions, that additionally confirmed misconceptions discovered by drawn *SMRs* (e.g. *»There are more hydronium ions in scheme 2, so the acid is stronger«; »There is more acid molecules in the stronger acid.«; »The acid is stronger, because water molecules are smaller.«)*. It can be concluded from the content analysis of the students' elaborations that 24.5% of them tried to illustrate their *SMR* by saying that they had drawn larger number of hydronium ions, lower number of acid molecules or they mentioned higher number of dissociated acid molecules, and 12.3% of students associated the acid strength with its concentration.

Content analysis of selected chemistry *SMRs* reading and drawing problems suggests that different variables may influence students' problem solving achievements, so a more detailed analysis of some selected independent variables (students' gender, reasoning abilities and motivation) was conducted in an attempt to explain these influences.

Students' gender and achievement scores on CK

In the present study statistically significant differences in total *CK* score between males and females were proven by an independent-samples t-test. The results show that males' (M =

22.83; SD = 6.50) scores are statistically significantly higher than females' (M = 20.16; SD = 6.24); t (384) = - 4.04, $p \leq 0.000$). An independent-samples t-test was also conducted to compare the success of males (M = 11.45; SD = 3.29) and females (M = 10.29; SD = 3.16) on items that required reading *SMRs*. Males scored significantly higher than females (t (384) = - 3.48, $p \leq 0.000$). Similar results were obtained by comparing students' scores on items that required drawing *SMRs*. Males (M = 11.38; SD = 3.86) scored significantly higher than females (M = 9.87; SD = 3.78); t (384) = - 3.80, $p \leq 0.000$).

Students' mental abilities and achievement scores on CK

It can be concluded from the results that 86.3 % of students are formal reasoners, 11.1 % of students fall into the group of transitional reasoners and even 2.6 % of the students are still on the concrete level of reasoning. Those students who have better developed formal reasoning abilities are more successful in solving problems that include drawing ($r = 0.50$; $p \leq 0.000$) and reading ($r = 0.53$; $p \leq 0.000$) *SMRs*. On average 28.1 % of students' success in solving the items that demand reading *SMRs* can be explained by the *TOLT* score. On the other hand, 25.0 % of students' ability to solve the problems that require drawing *SMRs* can be explained by students' formal reasoning abilities. The correlation between the overall successes in solving problems requiring understanding the *ITLS* model shows, that 31.8 % of students' success on *CK* can be explained by their reasoning abilities ($r = 0.56$; $p \leq 0.000$). It can be concluded that students need to have developed higher levels of reasoning abilities to solve the CK items more successfully.

For further analysis, the one-way between-groups analysis of variance was conducted to explore the influence of formal reasoning abilities on total success in *CK* and in solving tasks of reading and drawing *SMRs*. Students were divided into three groups according to their reasoning abilities (Group 1: concrete reasoners, Group 2: transitional reasoners and Group 3: formal reasoners).

The differences in overall success in *CK* between the three groups of students of different formal reasoning abilities are statistically significant ($F(2, 383) = 33.39$, $p \leq 0.000$). Post hoc comparisons using Tukey HSD showed that there is a statistically significant difference ($p \leq 0.000$) between the mean scores for Group 1 (M = 13.43, SD = 5.88) and Group 3 (M = 22.20, SD = 5.99) and also for Group 2 (M = 15.38, SD = 5.98) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.622$) between the groups of concrete and transitional reasoners in success in *CK*. There is a statistically significant difference between groups of students with different reasoning abilities in success at reading ($F(2, 383) = 29.81$, $p \leq 0.000$) and drawing ($F(2, 383) = 24.25$, $p \leq 0.000$) *SMRs*. Post hoc comparisons using Tukey HSD indicated that the mean scores for reading *SMRs* between Group 1 (M = 6.80, SD = 3.16) and Group 3 (M = 11.22, SD = 2.99) were statistically significantly different ($p \leq 0.000$) and also between Group 2 (M = 8.02, SD = 3.22) and Group 3 ($p \leq 0.000$). Group 1 did not differ significantly from Group 2 ($p = 0.485$) regarding reading *SMRs*. Similar results were obtained by post hoc comparisons using the Tukey HSD test regarding mean scores for drawing *SMRs*. Group 1 (M = 6.63, SD = 3.57) was statistically significantly different ($p = 0.001$) from Group 3 (M = 10.98, SD = 3.72) and also for Group 2 (M = 7.35, SD = 3.25) and Group 3 ($p \leq 0.000$). Group 1 did not differ significantly from Group 2 ($p = 0.839$).

The next two independent variables include students' visualization abilities.

Table 2. Pearsons' correlation coefficients between students' visualization abilities and success on CK.

Students' visualization abilities are not so highly correlated with *CK* scores as are formal reasoning abilities (*Table 2*). Students' speed of perception is not statistically significant correlated with their success in problem solving regarding reading *SMRs*, on the other hand a very low but statistically significant factor is students' ability for drawing *SMRs* ($r = 0.11$; $p = 0.025$). Another students' visualization ability, i.e. spatial relations, is somewhat more highly correlated with drawing *SMRs* ($r = 0.18$; $p = 0.001$) than reading ($r = 0.11$; $p = 0.027$), but the correlation coefficients are still very low, and the connection between students' *CK* achievements and their visualization abilities could be neglected. It can be summarised that only 2.6 % of students' *CK* scores can be explained by spatial relations and even less - only 1.4 % - by speed of perception.

The *ANOVA* was conducted to explore the influence of visualization abilities on students' success in solving tasks that include reading and drawing *SMRs*. Students were divided into three groups according to their speed of perception and spatial relations abilities (Group 1: poor speed of perception or spatial relations abilities, Group 2: average speed of perception or spatial relations abilities, and Group 3: superior speed of perception or spatial relations abilities). The differences in total scores on *CK*, and problems that demand reading or drawing *SMRs*, between the three groups of students with different speed of perception abilities are not statistically significant.

On the other hand there are statistically significant differences between the groups of students in spatial relations abilities and their success in solving the tasks on *CK* ($F(2, 382) = 5.91$, $p = 0.003$). Post hoc comparisons using Tukey HSD showed that there is a statistically significant difference ($p = 0.035$) between the mean scores for Group 1 ($M = 19.08$, $SD = 5.85$) and Group 2 ($M = 21.31$, $SD = 6.63$) and also between the mean scores for Group 3 ($M = 22.93$, $SD = 5.90$) and Group 1 ($p = 0.002$). There is no statistically significant difference (p

= 0.162) between groups of students with average and superior spatial relations abilities in total success on *CK*.

The one-way analysis of variance shows that there are also statistically significant differences between the groups of students in spatial relations abilities and their success in solving the tasks that demand reading ($F(2, 382) = 3.43$, $p = 0.033$) and drawing *SMRs* ($F(2, 382) = 6.23$, $p = 0.002$). Post hoc comparisons using the Tukey HSD showed that the mean scores for reading *SMRs* are statistically significantly different ($p = 0.027$) between Group 1 ($M = 9.90$, $SD = 3.09$) and Group 3 ($M = 11.38$, $SD = 2.79$). There is no statistically significant difference ($p = 0.121$) between the groups of students with poor and average spatial relations abilities and also between groups with average and superior spatial relations abilities ($p = 0.397$) in success in solving items that include reading *SMRs*. Post hoc comparisons showed that there is a statistically significant difference ($p = 0.001$) between the mean scores for drawing *SMRs* for Group 1 ($M = 9.17$, $SD = 3.46$) and Group 3 ($M = 11.55$, $SD = 3.65$) and also for Group 2 ($M = 10.51$, $SD = 3.96$) and Group 1 ($p = 0.035$). There is no statistically significant difference ($p = 0.125$) between Group 2 (average spatial relations abilities) and Group 3 (superior spatial relations abilities) in success in drawing *SMRs*.

Students' intrinsic motivation and CK score

The last set of variables includes intrinsic motivation for learning chemistry, which is statistically significantly correlated to students' success in solving the *CK* ($r = 0.31$; $p \leq 0.000$). The results show that there is a lower correlation between learning chemistry in general and students' reading *SMRs* scores ($r = 0.22$; $p \leq 0.000$) than between the same intrinsic motivation and drawing *SMRs* ($r = 0.32$; $p \leq 0.000$). The results seem to indicate that only 9.36 % of the *CK* score variance can be accounted for by students' level of intrinsic motivation for learning chemistry. The even lower percentage of success in solving tasks that require reading *SMRs* (4.93 % variance) can be explained by intrinsic motivation for learning chemistry, but on the other hand the most intrinsically motivated students successfully solve tasks with drawing *SMRs* (10.43 % of variance explained).

Students were divided into three groups according to their level of intrinsic motivation for learning chemistry (Group 1: poor intrinsically motivated, Group 2: average intrinsically motivated, and Group 3: superior intrinsically motivated).

Table 3. ANOVA between the three groups of students of different intrinsic motivation for learning chemistry and their success in *CK*.

It can be concluded from the post hoc analysis using Tamhane (for equal variances not assumed) that there is a statistically significant difference ($p \leq 0.000$) between the mean scores on *CK* for poor (Group 1) intrinsically motivated students for learning chemistry (M = 19.21, SD = 7.11) and Group 3 – superior intrinsically motivated (M = 25.61, SD = 6.75) and also between average – Group 2 (M = 20.63, SD = 5.76) and superior – Group 3 intrinsically motivated students ($p \leq 0.000$). There is no statistically significant difference ($p = 0.373$) between Group 1 and Group 2 in success in solving the tasks on *CK*. The post hoc analysis using Tamhane (for equal variances not assumed) also showed that there is a statistically significant difference ($p \leq 0.000$) between the groups of students with different level of intrinsic motivation and their success in solving the tasks that demand drawing *SMRs* for Group 1 (M = 9.17, SD = 4.04) and Group 3 (M = 13.27, SD = 4.40) and also for Group 2 (M = 10.09, SD = 3.37) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.270$) between students with poor and average score in the intrinsic motivation questionnaire in success in solving tasks drawing *SMRs*. Post hoc comparisons using the

Tukey HSD revealed that there is a statistically significant difference ($p \leq 0.000$) between the mean scores for Group 1 (M = 10.03, SD = 3.57) and Group 3 (M = 12.33, SD = 3.05) and also for Group 2 (M = 10.54, SD = 3.11) and Group 3 ($p \leq 0.000$) in reading *SMRs* achievements. There is no statistically significant difference ($p = 0.493$) between students with poor and average intrinsic motivation for learning chemistry in success at reading *SMRs*.

Students' intrinsic motivation for learning the macro level of chemical concepts is also statistically significantly correlated with the overall *CK* score ($r = 0.24$; $p \leq 0.000$) and with students' ability for reading and drawing *SMRs*. The correlation coefficients extend from ($r = 0.15$; $p \leq 0.000$) for reading and ($r = 0.27$; $p \leq 0.000$) for drawing *SMRs*. The results show that similar low percentages, as obtained regarding students' intrinsic motivation for learning chemistry, of total *CK* score (5.5 %), *CK* reading *SMRs* score (2.3 %) and drawing *SMRs* score (7.0 %) variance can be explained by intrinsic motivation for learning chemistry at the macroscopic level.

Table 4. ANOVA between the three groups of students of different intrinsic motivation for the macroscopic level of chemical concepts and their success on CK.

The *ANOVA* showed that the differences between the three groups of students of different intrinsic motivation for the macroscopic level of chemical concepts and their success on *CK* are statistically significant regarding the total score on *CK* ($p = 0.005$) and drawing *SMRs* ($p = 0.006$) but not reading them ($p = 0.151$). Post hoc comparisons using Tukey HSD showed that there is a statistically significant difference ($p = 0.008$) between the mean total scores on *CK* for poor (M = 20.27, SD = 7.06) and superior (M = 23.73, SD = 7.15) intrinsically motivated students for learning chemical concepts on the macroscopic level and also for average (M = 20.93, SD = 6.04) and superior intrinsically motivated ($p = 0.009$).

There is no statistically significant difference ($p = 0.724$) between Group 1 and Group 2 in success on *CK*. Because the test of homogeneity of variances for drawing *SMRs* was statistically significant (*Table 4*), the Welch test of equality of means was used. The Welch test showed that the differences between the three groups of students of different intrinsic motivation for learning the macro level of chemical concepts and their success in drawing *SMRs* are statistically significant ($p = 0.006$). It can be concluded from the post hoc analysis using Tamhane (for equal variances not assumed) that there is a statistically significant difference ($p = 0.006$) between the mean scores for Group 1 ($M = 9.77$, $SD = 3.89$) and Group 3 ($M = 12.20$, $SD = 4.54$) and also for Group 2 ($M = 10.28$, $SD = 3.63$) and Group 3 ($p = 0.013$). There is no statistically significant difference ($p = 0.685$) between Group 1 and Group 2 in success at solving the tasks that include drawing of *SMRs*.

It is important to emphasise that those students who show more interest in learning chemical concepts on submicro level are also more efficient in drawing ($r = 0.36$; $p \leq 0.000$) than in reading ($r = 0.26$; $p \leq 0.000$) *SMRs*. The correlation between the total score on *CK* and interest in learning chemistry on submicroscopic level is moderate ($r = 0.34$) and statistically significant ($p \leq 0.000$). It can be concluded that 12.7 % of variance in drawing, and only 6.5 % respectively of students' ability in reading *SMRs*, can be explained by their intrinsic motivation scores for learning chemistry on submicro level.

Table 5. ANOVA between the three groups of students of different intrinsic motivation for the submicroscopic level of chemical concepts and their success on CK.

Post hoc comparisons using the Tukey HSD showed that there is a statistically significant difference ($p \leq 0.000$) between the mean scores for Group 1 ($M = 10.15$, $SD = 3.58$) and Group 3 ($M = 12.63$, $SD = 3.08$) and also for Group 2 ($M = 10.47$, $SD = 3.06$) and

Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.743$) between the group of students with poor and average intrinsic motivation for learning chemical concepts on submicro level in success in reading *SMRs*.

The post hoc analysis using Tamhane (for equal variances not assumed) shows that there is a statistically significant difference ($p \leq 0.000$) between the mean scores on *CK* for poor (M = 19.22, SD = 6.99) and superior (M = 26.15, SD = 6.80) intrinsically motivated students for learning submicroscopic level of chemical concepts and also for the average (M = 20.58, SD = 5.69) and superior group of students ($p = 0.000$). There is no statistically significant difference ($p = 0.370$) between Group 1 and Group 2 in success in solving the tasks on *CK*. It can be concluded from the post hoc analysis using Tamhane that there is a statistically significant difference ($p \leq 0.000$) between the mean scores regarding success in solving problems with drawing *SMRs* for Group 1 (M = 9.07, SD = 4.02) and Group 3 (M = 13.51, SD = 4.38) and also for Group 2 (M = 10.11, SD = 3.34) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.149$) between Group 1 and Group 2 in success in solving the tasks of drawing *SMRs*.

Students' intrinsic motivation for learning chemistry at the symbolic level of the *ITLS* model is statistically significantly correlated ($r = 0.28$; $p \leq 0.000$) to the students' achievements in *CK* (*i.e.* reading *SMRs* $r = 0.20$; $p = 0.000$, and drawing *SMRs* $r = 0.31$; $p \leq 0.000$). The correlation coefficients show higher correlation for drawing than for reading *SMRs*. It can be summarised that only 4 % of variance on reading *SMRs* scores can be accounted for by students' interest in learning symbolic chemical concepts and 9.6 % of variance on drawing *SMRs*, respectively.

Table 6. ANOVA between the three groups of students of different intrinsic motivation for the symbolic level of chemical concepts and their success on *CK*.

The *ANOVA* showed (*Table 6*) that the differences between the three groups of students of different intrinsic motivation for symbolic level of chemical concepts and their success in *CK* is statistically significant ($p \leq 0.000$). Post hoc comparisons using the Tukey HSD showed that there is a statistically significant difference ($p \leq 0.000$) between the mean total scores on *CK* for Group 1 (poor intrinsic motivation) (M = 19.80, SD = 7.00) and Group 3 (superior intrinsic motivation) (M = 25.59, SD = 6.58) and also for Group 2 (average intrinsic motivation) (M = 20.60, SD = 5.86) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.597$) between Group 1 and Group 2 in success on *CK*. The one-way analysis of variance showed that the differences between the three groups of students of different intrinsic motivation for the symbolic level of chemical concepts and their ability in reading *SMRs* is also statistically significant ($p \leq 0.000$). Post hoc comparisons using Tukey HSD showed that there is a statistically significant difference ($p \leq 0.000$) between the mean scores for Group 1 (M = 10.35, SD = 3.49) and Group 3 (M = 12.53, SD = 2.96) and also for Group 2 (M = 10.45, SD = 3.13) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.970$) between students with low level of intrinsic motivation and those with average motivation in success in reading *SMRs*. The Welch test showed that the differences between the three groups of students of different intrinsic motivation for learning the symbolic level of chemical concepts and their success in problems that include drawing ($p = 0.000$) are statistically significant. The post hoc analysis using Tamhane (for equal variances not assumed) shows that there is a statistically significant difference ($p \leq 0.000$) between the mean scores for Group 1 (M = 9,45, SD = 4.07) and Group 3 (M = 13.07, SD = 4.27) and also for Group 2 (M = 10.15, SD = 3.46) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.458$) between Group 1 and Group 2 in success in drawing *SMRs*.

Discussion and implications for education

Research question 1: *Are students' achievement scores significantly higher on problems that include reading SMRs than on those that include drawing them?*

It can be concluded that the average points scored by the students on items that require reading submicrorepresentations are higher (by 14.1%) compared to the average points for items that include drawing the *SMRs.* These results are consistent with some other research (Kelly & Jones, 2008; Margel, Eylon, & Scherz, 2008) which indicate that students have specific problems with drawing the correct submicrorepresentations of the natural phenomena.

Results in our study show specific misconceptions that are presented by the students while transferring the submicro world of particles into the symbolic level. Students demonstrate difficulties also trying to describe the submicrorepresentations or they just try to illustrate the phenomena on the particulate level.

Firstly, students have difficulties in representing different states of matter (Item 4). They express the most misconceptions representing the liquid state of water. A lot of students also had difficulties in illustrating ice on a submicroscopic level. Students also struggle to distinguish between pure substances and mixtures, because they anticipate that those particles that are represented by two circles represent a compound, no matter what sort of atoms are bonded in the molecule (Item 1). It can be concluded that students connect elements only with separate atoms and compounds with multiple atoms molecules.

Secondly, it is important to be aware that almost half of the students aged 16 think that the reactant that is not used completely in the chemical reaction, is written into the chemical equation (Item 2). Students are also imprecise in reading the text of the problem (Item 5), because they draw the wrong number of product molecules or do not consider the differences in atomic radius of different elements. Legend analysis showed that students do not develop the connections between the macroscopic and the submicroscopic levels of concepts, because they attribute the macroscopic name of an element to the substance particle.

It can be recommended that teachers can help students to develop adequate mental models of chemical reaction also by using *SMR,* where the correct quantity of matter and correct molecule geometry can be stressed with the support of the legends of the particles used in *SMRs* with their names. It is also important to suggest that teachers try to encourage precise reading of the scientific text, because students' success in solving the chemistry problems is dependent on that. They must not encourage students to learn chemical equations by heart because it has a negative influence on students' motivation for learning chemistry, because just memorizing the formulae is meaningless to students. Emphasizing the importance of putting the symbolic chemical language into the context and breaking it down into meaningful parts – not overloading students working memory capacity – has been shown to be an important aspect of effective chemistry learning also by other researchers (Bunce, & Gabel, 2002; Chittleborough et al., 2002).

Thirdly, it can be summarised that students had difficulties correctly representing the ionic substance water solutions in particulate level (Item 6). This shows that the majority of students after four years of chemical education do not understand what happens with soluble ionic substances when added into water. Students ought to use their knowledge acquired during chemistry lessons on a more theoretical level (ionic bonding, solubility, atomic and ionic radii) on concrete samples. Students' transfers between macroscopic and submicroscopic level of chemical concepts during problem solving processes are not satisfactory.

The analysis of the last set of concepts (acids and bases) showed that only slightly more than half of the students correctly recognise the *SMRs* of acid, base and salt aqueous solutions (Item 3) but a lot more students had problems representing acidic solution on a submicroscopic level, especially when they had to consider more than one variable to solve the problem (Item 7). It can be concluded that students do not associate the acid strength with acid dissociation ability, but often with the concentration of acid particles in the aqueous solution. It is important to emphasize that teachers have to use *SMRs* also to illustrate acid or base dissociation and connect this concept with acid or base strength and pH value, because the most frequent misconception presented by students is that stronger acid has more molecules of acid in water solution, and they do not connect this concept with the hydronium or hydroxide and conjugated base or acid ions.

Research question 2: *Do male and female students achieve significantly different scores on problems that include reading and drawing SMRs?*

It can be summarized that female students score significantly lower than male students in drawing or reading submicrorepresentations while solving particulate problems. Bunce and Gabel (2002) reported similar findings. They said that females score lower than males on the pre-test, but after implementing the educational strategies that connect all three levels of chemical concepts the significant gender score difference would diminish. The results reported by Barke and Engida (2001) can explain the results found in this research. They anticipated that girls have lower developed visualization abilities than boys, and they propose that students should use different models and visualization material very early in the science education process to stimulate development of visualization abilities. It can be speculated that visualization abilities can influence motivation, and then hence the science problem solving achievements by both males and females.

During the educational process teachers should, therefore, pay more attention to female students' progress in developing adequate mental models of chemical concepts especially at submicroscopic and symbolic.

Research question 3: *Do students with higher mental abilities (i.e. formal reasoning and visualization abilities) achieve significantly higher scores on problems that include drawing SMRs than on those that include reading them?*

The first part of the third research question refers to the students' formal reasoning abilities. Results show that students with higher formal reasoning abilities are slightly more successful in problems that require reading than drawing *SMRs*. Drawing *SMRs* seems to be more intellectually demanding than reading them, but results of the present study do not confirm this assumption. It is also evident that students with developed formal reasoning abilities are equally successful in reading or drawing submicrorepresentations as are those students that reach transitional level, but there is a statistically significant difference between concrete and formal reasoners. The difference between concrete and transitional reasoners in reading or drawing *SMRs* is not significant. However, it is important to stress, that even students on the concrete level of reasoning abilities are sufficiently capable of solving some problems on submicro level. It is also evident that those students that fall into the group of concrete or transitional reasoners had more difficulties with solving problems that involve reading or drawing *SMRs* than those that fall into the group of formal reasoners. The lower percent of explained variance was obtained by Gabel, Samuel, and Humm (1987) and Haidar and Abraham (1991), that was attributed to the results on chemical concepts test 22.8 % and 17.5 % respectively of the variance by the students' reasoning abilities. The findings of the present study are consistent with the findings of the study by Williamson and Abraham (1995), who reported that 27 % of variance can be explained by formal reasoning abilities, and Valanides (1998) reported similar results.

The second part of the third research question refers to students' visualization abilities. Results shows that, in the contrast with formal reasoning ability and its influence on students' achievements in solving problems on particulate level, it can be concluded that visualization abilities are not so strongly correlated with chemistry knowledge that refers to 2-D submicrorepresentations. This is shown by the results, and only a small portion of variance on the *CK* score can be explained by students' visualization abilities. Further analysis of variance shows, that differences between students with low and average, and average and superior visualization abilities are not statistically significant in most cases. It can, for that reason, be emphasised that students can solve particulate problems even if their visualization abilities are not so highly developed. However it is important to emphasise that there is no statistically significant difference between students with different speeds of perception abilities in solving problems regarding reading or drawing *SMRs*. On the other hand, somewhat bigger differences can be determined regarding the use of 2-D submicrorepresentations between students with different levels of spatial relations. The difference is not statistically significant between students with average and superior spatial relations abilities. The difference between students with poor and average spatial relations abilities is statistically significant in the total *CK* score and reading *SMRs* score. However the difference is also significant on all three levels of *CK* tasks, between students with poor and those with superior spatial relations abilities. It can be concluded that chemical problems which include just 2-D submicrorepresentations do not pose great difficulties in solving them, even for those students with lower visualization abilities.

These conclusions indicate that teachers should be encouraged to use submicrorepresentations in classrooms for evaluating students' knowledge, without apprehension that students with lower abilities would be discriminated.

These results confirmed the predictions of Wu and Shah (2003) and Keig and Rubba (1993) that secondary school students' chemical concepts test scores variance would not be in a very large percentage accounted for by students' visualization abilities, but by more general reasoning abilities. Gabel et al. (1987) also reported no significant correlation between students' visualization abilities and achievements on the chemistry test that comprises items on submicroscopic level. Higher correlations between visualization abilities of secondary school students in Slovenia ($r = 0.472$; $p < 0.01$) were registered by Ferk Vrtačnik, Blejec, & Gril (2003). Similar results were obtained also by Yang et al. (2003). These results may have their cause in different chemistry conceptual problems (3D model manipulations, computer animations …) that were used for evaluating students' knowledge.

Research question 4: *Do students with higher levels of intrinsic motivation score significantly higher on problems that include drawing SMRs than on those that include reading them?*

It can be concluded from the results that the correlations between *CK* scores, either in reading, drawing or overall scores and intrinsic motivation for learning chemistry, are the highest regarding motivation for the submicro level of chemical concepts, and the lowest regarding macro level. From the ANOVA results it can be summarised that the differences between the groups of students with different levels of intrinsic motivation is significant almost in all cases, except for reading *SMRs* and intrinsic motivation for the experimental level of chemical education. However it is important to emphasise that on all levels of *ITLS* intrinsic motivation for learning chemistry, the difference between poor and average intrinsically motivated students is not significant. According to these results, students with higher general or specific chemical intrinsic motivation achieve higher scores on the chemistry test comprising reading or drawing submicrorepresentations.

Most students do like chemistry at the macro level, so teachers should take advantage of this and after experimental work could have the chance to develop intrinsic motivation also for the submicroscopic and symbolic level of chemical concepts. To achieve this goal, teachers encounter a difficult task in achieving a sufficient level of external stimulation for students to become interested in submicro level of chemistry, because students often do not realize the meaning of these explanations of the phenomena and their symbolic representations. It can be concluded that the most successful in solving chemistry problems on different levels of the *ITLS* model would be those students that are highly intrinsically motivated for learning chemistry at the particulate level.

Similar results of several studies were reported by Tuan et al. (2005), but their research shows a slightly higher correlation between school science achievement and motivation ($r = 0.40$; $p < 0.01$). Previous research (Napier & Riley, 1985) also indicated that motivation has a moderate but significant correlation with students' science achievement. The results obtained in this study can confirm Keigs' and Rubbas' (1993) predictions, i.e. that motivation can be a potential source of variance regarding students' success on the chemical concepts test. On the other hand, Nieswandt (2007) reports the result of her study, that affective variables (students' interest and attitudes for chemistry and their chemistry-specific self-concepts) do not have a statistically significantly effect on conceptual understanding, but the results do reveal the importance of strong and positive self-concept for developing a meaningful understanding of science concepts.

The overall conclusions indicate that teachers should devote more time to the activities where students, and especially females, are engaged in drawing submicrorepresentations and explaining their meaning (e.g using particles names). They should also emphasise the meaning of correct and accurate reading of the chemistry problem text. Teachers should be aware that students can develop the understanding of *SMRs* also when their formal reasoning abilities and/or visualization abilities are not highly developed in relation to their age. Teachers can collect useful data about students' incomplete comprehension and/or misunderstandings of chemical concepts by analyzing students' drawing of *SMRs,* and also by analysing their own classroom instructions and their pedagogical knowledge obtained through action research; especially if they see the teaching as transfer of knowledge or as a process of building the students' knowledge (Vogrinc & Valenčič Zuljan, 2009). These conclusions can influence teachers' realization of the classroom activities and could modify their future educational strategies implemented in the classroom. It should be emphasised, indicated by the findings that teachers should, nevertheless, encourage students to learn chemistry at the particulate level. Such attempts are going to be only external, and for students mostly unnecessary or even discouraging and highly difficult to understand at the beginning, but with the progress in understanding of the basic chemical concepts (e.g. atom structure, chemical bond, etc.) in context, students' interest in understanding chemistry at submicro level will increase and deeper knowledge with understanding would develop.

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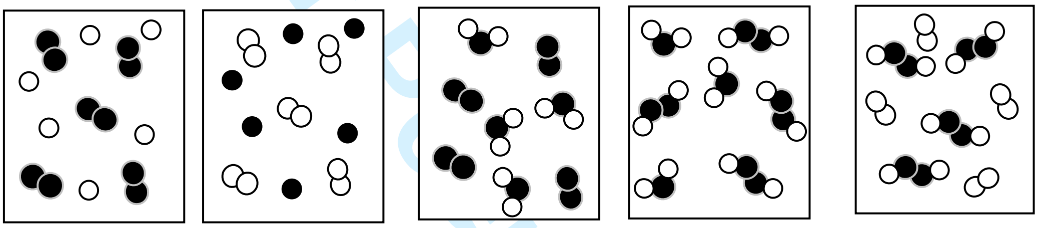
Appendix 1: Sample items from diagnostic instrument for determining *Chemical Knowledge (CK).*

Reading *SMRs*

Pure substances and mixtures (PSM reading SMRs)

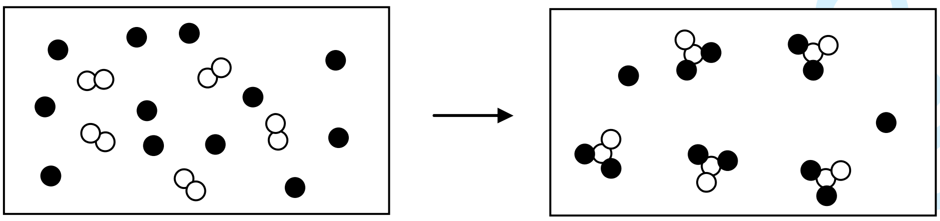
1. Which scheme represents a mixture of two compounds? One circle represents one atom.



A B C D E

Chemical reactions (CR reading SMRs)

2. The scheme represents the reaction between substance A and B. Which equation correctly represents this reaction?



Mixture before the reaction Mixture after the reaction

Legend: - Substance A; - Substance B; - Product

A $A_2 + 2\,B \rightarrow A_2B_2$

B $12\,A + 10\,B \rightarrow 6\,A_2B_2$

C $2\,A + 2\,B \rightarrow A_2B_2$

D $5\,A + 5\,B_2 \rightarrow 5\,A_2B_2 + 2\,A$

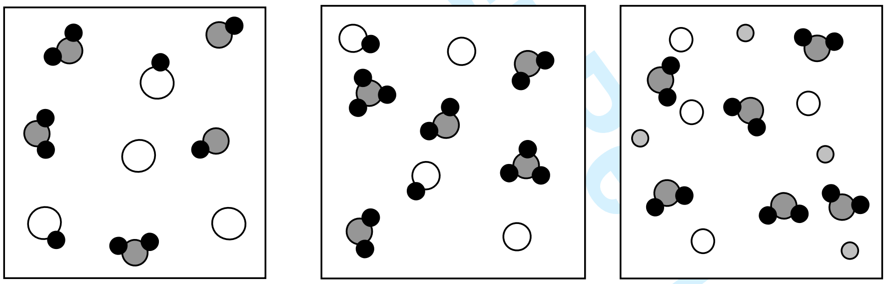
E $2\,A + B_2 \rightarrow A_2B_2$

Which substance was completely used during the reaction? ____________

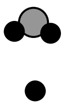
Elaborate the answer: ____

Electrolyte chemistry (EC drawing SMRs)

3. Scheme A to C represents aqueous solutions of three different substances. Most of the water molecules were omitted for clarity.



Legend:



Answer the following questions.

Which scheme represents an aqueous solution of acid? ____________

Which scheme represents an aqueous solution of base? _____________

Which scheme represents an aqueous solution of soluble salt? ___________

Drawing *SMRs*

Pure substances and mixtures (PSM drawing SMRs)

4. Water can be found in three states of matter in nature. Draw schemes to show different states of water. Draw ten water molecules in each box represented by ● and on the line write the correct state of matter represented in the box above.

a ________________ b ________________ c ________________

Chemical reactions (CR drawing SMRs)

5. Draw the scheme of a chemical reaction product between two molecules of chlorine and two molecules of hydrogen in the box below.

Legend: ________________________________

Elaborate the answer: ____

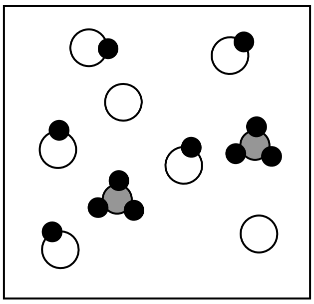
Solution Chemistry (SC drawing SMRs)

6. Draw a scheme to show the dissolved potassium bromide with optional concentration in water. Use the legend to illustrate the particles which you have used in the scheme. You need not draw water molecules.

Legend: ________________________

Electrolyte chemistry (EC reading SMRs)

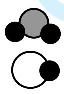
7. Scheme 1 represents aqueous solution of an acid. Water molecules were omitted for clarity. Draw Scheme 2 representing aqueous solution of a stronger acid, but the same concentration. You need not draw water molecules.



Scheme 1

Scheme 2

Legend:



- water molecule
- acid molecule

Elaborate the answer: ____

Appendix 2: Sample items from the questionnaire Intrinsic Motivation for Learning Science (*IMLS*)

1. <u>Emotional component of interest:</u>

I enjoy learning.

I am often bored during:

…chemistry course.

… biology course.

…physics course.

… foreign language course.

… mathematics course.

I enjoy the chemistry course when:

…we observe chemical changes in experiments.

…we learn about particles (atoms, ions, molecules).

…we learn and write chemical symbols, formulae and equations.

<u>2. Cognitive component of interest:</u>

I often look for additional information about school science topics in books, magazines, in the internet, CDs …

The media attract my attention when reporting on:

…chemistry topics.

…biology topics.

…physics topics.

…foreign language topics.

…mathematics topics.

I often think about:

…observation of chemical changes in experiments*, also out of school.*

… particles (atoms, ions, molecules), *also out of school.*

…learning and writing chemical symbols, formulae and equations, *also out of school.*

3. Challenge component of internal motivation:

I persevere with learning.

New problems in:

… chemistry, *challenge me.*

…biology, *challenge me.*

…physics, *challenge me.*

…foreign language, *challenge me.*

…mathematics*, challenge me.*

If I do not understand something, connected with:

…observation of chemical changes in experiments, *I give up.*

…learning about particles (atoms, ions, molecules), *I give up.*

…learning and writing chemical symbols, formulae and equations, *I give up*.

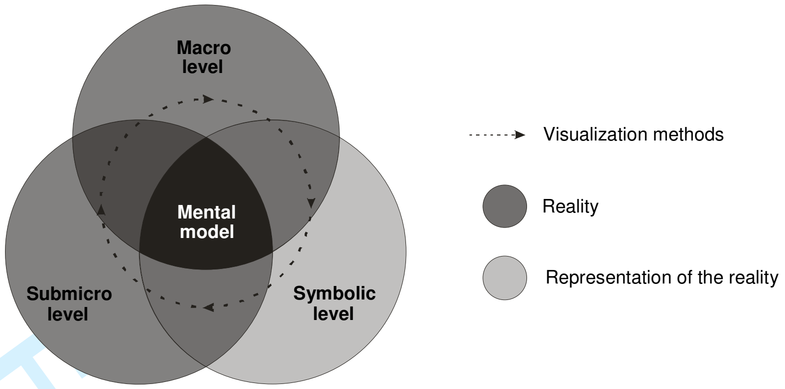


Figure 1: Model representing Interdependence of Three Levels of Science concepts representations – ITLS model (Author).

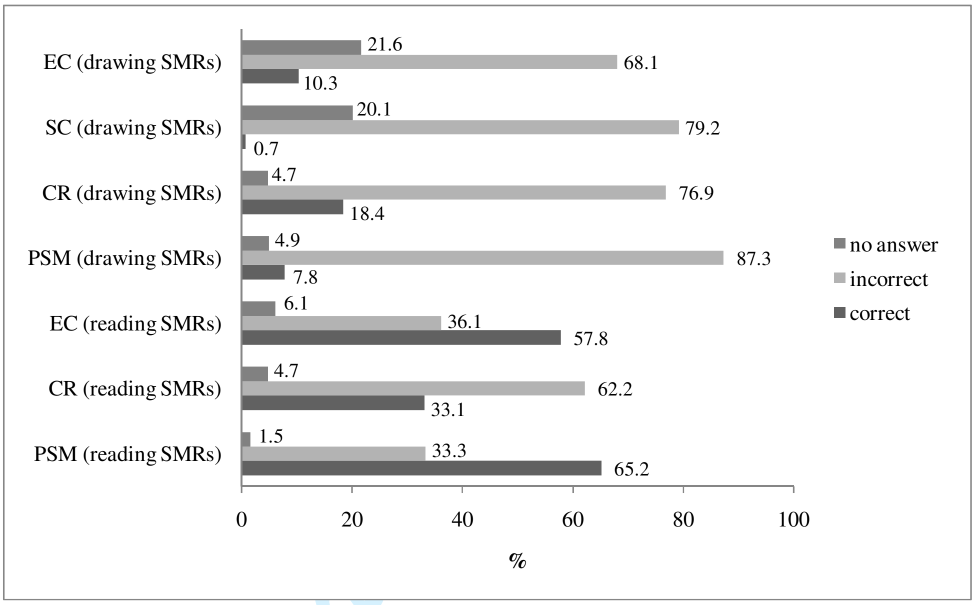


Chart 1. Students' achievements at sample chemistry problems (PSM – Pure substances and mixtures; CR – Chemical reactions; EC – Electrolyte chemistry; and SC – Solution chemistry).

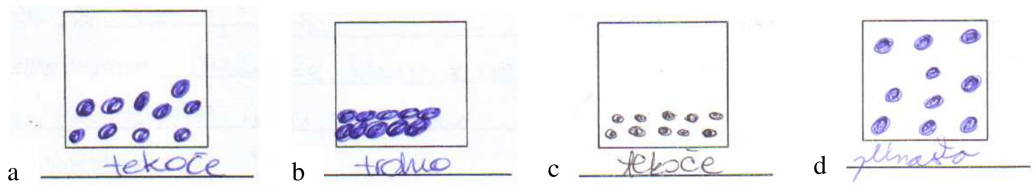


Figure 2. Incorrectly presented all three states of water; original students' drawing, written on a line means: a liquid; b solid; c liquid and d gas.

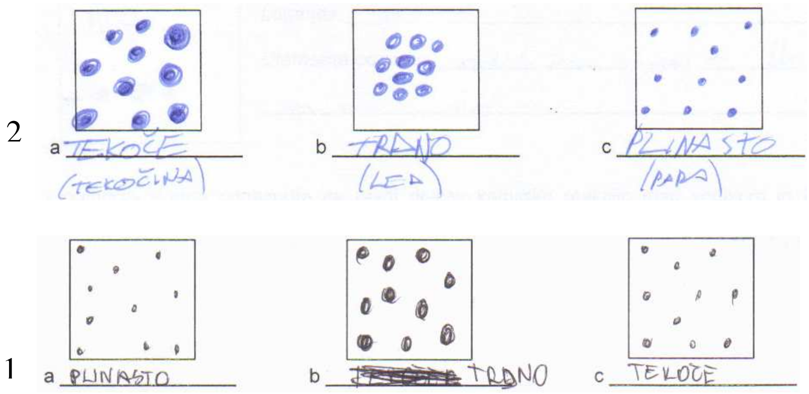


Figure 3. SMRs of different states of water presenting different sizes of molecules and their organisation in a specific state of water; original students' drawing, written on a line means: 1 - a gas; b solid; c liquid and 2 - a liquid; b solid; c gas).

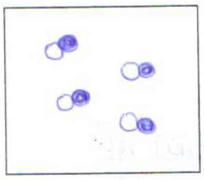


Figure 4. The same size of hydrogen and chlorine atoms in the molecule of hydrogen chloride.

Figure 5: *SMR* illustrating misconceptions of aqueous solution of potassium bromide.

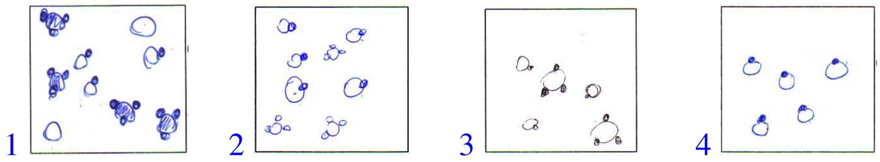


Figure 6: SMR illustrating misconceptions of an acid aqueous solution.

Table 1. Descriptive statistics for *CK*.

	Minimum points	Maximum points possible	Students' maximum points	Average points	SD	Kortusus	Skewness
Total CK score	1	43.5	40.25	21.21	6.47	0.036	-0.089
Reading of *SMRs* CK score	0	19.0	16.0	10.75	3.25	-0.233	-0.421
Drawing of *SMRs* CK score	0	24.5	24.25	10.46	3.88	0.546	0.082

Table 2. Pearsons' correlation coefficients between students' visualization abilities and success on CK.

	Speed of perception	p	Spatial relations	p
Total *CK* score	0.117	0.021	0.162	0.001
Reading of *SMRs CK* score	0.097	0.058	0.113	0.027
Drawing of *SMRs CK* score	0.114	0.025	0.176	0.001

Table 3. ANOVA between the three groups of students of different intrinsic motivation for learning chemistry and their success on CK.

	df, df	F	p
Total *CK* score *	2, 107.07	17.05	≤ 0.000
Reading of *SMRs CK* score	2, 383	9.99	≤ 0.000
Drawing of *SMRs CK* score **	2, 105.49	17.25	≤ 0.000

* the test of homogeneity of variances was statistically significant F (2, 383) = 3.74; p = 0.025), so the Welch test of equality of means was applied

** the test of homogeneity of variances was statistically significant F (2, 383) = 6.75; p = 0.001), so the Welch test of equality of means was applied

Table 4. ANOVA between the three groups of students of different intrinsic motivation for the macroscopic level of chemical concepts and their success on *CK*.

	df, df	F	p
Total *CS* score	2, 383	5.28	0.005
Reading of *SMRs CS* score	2, 383	1.90	0.151
Drawing of *SMRs CS* score *	2, 106.18	5.38	0.006

* the test of homogeneity of variances was statistically significant F (2, 383) = 3.95; p = 0.020), so the Welch test of equality of means was applied

Table 5. ANOVA between the three groups of students of different intrinsic motivation for the submicroscopic level of chemical concepts and their success on *CK*.

	df, df	F	p
Total *CS* score *	2, 107.40	19.92	0.000
Reading of *SMRs CS* score	2, 383	12.92	0.000
Drawing of *SMRs CS* score **	2, 105.83	19.55	0.000

* The test of homogeneity of variances was statistically significant (F (2, 383) = 3.61; p = 0.028), so the Welch test of equality of means was applied.

** The test of homogeneity of variances was statistically significant (F (2, 383) = 4.98; p = 0.007), so the Welch test of equality of means was applied.

Table 6. ANOVA between the three groups of students of different intrinsic motivation for the symbolic level of chemical concepts and their success on *CK*.

	df, df	F	p
Total *CK* score	2, 383	17.85	0.000
Reading of *SMRs CK* score	2, 383	10.94	0.000
Drawing of *SMRs CK* score *	2, 112.82	14.12	0.000

* The test of homogeneity of variances was statistically significant F (2, 383) = 3.60; p = 0.028), so the Welch test of equality of means was applied.

THE INFLUENCE OF 16-YEAR-OLD STUDENTS' GENDER, MENTAL ABILITIES, AND MOTIVATION ON THEIR READING AND DRAWING SUBMICROREPRESENTATIONS ACHIEVEMENTS

Abstract: Submicrorepresentations are a powerful tool for identifying misconceptions of chemical concepts and for generating proper mental models of chemical phenomena in students' long term memory during chemical education. The main purpose of the study was to determine which independent variables (gender, formal reasoning abilities, visualization abilities and intrinsic motivation for learning chemistry) have the most influence on students' reading and drawing submicrorepresentations. 386 secondary school students (aged 16.3 years) participated in the study. The instruments used in the study were: test of Chemical Knowledge, Test of Logical Thinking, two tests of visualization abilities Patterns and Rotations, and Questionnaire on Intrinsic Motivation for Learning Science. The results show moderate, but statistically significant correlations between students' intrinsic motivation, formal reasoning abilities and chemical knowledge at submicroscopic level based on reading and drawing submicrorepresentations. Visualization abilities are not statistically significantly correlated with students' success on items that comprise reading or drawing submicrorepresentations. It can be also concluded that there is a statistically significant difference between male and female students in solving problems that include reading or drawing submicrorepresentations. Based on these statistical results and content analysis of the sample problems, several educational strategies can be implemented for students to develop adequate mental models of chemical concepts on all three levels of representations.

Key Words: secondary school students', submicrorepresentations, students' mental abilities, intrinsic motivation, misconceptions.

INTRODUCTION

Learning science is strongly connected with building knowledge through understanding and concepts linking in students' long-term memory by interpreting multi-modal representations of science phenomena (Ainsworth, 1999; Russell & McGuigan, 2001). Students who recognized relationships between different representations demonstrated better conceptual understanding than students who lacked this knowledge (Prain & Waldrip, 2006). Students should be also able to translate one representation into another one and co-ordinate their use in representing scientific knowledge (Ainsworth, 1999). Russell and McGuigan (2001) argued that learners need opportunities to generate various representations of a concept, and to recode these representations in different modes, as they refined and made more explicit their understanding. In the process of science learning, the teacher should therefore incorporate students' "rich pool of representational competence" in creating lessons so that they are motivating for students (diSessa, 2004, p. 298). diSessa (2004) also points out that the quality of the representation ought to be evaluated according to its purpose. Waldrip, Prain, and Carolan (2006) argue that, in order to maximize the effectiveness of designed representational environments, it is necessary to take into account the diversity of learner background knowledge, expectations, preferences, and interpretive skills.

Representations of the chemical concepts could be defined on three levels (i.e. macro, submicro and symbolic level). Adequately merged, these representations can help students to develop a conceptual understanding of chemical phenomena. The *ITLS (Interdependence of Three Levels of Science concepts)* model shows these connections between different representations and the role of visualization methods used in the process of mental model construction of chemical phenomena that students ought to develop. The *ITLS* model draws on different educational theories, such as Paivio's dual coding theory, Mayer's SOI model of meaningful learning and Johnstone's model of information processing, cognitive theory of multimedia learning and Mayer's theory of effective illustrations (see for more details Author; Author).

To illustrate chemical concepts on the level of particles, submicrorepresentations *(SMR)* can be used and can be presented as static or dynamic modes of representations. Research shows (Bunce & Gabel, 2002; Tien, Teichert, & Rickey, 2007; Kelly & Jones, 2008) that those students who were exposed to *SMRs* during the educational process more adequately understand the nature of the particle interactions compared to those who learned the same concepts only by textbooks reading. Studies in the last two decades (Williamson & Abraham, 1995; Johnson, 1998; Chittleborough, Treagust, & Mocerino, 2002; Solsona, Izquierdo, & DeJong, 2003; Papageorgioua & Johnson, 2005; Stains & Talanquer, 2007a; Tien et al, 2007; Kelly & Jones, 2008; Author) also show that students have many difficulties in understanding the submicro and symbolic levels of chemical concepts, and that previous knowledge of a specific topic has an influence on integrating new science concepts into students' mental structure. It is also important to emphasise that a lot of different factors influence students' achievement on different pictorial test questions (Halakova & Prokša, 2007; Sanger & Phelps, 2007; Stains & Talanquer, 2008) and that the students' knowledge evaluation part of the educational process needs further study. Research also shows that teachers use mostly the symbolic level of chemical concepts to teach chemistry (Williamson & Abraham, 1995; Chittleborough et al., 2002). It is important to introduce different visualization abilities to illustrate abstract science concepts to the students at the beginning of science education - age 10 or 11 (Longden, Black, & Solomon, 1991) - thus also the application of submicrorepresentations (Papageorgioua & Johnson, 2005).

For the purpose of this paper some independent variables such as mental abilities (i.e. formal reasoning and visualization abilities) and intrinsic motivation were selected because, according to the research literature, these variables influence chemistry learning.

Piaget defined four stages of individuals' cognitive reasoning development: sensorimotor (from birth to about age 2), preoperational (begins about the time the child starts to talk to about age 7), concrete (about first grade to early adolescence) and formal operations (adolescence). Five modes of reasoning (i.e., controlling variables, proportional, correlational, probabilistic, and combinatorial reasoning) were defined and according to those modes subjects can be differentiated into three groups: concrete reasoners, transitional reasoners and formal reasoners (Tobin & Capie, 1981).

Thiele and Treagust (1994) report that students who cannot visualise chemical phenomena and/or do not have properly developed formal reasoning abilities cannot properly understand chemical concepts; thus those concepts are hard to understand, unattractive and pointless for them. According to some research results (Wu & Shah, 2003) the significant correlation between spatial ability and chemistry problem solving skills is based on general reasoning abilities or intelligence rather than on visuospatial thinking. Valanides (1996) reported that students aged 12 to 14 years show relatively low developed formal reasoning abilities. 64.6 % of these students show concrete operational abilities. The difference in their levels of formal reasoning abilities is not statistically significant. Similar results were obtained by Shemesh, Eckstein, & Lazarowitz, (1992). Statistically significant correlations were proven between formal reasoning abilities and students' chemical knowledge especially on submicro level (Haidar & Abraham, 1991; Williamson & Abraham, 1995)

It is important to emphasize that Yang, Andre, & Greenbowe (2003) concluded that students with low levels of visualization abilities show greater difficulties in understanding computer animations of chemical phenomena on particulate level. Research (Barke & Engida,

2001) also shows that girls have lower developed visualization abilities than boys, and they propose that students should use different models and visualization material very early in the science education process to stimulate development of visualization abilities. On the other hand, Wu and Shah (2003) reported no statistically significant correlations between students' achievements on the test with static *SMRs* and spatial abilities. They anticipated that the knowledge achievement is more dependent on students' prior knowledge and the general cognitive factor than on visualization abilities.

A negative relationship towards chemistry does not enable proper concept change and/or modification of students' mental model of chemical phenomena. Students often do not have a proper knowledge base that would make it possible to upgrade their knowledge of more and more abstract chemical concepts when they make progress on the educational vertical (Treagust, Harrison, & Venville, 1998).

Learning motivation is defined as a construct which includes different motivational elements (interests, goals, attributes, self-image, external enticements, etc.). Some of these form a more extrinsic stimulus for learning (e.g., learning for grades, praises, avoiding punishment, social acceptance, etc.), while others are manifested more intrinsically (i.e., learning for mastering, learning for knowledge) (Authors).

According to Ryan and Deci (2000), intrinsic motivation is an individual's inherent inclination from which stems his/her tendency to learn about particular areas of life regardless of the presence of external enticements. This construction encourages humans to '… assimilate, control, generate spontaneous interests and to research which makes it essential for the individual's social and cognitive development while on the other hand it represents the fundamental source of personal satisfaction and life energy.' (p. 70).

Highly intrinsically motivated students are more successful in learning new concepts and show better understanding of the learning matter (Stipek, 1998). Rennie (1990), on the basis of the research on science learning, also concluded that higher results in science are related to the learner's active engagement in learning tasks, to his/her positive attitude towards the subject and to a highly positive self-concept in science, which all imply the learner's intrinsic motivation to learn. This is especially important, since many writers (Anderman & Young, 1994; Zusho, Pintrich, & Coppola, 2003) report that the decrease in intrinsic motivation with years of schooling is particularly noticeable in mathematics and science and is at its peak in the period of early adolescence.

Keig and Rubba (1993) pointed out that motivation can be a potential source of variance on students' chemistry knowledge achievements. These claims were confirmed by Tuan et al. (2005). They reported that from 7 to 16% of variance on the science knowledge test could be explained by students' motivation. But on the other hand Nieswandt (2007) reported no statistically significant effect of students' affective variables (situational interest, attitudes towards chemistry and students chemistry-specific self-concept) on their understanding of grade 9 (age 15 to 16) chemistry concepts.

Chittleborough et al. (2002), according to their qualitative research, reported that students are not motivated for learning chemistry more that is necessary for passing the exam. Students' motivation for learning science and chemistry for that matter can be stimulated by using different visualization elements and analogies because this element of the lessons increases students' attention (Theile & Treagust, 1994) and also by different experimental work supported by ICT (Šorgo & Kocijančič, 2006).

Research (Anderman & Young, 1994; Meece & Jones, 1996) also shows that gender differences in motivation for science learning are connected with achievements on the standardized test of science knowledge. It was also established that girls show lower interest in science, that science is boring for them, especially because they just have to learn everything by heart. Results also show that girls possess lower levels of self-confidence in demonstrating their science knowledge (Simpson & Oliver, 1990). On the other hand, Meece and Jones (1996) did not confirm these results; they established that there is no difference between girls and boys regarding the interest in learning science and they also pointed out that gender influence on motivation and in its effect on the manifestation of science knowledge are more complex processes than other researchers try to show.

Purpose and research questions

According to the literature review the study of some independent variables that can influence chemistry learning was conducted. In this research the *SMRs* were used as a way for gathering students' chemical knowledge on the higher cognitive level. Submicrorepresentations were defined as tools for determining students' understanding of chemical concepts, and could be used mostly in two different ways. Firstly, students could read them and then use the information given by the specific *SMR* for solving the problem (reading *SMRs*), and secondly they could use the submicrorepresentations for presenting the solution of the science problem (drawing *SMRs*).

Regarding the purpose of this study four research questions can be addressed: (1) Are students' achievement scores significantly higher on problems that include reading *SMRs* than on those that include drawing them?, (2) Do male and female students achieve significantly different scores on problems that include reading and drawing *SMRs*?, (3) Do students with higher mental abilities (i.e. formal reasoning and visualization abilities) achieve significantly higher scores on problems that include drawing *SMRs* than on those that include reading them?, and (4) Do students with higher levels of intrinsic motivation score significantly higher on problems that include drawing *SMRs* than on those that include reading them?

Hypothesis

From the research questions five hypotheses can be stated:

(1) Students' achievement scores on chemistry problems that include reading *SMRs* are statistically significantly higher than scores on problems that include drawing *SMRs*.

(2) There is no statistically significant difference between males and females in solving problems involving reading and drawing *SMRs*.

(3) Students with higher formal reasoning abilities score statistically significantly higher on problems that include drawing *SMRs*.

(4) Students with higher visualization abilities score statistically significantly higher on problems that include drawing *SMRs*.

(5) Students with higher levels of intrinsic motivation for learning chemistry on different levels of chemical representations score statistically significantly higher on problems that include drawing *SMRs* than on those that include reading them.

Method

Participants

A total of 386 secondary school students (60.6 % females; 39.4 % males) participated in the study. On average, the students were 16.3 years old (M= 195.4 months; SD = 5.7 months). All students attended second year of the general type of secondary school (Gymnasium). The chemistry curriculum of the Gymnasium is common to all students. The students attended the fourth year of chemical education in the period that testing occurred (two years in higher primary school - age 13 and 14 and two years in secondary school - age 15 and 16). The sample included 5.5 % of the whole population of the students (N = 7033) in school year 2005/06, throughout Slovenia. Three schools were located in the larger towns (more than

100,000 residents) and three in smaller towns (between 35,000 and 100,000 residents). The sample represented a predominantly urban population with mixed socioeconomic status. Parents' basic educational background was diverse (3.1 % finished primary school; 45.1 % finished secondary school; 43.0 % finished university and 7.3 % finished other formal education) but only 11.6 % of parents had finished some kind of science or technology education.

Instruments

Students' abilities to read and draw the *SMRs* were measured using the diagnostic instrument for determining *Chemical Knowledge (CK)*. The instrument comprises 19 items. Eight items required reading and eleven items drawing *SMRs* in solving the chemistry problems considering the *ITLS* model. The *CK* includes four different contents: pure substances and mixtures (4 items), chemical reactions (6 items), water solutions (4 items) and electrolyte chemistry (5 items). The *CK* showed satisfactory measuring characteristics (i.e. internal consistency reliability - Cronbach's alpha was 0.80; discriminate indexes for every item between 0.21 and 0.80 were all statistically significant). Kortusis and skewness coefficients show normally distributed data (see Table 1). Students had 60 minutes to solve the *CK*. One sample item of each content of *CK* is introduced in Appendix 1.

To determine other independent variables, four different tests and a questionnaire were administered to the students: Test of Logical Thinking (*TOLT*), Rotations (*RO*), Patterns (*PA*), and Intrinsic Motivation for Learning Science questionnaire (*IMLS*).

The level of students' formal reasoning abilities was obtained with the *Test of Logical Thinking (TOLT)* (Tobin & Capie, 1981). The *TOLT* is a ten-item group paper-pencil test. The authors of the test reported a strong correlation ($r = 0.82$; $p < 0.0001$) between performance on tasks during Piagetian clinical interviews that are considered a traditionally preferable method in measuring individuals' formal reasoning abilities and the results on *TOLT*. The *TOLT* has high internal consistency reliability (Cronbach's alpha was 0.85). The test consists of two items designed to measure each of the five modes of reasoning (i.e., controlling variables, proportional, correlational, probabilistic, and combinatorial reasoning). The test scores from 0-1 points (concrete reasoners), 2-3 points (transitional reasoners) and 4-10 points (formal reasoners) were used as a basis for classifying the students. Students had 38 minutes to solve the test.

The students' visualization abilities were measured with two tests: *Patterns (PA)* and *Rotations (RO)* (Pogačnik, 1998; 2000). The *PA* measures students' speed of perception and the *RO* measures students' spatial relations abilities. Both tests were developed based on the Cattell-Horn theory of mental abilities. The *PA* is a 36 item group paper-pencil test. It requires individuals to find and mark exactly the same pattern among the four similar patterns on the right side of the paper to the one on the left part of the paper as quickly as possible. The *PA* has high internal consistency (Cronbach's alpha was 0.86). Correlations between some other instruments for determining individuals' perception abilities (*BTI-Or; BTI-Pr, Beta 6* and *4)* determine that the instruments' validity was higher and statistically significant. Students had 4.5 minutes to solve the test. The *RO* is a 90 item group paper-pencil test. The *RO* requires individuals to find and encircle those patterns on the right side of the paper that are just rotated in comparison with the left pattern. Individuals have to cross those patterns that are not just rotated in the plane but represent a different pattern. Cronbach's alpha for the *RO* was 0.94. Correlations between some other instruments for determining individuals' perception abilities (*BTI-Pr, Beta 4)* were also high and statistically significant. Students had 6 minutes to solve the test. The classifications of students into three groups with regard to their visualization abilities were performed according to the statistical equations. Into Group 1 (poor visualization abilities) were classified students that scored less than M - 1SD points, into Group 2 (average visualization abilities) those that scored between M - 1DS and M + 1SD points, and into Group 3 (superior visualization abilities) students that scored above M + 1SD points on the *PA* and *RO*.

The last independent variable, the intrinsic motivation for learning chemistry was measured by the *IMLS* questionnaire. There are many questionnaires to measure students' attitudes or interests in science and/or chemistry (e.g. Moore & Foy, 1997; Tuan et. al., 2005; Coll et al., 2002; Nieswandt, 2007). All these instruments show a rather general structure of students' attitudes towards science, but they lack the dimension with reference to the *ITLS* model and separately for different science school subjects. These questionnaires do not show enough specific characteristics regarding the research questions asked in this study and would need extensive revision for adapting the instrument to secondary level. For those reasons the new instrument for measuring intrinsic motivation, 125-item *IMLS (Intrinsic Motivation for Learning Science* questionnaire, was developed (Authors). The response to each item is on a five-point Likert-type scale ranging from 1 as strongly disagree to 5 as strongly agree. The internal consistency (Cronbach α) of *IMLS* was 0.78. Students had 20 minutes to complete the questionnaire. The classifications of students into three groups with regard to their intrinsic motivation for learning chemistry were performed according to the statistics. Into Group 1 (poor intrinsically motivated) were classified students that scored less than M - 1SD points, into Group 2 (average intrinsically motivated) those that scored between M - 1DS and M + 1SD points, and into Group 3 (superior intrinsically motivated) students that scored above M + 1SD points on the *IMLS*. Three sample items of each component of intrinsic motivation from the *IMLS* questionnaire are included in Appendix 2.

Research design

The research was a non-experimental, cross-sectional and descriptive study (Bryman, 2004).

The students had received no special teaching about using *SMRs* in the chemistry classroom. The chemical concepts comprised in the *CK* were not instructed using *SMRs* by the teachers that taught the students participating in the study.

CK and *IMLS* were designed specifically for this study. The *CK* was administered to two university chemistry and chemical education professors. Their responses provided scientifically correct answers and content validation for the instrument. The *IMLS* was distributed to two experts in science education and one in educational psychology. Their evaluation of the instrument confirmed that the *IMLS* measures students' intrinsic motivation for learning and their analysis provided validation for the questionnaire. The Slovene translation of the *TOLT* was used for the study. The test was separately translated into the Slovene language by one expert in chemistry and one expert in physics education. The translations were compared and possible modifications were made in preparing the third version of the test. The third expert translated the test back into English. The original and the translated version of the English test were compared and possible modifications were made in designing the final Slovene version of the *TOLT*. Four independent experts in chemistry, physics and mathematics education finally reviewed the test, and their responses provided content validation of the instrument.

After all the instruments had been developed or chosen in relation to the purpose of the study, a pilot study was conducted with 77 students. The *CK*, *TOLT* and *IMLS* were used in the pilot study. Taking into account the statistical analysis of the results obtained in the pilot study, the *SK* and *IMLS* were modified.

All instruments were applied on the research sample at the end of the second school year 2005/06 of the secondary school. The testing took students about 135 minutes on two separate days. Students solved the *IMLS* and *CK* in the first week and in the second one they solved the *TOLT, RO* and *VZ.* The last testing was conducted by a trained psychologist. All instruments were applied in a group and under normal examination conditions.

Descriptive statistics were obtained for illustrating the *CK* characteristics. For determining differences in the means of *CK,* the paired-sample t-test was used. Pearsons' correlation coefficients for determining the correlation between knowledge of chemical concepts and other independent variables were calculated. The percentage of variance two variables share is referred to as the coefficient of determination. The coefficient of determination is calculated by square the correlation coefficient (r^2) value and then converted into percentage of variance by multiplying it by 100 (Pallant, 2005). In other words, the square of correlation coefficient (r^2) is the fraction of the variation in the values of independent variable that is explained by the least-squares regression of independent on dependent variable (Moore & McCabe, 1997).

In addition, the one-way between-groups analysis of variance (*ANOVA*) was conducted to explore the influence of reasoning abilities, visualization abilities and intrinsic motivation for learning chemistry on students' success in solving *CK* tasks. If the test of homogeneity of variances was statistically significant when comparing the means of the groups of students, the more robust test (Welch test) of equality of means was used.

The 5% cut off was used in presenting the most frequent misconceptions detected by analysing the students' sample problem solving achievements. The decision was made according to the statistical significance of results. It tells us something about the degree to which the result is "true" in the sense of being "representative of the population": 5% is customarily treated as a "border-line acceptable" error level (Moore & McCabe, 1997).

Results

The *CK* analysis show secondary school students' average chemical knowledge of the tested basic chemical concepts (*Table 1*). Students achieved on average 49 % of all points possible on the *CK*.

Students were more successful in reading *SMRs* than drawing them. Students managed to get on average 56.5 % of all points on items that required reading the *SMRs*. On the other hand, students achieved on average 42.4 % of all points available on problems that required drawing the most suitable *SMRs*.

Table 1. Descriptive statistics for *CK*.

The paired samples t-test shows that students score statistically significantly higher in solving problems that require reading *SMRs* than in those that require drawing them (t (385) = 1.97, p = 0.048). More detailed presentation of students' achievements in solving specific sample problems (See Appendix 1) is presented in Chart 1.

Chart 1. Students' achievements at sample chemistry problems (PSM – Pure substances and mixtures; CR – Chemical reactions; EC – Electrolyte chemistry; and SC – Solution chemistry).

Some results of the detailed analysis of students' responses to the sample *SMRs* chemistry problems are presented below in the same order as in Chart 1.

Pure substances and mixtures (PSM Reading SMRs)

Results of the analysis of Problem 1 (See Appendix 1) show, that 34.8% of students incorrectly select the *SMRs* representing the mixture of two compounds (Chart 1). Some students correctly selected one of them, out of two possible solutions.

13.4% and 13.7% of students think that a mixture of molecules with the same atoms and molecules with different atoms, presented on *SMR* C and *SMR* E respectively, is also a mixture of two compounds. 9.6 % of students selected the *SMR* A as a correct answer. These results show, that about 10% of students after three years of chemical education do not adequately understand the differences between a molecule of element and compound at the particulate level. There were other mistakes which were less frequent (less than 5% cases).

Chemical reaction (CR reading SMRs)

Results presented in Chart 1 show that 33.1% of students correctly solve Problem 2 (See Appendix 1). 40% of students selected the chemical equation representing the given *SMR*. More than 42% of students selected the incorrect chemical equation ($5A + 5B_2 \rightarrow 5A_2B_2 + 2A$). Those students do not understand the connection between the concept of chemical reaction on submicroscopic level and its symbolic representation and/or do not understand the basic roles of symbolic chemical language. More than 6% of the students also selected the equation $12A + 10B \rightarrow 6A_2B_2$. The equation is actually presenting the situation on the *SMR* but students usually do not write the chemical equations with more than the list numbers of moles of reactants and products that are possible, so those students who selected this equation just counted the numbers of molecules or atoms of reactants and products. All students that correctly selected the equation representing the *SMR* also knew which reactant did not react completely and also 36% of those students that were incorrect in selecting the equation did succeed in determining which reactant did not react completely. It is important to emphasize that 42.2% of students think that the reactant that does not react completely in the chemical reaction is written as a product into the chemical equation. 32 % of students wrote in elaborating their answer, that substance B was completely used in the reaction, and 24 % wrote vice versa, that substance A remains after the reaction. 7.4% of students did not elaborate their answer adequately. 22.5% of students elaborate their answer at the submicroscopic level (e.g. *»All atoms (A) were used in the reaction.«*) but almost 44% of the students elaborated their answer on the macroscopic level (e.g. *»Substance A didn't completely react.»*; *»There is still substance A after the reaction.«; »Remains only substance A.«; »At the end there is no substance B only A.«*). It is also interesting to note out that 19.9% of students did not elaborate their answer. There were other mistakes which were less frequent (less than 5% cases).

Electrolyte chemistry (EC reading SMRs)

57.8% of students correctly assigned all three *SMRs* to the aqueous solution of base, acid and soluble salt in Problem 3 (See Appendix 1). 6.1% of students did not solve the problem and 33.1 % of them incorrectly assigned one or more *SMRs* to the correct aqueous solution. These students tried to answer the question by guessing the right answer so they didn't understand the submicroscopic properties of electrolyte. Other mistakes represent less than 5% of all cases.

Pure substances and mixtures (PSM drawing SMRs)

87.3% of students didn't draw the correct *SMRs* of all three states of water (Chart 1) in Problem 4 (See Appendix 1). Only 7.8% of students drew the *SMRs* similar to those presented in Figure 1.

Figure 1. Correctly presented all three states of water; original students' drawing, written on line means: a solid; b liquid and c gas.

Students were the most successful at drawing water in a gaseous state (65.2%) whilst only 7.8% of students correctly represented liquid water. 29.2% of students draw water molecules too far apart (Figure 2a) and 23.9% of them represent liquid water as a gas (large distances between the molecules). Students also didn't take into account that the distances between water molecules during freezing increases (ice has about 9 % lower density as liquid water), but they just adopted the general characteristic of substances that there are larger distances between particles in liquid than in solid state (Figure 2).

Figure 2. Incorrectly presented states of water; original students' drawing, where written on a line means: a liquid; b solid; c liquid and d gas.

The next most frequent misconception of particle organization in different states of water is shown in Figure 3.1b, 3.1c, 3.2c and 3.2d. 26.7% of students present an ordered structure of water molecules in liquid (Figure 3.2a) and 4.4% in gas state (Figure 3.2c). 4.2% of students presented different sizes of water molecules in different states (Figure 3.1) and 6.1% of students draw ice on submicroscopic level with molecules too apart and not ordered (Figure 3.1b.). There were other mistakes which were less frequent (less than 5% cases).

Figure 3. SMRs of different states of water presenting different sizes of molecules in a specific state of water; original students' drawing, written on a line means: 1 - a gas; b solid; c liquid and 2 - a liquid; b solid; c gas).

Chemical reaction (CR drawing SMRs)

Only 18.4% of students correctly presented the chemical reaction between chlorine and hydrogen molecules on submicroscopic level (See Chart 1). The Problem 5 (See Appendix 1) was three-parted. In the first part students had to write the *SMR* (18.4 % correct drawings and 75.2 incorrect), in the second part they had to present the drawn particles in a legend with their nemeses or formulas (39.1% sufficient legends and 55.3% with some sort of incorrectness) and in the third part students had to elaborate their solution of the problem.

34.3% of students did not take into account the different size of chlorine and hydrogen atoms and they just drew the *SMR* as shown in Figure 4.

Figure 4. The same size of hydrogen and chlorine atoms in the molecule of hydrogen chloride.

38% of students did not consider the correct number of product molecules according to the problem text, so they illustrated only two molecules of hydrogen chloride.

Analysis of the legend shows, that 27.2% of students who correctly presented the legend used symbols of elements to illustrate the drawn particles, but in only 2.7% of cases students used a correct name of the particle (e.g. hydrogen atom and chlorine atom). In average more than 27% (hydrogen – 28.2%; chlorine – 27.5%) of students just wrote the name of an element in the legend and not the name of the particles.

48.2% of the students elaborate their *SMR* using some part of submicroscopic level of chemical concepts; this means that they try to incorporate the particulate description into their elaboration (e.g. *»1 atom Cl and 1 atom H is needed for HCl«; »One atom H is bonded with one atom Cl; in two molecules of each element are 4 atoms, and so 4 molecules of HCl are formed.« »HCl is composed from 1atom H and 1 atom Cl.«*). It is also important to take into account that 20.8% of students did not write any elaboration. There were other less frequent mistakes, less than 5% of all cases.

Solution chemistry (SC drawing SMRs)

Students had a lot of problems drawing the correct *SMR* of aqueous solution of potassium bromide and presented the drawn particles in the legend while solving problem 6 (See Appendix 1). 7.6% of students otherwise drew the *SMR* correctly, but made the same mistake in the legend or vice versa, because only 2.9% of students correctly named the particles in the solution as bromide and potassium ions. Only 0.7% of students correctly solve both parts of the problem, and more than 20 % did not even attempt to solve it (see Chart 1).

The most frequent misconception (46.1% of students) of potassium bromide aqueous solution is that students draw molecules of the solute. Almost half of these students did not consider the different ionic (atomic) radius of the ions (atoms) and drew the solution as shown on Figure 5.

Figure 5: SMR illustrating misconceptions of aqueous solution of potassium bromide (i.e. represented molecules of potassium bromide and also not taking into account that potassium and bromide particles differ in their radii).

10.7% of students did also not know that is the mol ration between potassium and bromide ions 1:1, so they attribute usually two bromide ions to one potassium ion.

Only 2.9% of all students correctly named the particles presented in the *SMR* in the legend. Most (28.2%) students wrote the symbol of an element to represent the particle, which was not requested by the problem. 13.5% of students also wrote the names of both elements and not names of the ions.

There were other mistakes which represent less than 5% of all cases. For more detailed analysis see Authors (…). But the overall conclusion is that a majority of students were unable to correctly represent the aqueous solution of an ionic substance on a submicroscopic level.

Electrolyte chemistry (EC drawing SMRs)

A lot of students participating in the study also had problems drawing the submicrorepresentation of the aqueous solution of the stronger acid as was represented by the given *SMR*, but with the same concentration. For the correct solution to Problem 7 (See Appendix 1) students should take into consideration five variables (i.e. represented the same acid concentration; higher number of hydronium ions and conjugated base ions like on the given *SMR* but the number of each should be the same; and the complete dissociation should be represented). The analysis of their *SMRs* shows, that 35.3% of students represent the same number of acid molecules as on given *SMR*. 34.1% of them associate the acid strength with the concentration of acid molecules in the aqueous solution and 25.7% of them with the level of dissociation. The same number of hydronium ions and conjugated base ions was given only by 21.6% of the students. All variables were considered in the process of problem solving only by 10.3% of the students and 21.6% did not even attempt to draw the *SMR*.

The most frequent mistake (30.6%) was that students represented lower concentrations of the strongest acid. 20.8% of the students did not draw the hydronium and conjugated base ions, and 12.5% of the students represented also the water molecules (the problem text specifically addressed that this was not requested). Other misconceptions are: (1) the same number of conjugate base ions as on *Scheme* 1 (11.8%) (Figure 6.1); (2) lower concentration of an acid as on *Scheme* 1 (11.5%) (Figure 6.1-6.4); (3) no conjugated base ions in the drawing, only hydronium ions (10.5%) (Figure 6.2-6.3); (4) the same number of hydronium ions as on *Scheme* 1 (9.8%) (Figure 6.3); (5) no hydronium ions (7.4%) (Figure 6.4) and (6) the same or less conjugated base ions as on *Scheme* 1 (6.6%) (Figure 6.1-6.4). There were other mistakes which represent less than 5% of all cases and they are not presented at this point.

Figure 5: SMR illustrating misconceptions of an acid aqueous solution drawn by the students using the *Scheme 1*.

In the second part of the problem students had to elaborate their decision. 44.1% of them did not elaborate their *SMR*, 35.5% did try to discuss their decision connecting macroscopic and submicroscopic level of chemical concepts, but they show numerous misconceptions, that additionally confirmed misconceptions discovered by drawn *SMRs* (e.g. *»There are more hydronium ions in scheme 2, so the acid is stronger«; »There is more acid molecules in the stronger acid.«; »Higher concentration because there are more acid molecules.«; »The acid is stronger, because water molecules are smaller.«; »More hydronium ions cause higher acidity.«; »Hydrogen detaches from the hydronium ions, and with free atoms form two new acid molecules.«; »Stronger acid has less water molecules.«)*. Only 7.8% of students also try to explain their solution of the problem only on a macroscopic level (e.g. *»If there is more acid, should be also more water to obtain the same concentration.«; and »Stronger acid has higher pH value.«)*, and other elaborations were less frequent (less than 5%). It can be concluded from the content analysis of the students' elaborations that 24.5% of them tried to illustrate their *SMR* by saying that they had drawn larger number of hydronium ions, lower number of acid molecules or they mentioned higher number of dissociated acid molecules, and 12.3% of students associated the acid strength with its concentration.

Content analysis of selected chemistry *SMRs* reading and drawing problems suggests that different variables may influence students' problem solving achievements, so a more detailed analysis of some selected independent variables (students' gender, reasoning abilities and motivation) was conducted in an attempt to explain these influences.

Students' gender and achievement scores on CK

In the present study statistically significant differences in total *CK* score between males and females were proven by an independent-samples t-test. The results show that males' (M = 22.83; SD = 6.50) scores are statistically significantly higher than females' (M = 20.16; SD = 6.24); t (384) = - 4.04, p ≤ 0.000). An independent-samples t-test was also conducted to compare the success of males (M = 11.45; SD = 3.29) and females (M = 10.29; SD = 3.16) on items that required reading *SMRs*. Males scored significantly higher than females (t (384) = - 3.48, p ≤ 0.000). Similar results were obtained by comparing students' scores on items that required drawing *SMRs*. Males (M = 11.38; SD = 3.86) scored significantly higher than females (M = 9.87; SD = 3.78); t (384) = - 3.80, p ≤ 0.000).

Students' mental abilities and achievement scores on CK

It can be concluded from the results that 86.3 % of students are formal reasoners, 11.1 % of students fall into the group of transitional reasoners and even 2.6 % of the students are still on the concrete level of reasoning. Those students who have better developed formal reasoning abilities are more successful in solving problems that include drawing (r = 0.50; p ≤ 0.000) and reading (r = 0.53; p ≤ 0.000) *SMRs*. On average 28.1 % of students' success in solving the items that demand reading *SMRs* can be explained by the *TOLT* score. On the other hand, 25.0 % of students' ability to solve the problems that require drawing *SMRs* can be explained by students' formal reasoning abilities. The correlation between the overall successes in solving problems requiring understanding the *ITLS* model shows, that 31.8 % of students' success on *CK* can be explained by their reasoning abilities ($r = 0.56$; $p \leq 0.000$). It can be concluded that students need to have developed higher levels of reasoning abilities to solve the CK items more successfully.

For further analysis, the one-way between-groups analysis of variance was conducted to explore the influence of formal reasoning abilities on total success in *CK* and in solving tasks of reading and drawing *SMRs*. Students were divided into three groups according to their reasoning abilities (Group 1: concrete reasoners, Group 2: transitional reasoners and Group 3: formal reasoners).

The differences in overall success in *CK* between the three groups of students of different formal reasoning abilities are statistically significant ($F(2, 383) = 33.39$, $p \leq 0.000$). Post hoc comparisons using Tukey HSD showed that there is a statistically significant difference ($p \leq 0.000$) between the mean scores for Group 1 ($M = 13.43$, $SD = 5.88$) and Group 3 ($M = 22.20$, $SD = 5.99$) and also for Group 2 ($M = 15.38$, $SD = 5.98$) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.622$) between the groups of concrete and transitional reasoners in success in *CK*. There is a statistically significant difference between groups of students with different reasoning abilities in success at reading ($F(2, 383) = 29.81$, $p \leq 0.000$) and drawing ($F(2, 383) = 24.25$, $p \leq 0.000$) *SMRs*. Post hoc comparisons using Tukey HSD indicated that the mean scores for reading *SMRs* between Group 1 ($M = 6.80$, $SD = 3.16$) and Group 3 ($M = 11.22$, $SD = 2.99$) were statistically significantly different ($p \leq 0.000$) and also between Group 2 ($M = 8.02$, $SD = 3.22$) and Group 3 ($p \leq 0.000$). Group 1 did not differ significantly from Group 2 ($p = 0.485$) regarding reading *SMRs*. Similar results were obtained by post hoc comparisons using the Tukey HSD test regarding mean scores for drawing *SMRs*. Group 1 (M = 6.63, SD = 3.57) was statistically significantly different (p = 0.001) from Group 3 (M = 10.98, SD = 3.72) and also for Group 2 (M = 7.35, SD = 3.25) and Group 3 (p ≤ 0.000). Group 1 did not differ significantly from Group 2 (p = 0.839).

The next two independent variables include students' visualization abilities.

Table 2. Pearsons' correlation coefficients between students' visualization abilities and success on CK.

Students' visualization abilities are not so highly correlated with *CK* scores as are formal reasoning abilities (*Table 2*). Students' speed of perception is not statistically significant correlated with their success in problem solving regarding reading *SMRs*, on the other hand a very low but statistically significant factor is students' ability for drawing *SMRs* (r = 0.11; p = 0.025). Another students' visualization ability, i.e. spatial relations, is somewhat more highly correlated with drawing *SMRs* (r = 0.18; p = 0.001) than reading (r = 0.11; p = 0.027), but the correlation coefficients are still very low, and the connection between students' *CK* achievements and their visualization abilities could be neglected. It can be summarised that only 2.6 % of students' *CK* scores can be explained by spatial relations and even less - only 1.4 % - by speed of perception.

The *ANOVA* was conducted to explore the influence of visualization abilities on students' success in solving tasks that include reading and drawing *SMRs*. Students were divided into three groups according to their speed of perception and spatial relations abilities (Group 1: poor speed of perception or spatial relations abilities, Group 2: average speed of perception or spatial relations abilities, and Group 3: superior speed of perception or spatial relations abilities). The differences in total scores on *CK*, and problems that demand reading or drawing *SMRs*, between the three groups of students with different speed of perception abilities are not statistically significant.

On the other hand there are statistically significant differences between the groups of students in spatial relations abilities and their success in solving the tasks on *CK* (F(2, 382) = 5.91, p = 0.003). Post hoc comparisons using Tukey HSD showed that there is a statistically significant difference (p = 0.035) between the mean scores for Group 1 (M = 19.08, SD = 5.85) and Group 2 (M = 21.31, SD = 6.63) and also between the mean scores for Group 3 (M = 22.93, SD = 5.90) and Group 1 (p = 0.002). There is no statistically significant difference (p = 0.162) between groups of students with average and superior spatial relations abilities in total success on *CK*.

The one-way analysis of variance shows that there are also statistically significant differences between the groups of students in spatial relations abilities and their success in solving the tasks that demand reading (F(2, 382) = 3.43, p = 0.033) and drawing *SMRs* (F(2, 382) = 6.23, p = 0.002). Post hoc comparisons using the Tukey HSD showed that the mean scores for reading *SMRs* are statistically significantly different (p = 0.027) between Group 1 (M = 9.90, SD = 3.09) and Group 3 (M = 11.38, SD = 2.79). There is no statistically significant difference (p = 0.121) between the groups of students with poor and average spatial relations abilities and also between groups with average and superior spatial relations abilities (p = 0.397) in success in solving items that include reading *SMRs*. Post hoc comparisons showed that there is a statistically significant difference (p = 0.001) between the mean scores for drawing *SMRs* for Group 1 (M = 9.17, SD = 3.46) and Group 3 (M = 11.55, SD = 3.65) and also for Group 2 (M = 10.51, SD = 3.96) and Group 1 (p = 0.035). There is no statistically significant difference (p = 0.125) between Group 2 (average spatial relations abilities) and Group 3 (superior spatial relations abilities) in success in drawing *SMRs*.

Students' intrinsic motivation and CK score

The last set of variables includes intrinsic motivation for learning chemistry, which is statistically significantly correlated to students' success in solving the *CK* ($r = 0.31$; $p \leq 0.000$). The results show that there is a lower correlation between learning chemistry in general and students' reading *SMRs* scores ($r = 0.22$; $p \leq 0.000$) than between the same intrinsic motivation and drawing *SMRs* ($r = 0.32$; $p \leq 0.000$). The results seem to indicate that only 9.36 % of the *CK* score variance can be accounted for by students' level of intrinsic motivation for learning chemistry. The even lower percentage of success in solving tasks that require reading *SMRs* (4.93 % variance) can be explained by intrinsic motivation for learning chemistry, but on the other hand the most intrinsically motivated students successfully solve tasks with drawing *SMRs* (10.43 % of variance explained).

Students were divided into three groups according to their level of intrinsic motivation for learning chemistry (Group 1: poor intrinsically motivated, Group 2: average intrinsically motivated, and Group 3: superior intrinsically motivated).

Table 3. ANOVA between the three groups of students of different intrinsic motivation for learning chemistry and their success in *CK*.

It can be concluded from the post hoc analysis using Tamhane (for equal variances not assumed) that there is a statistically significant difference ($p \leq 0.000$) between the mean scores on *CK* for poor (Group 1) intrinsically motivated students for learning chemistry ($M = 19.21$, $SD = 7.11$) and Group 3 – superior intrinsically motivated ($M = 25.61$, $SD = 6.75$) and also between average – Group 2 ($M = 20.63$, $SD = 5.76$) and superior – Group 3 intrinsically motivated students ($p \leq 0.000$). There is no statistically significant difference ($p = 0.373$)

between Group 1 and Group 2 in success in solving the tasks on *CK*. The post hoc analysis using Tamhane (for equal variances not assumed) also showed that there is a statistically significant difference ($p \leq 0.000$) between the groups of students with different level of intrinsic motivation and their success in solving the tasks that demand drawing *SMRs* for Group 1 (M = 9.17, SD = 4.04) and Group 3 (M = 13.27, SD = 4.40) and also for Group 2 (M = 10.09, SD = 3.37) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.270$) between students with poor and average score in the intrinsic motivation questionnaire in success in solving tasks drawing *SMRs*. Post hoc comparisons using the Tukey HSD revealed that there is a statistically significant difference ($p \leq 0.000$) between the mean scores for Group 1 (M = 10.03, SD = 3.57) and Group 3 (M = 12.33, SD = 3.05) and also for Group 2 (M = 10.54, SD = 3.11) and Group 3 ($p \leq 0.000$) in reading *SMRs* achievements. There is no statistically significant difference ($p = 0.493$) between students with poor and average intrinsic motivation for learning chemistry in success at reading *SMRs*.

Students' intrinsic motivation for learning the macro level of chemical concepts is also statistically significantly correlated with the overall *CK* score ($r = 0.24$; $p \leq 0.000$) and with students' ability for reading and drawing *SMRs*. The correlation coefficients extend from ($r = 0.15$; $p \leq 0.000$) for reading and ($r = 0.27$; $p \leq 0.000$) for drawing *SMRs*. The results show that similar low percentages, as obtained regarding students' intrinsic motivation for learning chemistry, of total *CK* score (5.5 %), *CK* reading *SMRs* score (2.3 %) and drawing *SMRs* score (7.0 %) variance can be explained by intrinsic motivation for learning chemistry at the macroscopic level.

Table 4. ANOVA between the three groups of students of different intrinsic motivation for the macroscopic level of chemical concepts and their success on CK.

The *ANOVA* showed that the differences between the three groups of students of different intrinsic motivation for the macroscopic level of chemical concepts and their success on *CK* are statistically significant regarding the total score on *CK* ($p = 0.005$) and drawing *SMRs* ($p = 0.006$) but not reading them ($p = 0.151$). Post hoc comparisons using Tukey HSD showed that there is a statistically significant difference ($p = 0.008$) between the mean total scores on *CK* for poor ($M = 20.27$, $SD = 7.06$) and superior ($M = 23.73$, $SD = 7.15$) intrinsically motivated students for learning chemical concepts on the macroscopic level and also for average ($M = 20.93$, $SD = 6.04$) and superior intrinsically motivated ($p = 0.009$). There is no statistically significant difference ($p = 0.724$) between Group 1 and Group 2 in success on *CK*. Because the test of homogeneity of variances for drawing *SMRs* was statistically significant (*Table 4*), the Welch test of equality of means was used. The Welch test showed that the differences between the three groups of students of different intrinsic motivation for learning the macro level of chemical concepts and their success in drawing *SMRs* are statistically significant ($p = 0.006$). It can be concluded from the post hoc analysis using Tamhane (for equal variances not assumed) that there is a statistically significant difference ($p = 0.006$) between the mean scores for Group 1 ($M = 9.77$, $SD = 3.89$) and Group 3 ($M = 12.20$, $SD = 4.54$) and also for Group 2 ($M = 10.28$, $SD = 3.63$) and Group 3 ($p = 0.013$). There is no statistically significant difference ($p = 0.685$) between Group 1 and Group 2 in success at solving the tasks that include drawing of *SMRs*.

It is important to emphasise that those students who show more interest in learning chemical concepts on submicro level are also more efficient in drawing ($r = 0.36$; $p \leq 0.000$) than in reading ($r = 0.26$; $p \leq 0.000$) *SMRs*. The correlation between the total score on *CK* and interest in learning chemistry on submicroscopic level is moderate ($r = 0.34$) and statistically significant ($p \leq 0.000$). It can be concluded that 12.7 % of variance in drawing, and only 6.5 %

respectively of students' ability in reading *SMRs*, can be explained by their intrinsic motivation scores for learning chemistry on submicro level.

Table 5. ANOVA between the three groups of students of different intrinsic motivation for the submicroscopic level of chemical concepts and their success on CK.

Post hoc comparisons using the Tukey HSD showed that there is a statistically significant difference ($p \leq 0.000$) between the mean scores for Group 1 (M = 10.15, SD = 3.58) and Group 3 (M = 12.63, SD = 3.08) and also for Group 2 (M = 10.47, SD = 3.06) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.743$) between the group of students with poor and average intrinsic motivation for learning chemical concepts on submicro level in success in reading *SMRs*.

The post hoc analysis using Tamhane (for equal variances not assumed) shows that there is a statistically significant difference ($p \leq 0.000$) between the mean scores on *CK* for poor (M = 19.22, SD = 6.99) and superior (M = 26.15, SD = 6.80) intrinsically motivated students for learning submicroscopic level of chemical concepts and also for the average (M = 20.58, SD = 5.69) and superior group of students ($p = 0.000$). There is no statistically significant difference ($p = 0.370$) between Group 1 and Group 2 in success in solving the tasks on *CK*. It can be concluded from the post hoc analysis using Tamhane that there is a statistically significant difference ($p \leq 0.000$) between the mean scores regarding success in solving problems with drawing *SMRs* for Group 1 (M = 9.07, SD = 4.02) and Group 3 (M = 13.51, SD = 4.38) and also for Group 2 (M = 10.11, SD = 3.34) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.149$) between Group 1 and Group 2 in success in solving the tasks of drawing *SMRs*.

Students' intrinsic motivation for learning chemistry at the symbolic level of the *ITLS* model is statistically significantly correlated ($r = 0.28$; $p \leq 0.000$) to the students' achievements in *CK* (*i.e.* reading *SMRs* $r = 0.20$; $p = 0.000$, and drawing *SMRs* $r = 0.31$; $p \leq 0.000$). The correlation coefficients show higher correlation for drawing than for reading *SMRs*. It can be summarised that only 4 % of variance on reading *SMRs* scores can be accounted for by students' interest in learning symbolic chemical concepts and 9.6 % of variance on drawing *SMRs*, respectively.

Table 6. ANOVA between the three groups of students of different intrinsic motivation for the symbolic level of chemical concepts and their success on *CK*.

The *ANOVA* showed (*Table 6*) that the differences between the three groups of students of different intrinsic motivation for symbolic level of chemical concepts and their success in *CK* is statistically significant ($p \leq 0.000$). Post hoc comparisons using the Tukey HSD showed that there is a statistically significant difference ($p \leq 0.000$) between the mean total scores on *CK* for Group 1 (poor intrinsic motivation) (M = 19.80, SD = 7.00) and Group 3 (superior intrinsic motivation) (M = 25.59, SD = 6.58) and also for Group 2 (average intrinsic motivation) (M = 20.60, SD = 5.86) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.597$) between Group 1 and Group 2 in success on *CK*. The one-way analysis of variance showed that the differences between the three groups of students of different intrinsic motivation for the symbolic level of chemical concepts and their ability in reading *SMRs* is also statistically significant ($p \leq 0.000$). Post hoc comparisons using Tukey HSD showed that there is a statistically significant difference ($p \leq 0.000$) between the mean scores for Group 1 (M = 10.35, SD = 3.49) and Group 3 (M = 12.53, SD = 2.96) and also for Group 2 (M = 10.45, SD = 3.13) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.970$) between students with low level of intrinsic motivation and those with average motivation in success in reading *SMRs*. The Welch test showed that the differences between the three groups of students of different intrinsic motivation for learning the symbolic level of chemical concepts and their success in problems that include drawing ($p = 0.000$) are statistically significant. The post hoc analysis using Tamhane (for equal variances not assumed) shows that there is a statistically significant difference ($p \leq 0.000$) between the mean scores for Group 1 ($M = 9{,}45$, $SD = 4.07$) and Group 3 ($M = 13.07$, $SD = 4.27$) and also for Group 2 ($M = 10.15$, $SD = 3.46$) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.458$) between Group 1 and Group 2 in success in drawing *SMRs*.

Discussion and implications for education

The first hypothesis relates to the difference in students' achievements between chemistry problems that include reading *SMRs* and those that include drawing them, and can be confirmed. It can be concluded that the average points scored by the students on items that require reading submicrorepresentations are higher (by 14.1%) compared to the average points for items that include drawing the *SMRs*. These results are consistent with some other research (Kelly & Jones, 2008; Margel, Eylon, & Scherz, 2008) which indicate that students have specific problems with drawing the correct submicrorepresentations of the natural phenomena.

Results in our study show specific misconceptions that are presented by the students while transferring the submicro world of particles into the symbolic level. Students demonstrate difficulties also trying to describe the submicrorepresentations or they just try to illustrate the phenomena on the particulate level.

Firstly, students also have difficulties in representing different states of matter (See sample item 4 in Appendix 1). They express the most misconceptions representing the liquid state of water (molecules too far apart, incorrect arrangement of molecules), and they were the most successful in presenting the gas state of water. A lot of students also had difficulties in illustrating ice on a submicroscopic level. Students also struggle to distinguish between pure substances and mixtures, because they anticipate that those particles that are represented by two circles represent a compound, no matter what sort of atoms are bonded in the molecule (See sample item 1 in Appendix 1). It can be concluded that students connect elements only with separate atoms and compounds with multiple atoms molecules. According to these results teachers should place more emphasise on the application of submicroscopic levels of chemical concepts connecting them with macroscopic properties of the substances and using *SMRs* for introducing new concepts and evaluating students' understanding.

Secondly, it is important to be aware that almost half of the students aged 16 think that the reactant that is not used completely in the chemical reaction, is written into the chemical equation (See sample item 2 in Appendix 1). The analysis of the students' drawing *SMRs* of chemical reaction products (See sample item 5 in Appendix 1) show that students are also imprecise in reading the text of the problem, because they draw the wrong number of product molecules or do not consider the differences in atomic radius of different elements. Legend analysis also showed that students do not develop the connections between the macroscopic and the submicroscopic levels of concepts, because they attribute the macroscopic name of an element to the substance particle. It can be recommended that teachers can help students to develop adequate mental models of chemical reaction also by using *SMR*, where the correct number of moles and correct molecule geometry can be stressed with the support of the legends of the particles used in *SMRs* with their names. It is also important to suggest that teachers try to encourage precise reading of the scientific text, because students' success in solving the chemistry problems is dependent on that. They must not encourage students to learn chemical equations by heart because the results of this study show that doing so has a negative influence on students' motivation for learning chemistry, because just memorizing the formulae is meaningless to students. Once again, as emphasized by other researchers (Bunce, & Gabel, 2002; Chittleborough et al., 2002) the importance of putting the symbolic chemical language into the context and breaking it down into meaningful parts – not overloading students working memory capacity with it – has been shown to be an important aspect of effective chemistry learning. This can help students to understand formulae and equations in a way that is more meaningful to the students. This aspect is also important from the teachers' point of view. Students progressing on the educational vertical would have more information stored in their long-term memory and teachers wouldn't have to repeat the explanation of the same basic concepts all over again on the higher level of students' schooling. The findings suggest that students only try to describe chemical reactions on macroscopic level, and the submicroscopic level is neglected or they don't even try to describe it with their own words. According to these results teachers should emphasize students' discussion about chemical phenomena individually to the teacher, in pairs or in specially designed group work and evaluate their ability to elaborate their decisions in problem solving strategies.

Thirdly, it can be summarised that students had difficulties correctly representing the ionic substance water solutions in particulate level (See sample item 6 in Appendix 1), because less than one tenth of students correctly drew their *SMR*. This shows that the majority of students after four years of chemical education do not understand what happens with soluble ionic substances when added into water. Students ought to use their knowledge acquired during chemistry lessons on a more theoretical level (ionic bonding, solubility, atomic and ionic radii) on concrete samples. According to the results presented here the students' transfers between macroscopic and submicroscopic level of chemical concepts during problem solving processes are not satisfactory. Because of these results teachers should devote more of their time to teaching students proper problem solving strategies using *SMRs* and their prior knowledge.

The last set of concepts assessed in sample items were acids and bases. Only more than half of the students correctly recognise the SMRs of acid, base and salt aqueous solutions (See sample item 3 in Appendix 1) but a lot more students had problems representing acidic solution on a submicroscopic level, especially when they had to consider more than one variable to solve the problem (See sample item 7 in Appendix 1). It can be concluded that students do not associate the acid strength with acid dissociation ability, but often with the concentration of acid particles in the aqueous solution. From the analysis of the students' *SMRs* representing acid in an aqueous solution, it is important to emphasize that teachers have to use *SMRs* also to illustrate acid or base dissociation and connect this concept with acid or base strength and pH value, because the most frequent misconception presented by students is that stronger acid has more molecules of acid in water solution, and they do not connect this concept with the hydronium or hydroxide and conjugated base or acid ions.

The overall conclusion of the content analysis of sample problems indicate, that teachers should devote more of their time in the classroom to introducing to the students the purpose and the meaning of correct drawing of the *SMRs*. These activities should be incorporated in all of the parts of the lessons, from introduction to the new topic to students' evaluating their knowledge at the end. Teachers would collect useful data by analyzing students' drawing of *SMRs,* and on the basis of the conclusions could modify future classroom activities to correct the discovered students' misinterpretations of chemical concepts at submicro level. Teachers' view of the instructions and their pedagogical knowledge - especially if they see the teaching as transfer of knowledge or as a process of building the students' knowledge - influence teachers' realization of the chemistry lessons (Valenčič Zuljan, 2007). Students' incomplete comprehension and/or misunderstandings of chemical concepts play an important role in the teaching process. Teachers should carefully analyze such concepts, and their corrected forms should be integrated into the students' learning process.

The difference is statistically significant, and further analysis shows a more detailed picture of some independent variables (i.e. gender, formal reasoning abilities, visualization abilities and intrinsic motivation for learning chemistry) and their influence on students' achievements in solving problems comprising *SMRs*.

The second hypothesis refers to the difference between males and females in solving problems involving reading and drawing *SMRs*, and cannot be confirmed. It can be summarized that female students score significantly lower than male students in drawing or reading submicrorepresentations while solving particulate problems. Bunce and Gabel (2002) reported similar findings. They said that females score lower than males on the pre-test, but after implementing the educational strategies that connect all three levels of chemical concepts the significant gender score difference would diminish. The results reported by Barke and Engida (2001) can explain the results found in this research. They anticipated that girls have lower developed visualization abilities than boys, and they propose that students should use different models and visualization material very early in the science education process to stimulate development of visualization abilities. It can be speculated that visualization abilities can influence motivation, and then hence the science problem solving achievements by both males and females. During the educational process teachers should, therefore, pay more attention to female students' progress in developing adequate mental models of chemical concepts regarding submicroscopic level through motivation for learning chemical concepts on all levels, thus stimulating the meaning of such learning for their professional career and everyday life.

The third hypothesis is connected to students' formal reasoning abilities, and it can be confirmed. Results show that students with higher formal reasoning abilities are slightly more successful in problems that require reading than drawing *SMRs*. Drawing *SMRs* seems to be more intellectually demanding than reading them, but results of the present study do not confirm this assumption. It is also evident that students with developed formal reasoning abilities are equally successful in reading or drawing submicrorepresentations as are those students that reach transitional level, but there is a statistically significant difference between concrete and formal reasoners. The difference between concrete and transitional reasoners in reading or drawing *SMRs* is not significant. However, it is important to stress, that even students on the concrete level of reasoning abilities are sufficiently capable of solving some problems on submicro level. It is also evident that those students that fall into the group of concrete or transitional reasoners had more difficulties with solving problems that involve reading or drawing *SMRs* than those that fall into the group of formal reasoners. The lower percent of explained variance was obtained by Gabel, Samuel, & Humm (1987) and Haidar and Abraham (1991), that was attributed to the results on chemical concepts test 22.8 % and 17.5 % respectively of the variance by the students' reasoning abilities. The findings of the present study are consistent with the findings of the study by Williamson and Abraham (1995), who reported that 27 % of variance can be explained by formal reasoning abilities, and Valanides (1998) reported similar results.

The fourth hypothesis is: "Students with higher visualization abilities score statistically significantly higher on the items regarding drawing *SMRs*", but it can not be confirmed. Results shows that, in the contrast with formal reasoning ability and its influence on students' achievements in solving problems on particulate level, it can be concluded that visualization abilities are not so strongly correlated with chemistry knowledge that refers to 2-D submicrorepresentations. This is shown by the results, and only a small portion of variance on the *CK* score can be explained by students' visualization abilities. Further analysis of variance shows, that differences between students with low and average, and average and superior visualization abilities are not statistically significant in most cases. It can, for that reason, be emphasised that students can solve particulate problems even if their visualization abilities are not so highly developed. However it is important to emphasise that there is no statistically significant difference between students with different speeds of perception abilities in solving problems regarding reading or drawing *SMRs*. On the other hand, somewhat bigger differences can be determined regarding the use of 2-D submicrorepresentations between students with different levels of spatial relations. The difference is not statistically significant between students with average and superior spatial relations abilities. The difference between students with poor and average spatial relations abilities is statistically significant in the total *CK* score and reading *SMRs* score. However the difference is also significant on all three levels of *CK* tasks, between students with poor and those with superior spatial relations abilities. It can be concluded that chemical problems which include just 2-D submicrorepresentations do not pose great difficulties in solving them, even for those students with lower visualization abilities. These conclusions indicate that teachers should be encouraged to use submicrorepresentations in classrooms, not just for laboratory work explanations, but also for evaluating students' knowledge, without apprehension that students with lower abilities would be discriminated. These results confirmed the predictions of Wu and Shah (2003) and Keig and Rubba (1993) that secondary school students' chemical concepts test scores variance would not be in a very large percentage accounted for by students' visualization abilities, but by more general reasoning abilities. Gabel et al. (1987) also reported no significant correlation between students' visualization abilities and achievements on the chemistry test that comprises items on submicroscopic level. Higher correlations between visualization abilities of secondary school students in Slovenia (r =

0.472; $p < 0.01$) were registered by Ferk Vrtačnik, Blejec, & Gril (2003). Similar results were obtained also by Yang et al. (2003). These results may have their cause in different chemistry conceptual problems (3D model manipulations, computer animations …) that were used for evaluating students' knowledge.

The last hypothesis relates to the students' intrinsic motivation for learning chemistry on different levels of chemical concepts regarding the *ITLS* model, and it can be confirmed. It can be summarised from the results that the correlations between *CK* scores, either in reading, drawing or overall scores and intrinsic motivation for learning chemistry, are the highest regarding motivation for the submicro level of chemical concepts, and the lowest regarding macro level. From the ANOVA results it can be summarised that the differences between the groups of students with different levels of intrinsic motivation is significant almost in all cases, except for reading *SMRs* and intrinsic motivation for the experimental level of chemical education. However it is important to emphasise that on all levels of *ITLS* intrinsic motivation for learning chemistry, the difference between poor and average intrinsically motivated students is not significant. According to these results, students with higher general or specific chemical intrinsic motivation achieve higher scores on the chemistry test comprising reading or drawing submicrorepresentations. Most students on all levels of education do like chemistry at the macro level, so teachers should take advantage of this and extrinsically motivate students through laboratory work. After this activity most students would have the chance to develop intrinsic motivation for the macro level of chemical concepts, and after that the intrinsic motivation for other two more abstract levels of *ITLS* model would evolve. To achieve this goal, teachers encounter a difficult task in achieving a sufficient level of external stimulation for students to become interested in chemistry, because students, at all levels of the educational system, often do not realize the meaning of submicroscopic explanations of the phenomena and their symbolic representations. It can be summarised that the most successful in solving chemistry problems on different levels of the *ITLS* model would be those students that are highly intrinsically motivated for learning chemistry on the particulate level. Similar results of several studies were reported by Tuan et al. (2005), but their research shows a slightly higher correlation between school science achievement and motivation ($r = 0.40$; $p < 0.01$). Previous research (Napier & Riley, 1985) also indicated that motivation has a moderate but significant correlation with students' science achievement. The results obtained in this study can confirm Keigs' and Rubbas' (1993) predictions, i.e. that motivation can be a potential source of variance regarding students' success on the chemical concepts test. On the other hand, Nieswandt (2007) reports the result of her study, that affective variables (students' interest and attitudes for chemistry and their chemistry-specific self-concepts) do not have a statistically significantly effect on conceptual understanding, but the results do reveal the importance of strong and positive self-concept for developing a meaningful understanding of science concepts.

The main implication for teaching chemistry or chemical concepts in science education is that teachers should encourage students and especially females in activities where they are engaged in drawing submicrorepresentations. It is important that teachers at the beginning of using *SMRs* in chemistry teaching use simple *SMRs*, especially when students have to draw them. Teachers should in the process of chemistry teaching emphasise the meaning of correct and accurate reading of the chemistry problem text. They should also stress the meaning of the legends of particles and their names before students start to draw the *SMRs*. Students are going to develop the abilities of drawing *SMRs* also when their formal reasoning abilities or visualization abilities are not highly developed in relation to their age. It is also important to stress, that students show an interest in understanding chemical concepts on a particulate level and that they try to comprehend the bases of chemical phenomena on the level where chemical reactions happen. On the other hand, students who enjoy learning chemistry only on the bases of symbols (chemical symbols of elements, formulae, equations) or observations of the experiments, without deeper understanding of the phenomena on particulate level, could not be very successful in achieving sufficient chemical knowledge. These findings indicate that teachers should, nevertheless, encourage students to learn chemistry at the particulate level. These attempts are going to be only external, and for students mostly unnecessary or even discouraging and highly difficult to understand at the beginning of the educational process. But with progress in understanding of the basic chemical concepts (e.g. atom structure, chemical bond, etc), students' interest in understanding chemistry on submicro level will increase and will bring them more success in getting better feedback from the teacher. This type of chemistry teaching should result in the increase of intrinsic motivation for deeper learning of chemical concepts on all levels of *ITLS* model.

Teachers with adequate chemical and didactical knowledge are able to conduct quality chemistry lessons by transferring scientific knowledge into the classroom. It is important to direct pre-service teacher students into the reflective way of teaching and into developing the constant need for researching their own pedagogical practice (Vogrinc & Valenčič Zuljan, 2009). In-service mentoring of beginning chemistry teachers (Author; Valenčič Zuljan, 2007; Valenčič Zuljan & Vogrinc, 2007) and the provision of quality permanent in-service teacher education (Kalin & Zuljan, 2007) are, beside the pre-graduate study, an important aspect in developing the future teacher as a reflective practician. On the basis of the results it is suggested that permanent in-service teacher education take into account teachers' expectations and needs so that it can offer them the chance to develop competences to implement quality, also in the student oriented instructions model.

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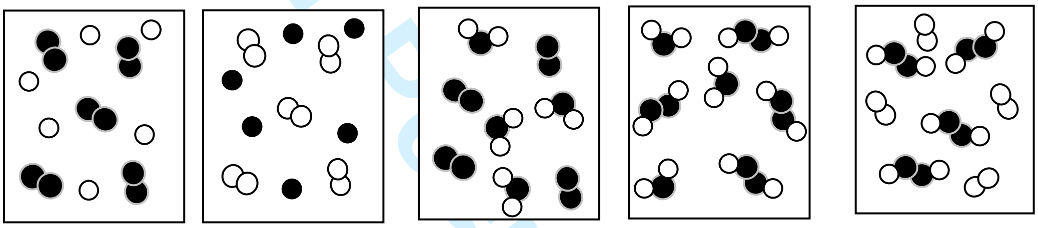
Appendix 1: Sample items from diagnostic instrument for determining *Chemical Knowledge (CK)*.

Reading *SMRs*

Pure substances and mixtures (PSM reading SMRs)

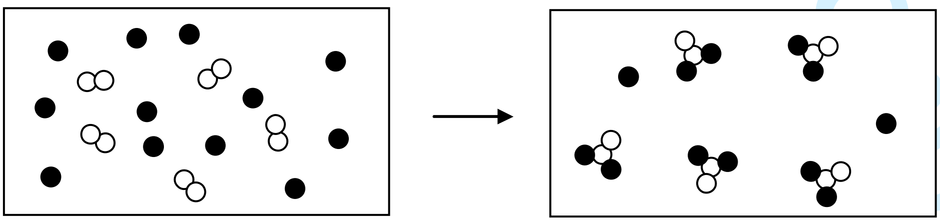
1. Which scheme represents a mixture of two compounds? One circle represents one atom.



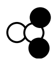
A B C D E

Chemical reactions (CR reading SMRs)

2. The scheme represents the reaction between substance A and B. Which equation correctly represents this reaction?



Mixture before the reaction Mixture after the reaction

Legend: ● - Substance A; ○○ - Substance B;  - Product

A $A_2 + 2\ B \rightarrow A_2B_2$

B $12\ A + 10\ B \rightarrow 6\ A_2B_2$

C $2\ A + 2\ B \rightarrow A_2B_2$

D $5\ A + 5\ B_2 \rightarrow 5\ A_2B_2 + 2\ A$

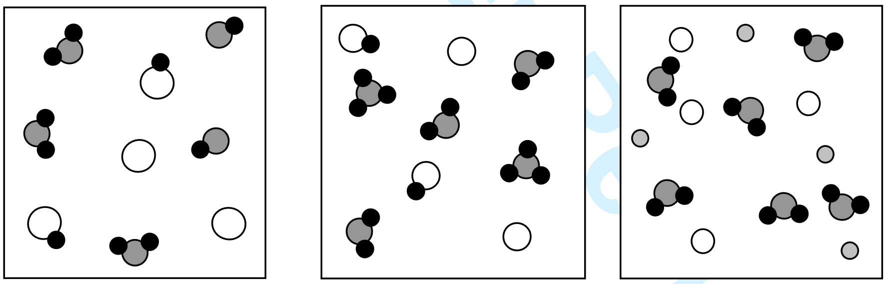
E $2\ A + B_2 \rightarrow A_2B_2$

Which substance was completely used during the reaction? ____________

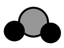
Elaborate the answer: ____

Electrolyte chemistry (EC drawing SMRs)

3. Scheme A to C represents aqueous solutions of three different substances. Most of the water molecules were omitted for clarity.



Legend:

 - water molecule

 - hydrogen atom

Answer the following questions.

Which scheme represents an aqueous solution of acid? ____________

Which scheme represents an aqueous solution of base? _____________

Which scheme represents an aqueous solution of soluble salt? ___________

Drawing *SMRs*

Pure substances and mixtures (PSM drawing SMRs)

4. Water can be found in three states of matter in nature. Draw schemes to show different states of water. Draw ten water molecules in each box represented by ● and on the line write the correct state of matter represented in the box above.

a ________________ b ________________ c ________________

Chemical reactions (CR drawing SMRs)

5. Draw the scheme of a chemical reaction product between two molecules of chlorine and two molecules of hydrogen in the box below.

Legend: ________________________________

Elaborate the answer: ____

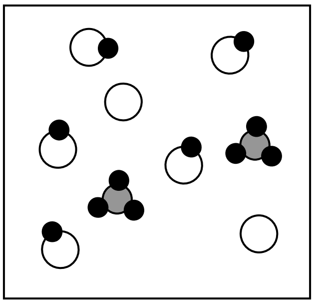
Solution Chemistry (SC drawing SMRs)

6. Draw a scheme to show the dissolved potassium bromide with optional concentration in water. Use the legend to illustrate the particles which you have used in the scheme. You need not draw water molecules.

Legend: ______________________

Electrolyte chemistry (EC reading SMRs)

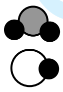
7. Scheme 1 represents aqueous solution of an acid. Water molecules were omitted for clarity. Draw Scheme 2 representing aqueous solution of a stronger acid, but the same concentration. You need not draw water molecules.



Scheme 1

Scheme 2

Legend:



- water molecule
- acid molecule

Elaborate the answer: ____

Appendix 2: Sample items from the questionnaire Intrinsic Motivation for Learning Science (*IMLS*)

1. Emotional component of interest:

I enjoy learning.

I am often bored during:

…chemistry course.

… biology course.

…physics course.

… foreign language course.

… mathematics course.

I enjoy the chemistry course when:

…we observe chemical changes in experiments.

…we learn about particles (atoms, ions, molecules).

…we learn and write chemical symbols, formulae and equations.

2. Cognitive component of interest:

I often look for additional information about school science topics in books, magazines, in the internet, CDs …

The media attract my attention when reporting on:

…chemistry topics.

…biology topics.

…physics topics.

…foreign language topics.

…mathematics topics.

I often think about:

…observation of chemical changes in experiments*, also out of school.*

… particles (atoms, ions, molecules), *also out of school.*

…learning and writing chemical symbols, formulae and equations, *also out of school.*

<u>3. Challenge component of internal motivation:</u>

I persevere with learning.

New problems in:

… chemistry, *challenge me.*

…biology, *challenge me.*

…physics, *challenge me.*

…foreign language, *challenge me.*

…mathematics*, challenge me.*

If I do not understand something, connected with:

…observation of chemical changes in experiments, *I give up.*

…learning about particles (atoms, ions, molecules), *I give up.*

…learning and writing chemical symbols, formulae and equations, *I give up*.

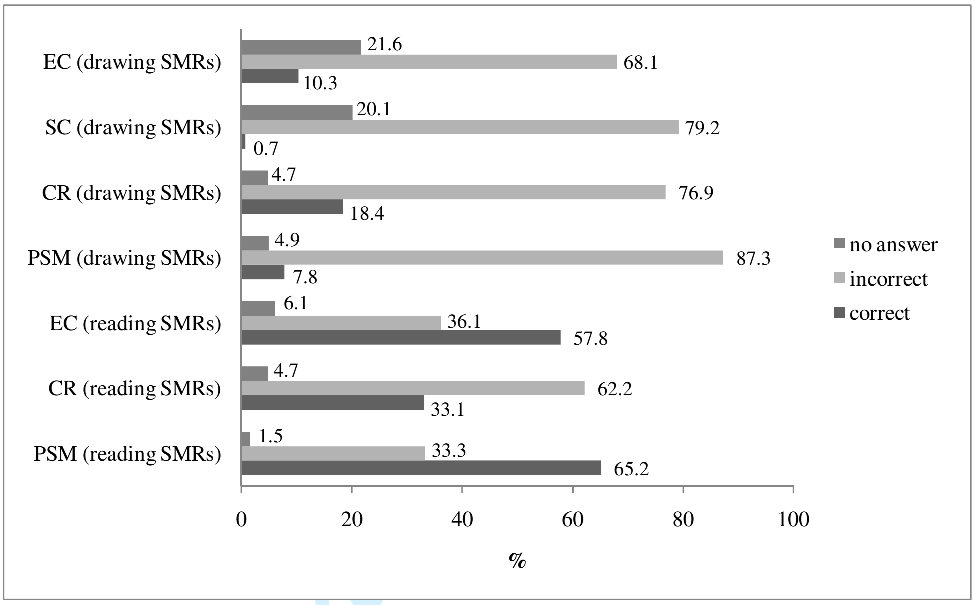


Chart 1. Students' achievements at sample chemistry problems (PSM – Pure substances and mixtures; CR – Chemical reactions; EC – Electrolyte chemistry; and SC – Solution chemistry).

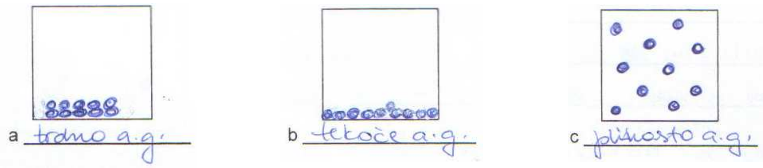


Figure 1. Correctly presented all three states of water; original students' drawing, written on a line means: a solid; b liquid and c gas.

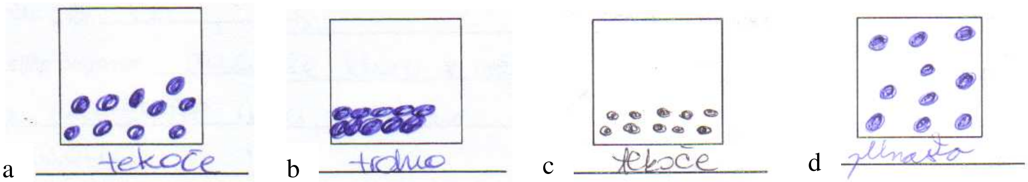


Figure 2. Incorrectly presented all three states of water; original students' drawing, written on a line means : a liquid; b solid; c liquid and d gas.

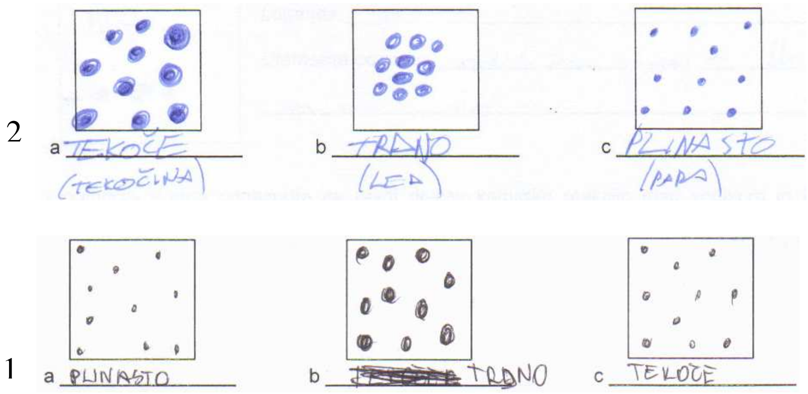


Figure 3. SMRs of different states of water presenting different sizes of molecules in a specific state of water; original students' drawing, written on a line means: 1 - a gas; b solid; c liquid and 2 - a liquid; b solid; c gas).

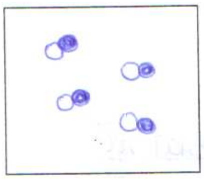


Figure 4. The same size of hydrogen and chlorine atoms in the molecule of hydrogen chloride.

Figure 5: SMR illustrating misconceptions of aqueous solution of potassium bromide (i.e. molecules of potassium bromide and not taking into account the potassium and bromide atoms different atomic radii).

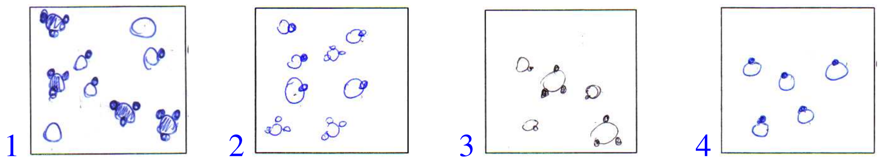


Figure 5: SMR illustrating misconceptions of an acid aqueous solution.

Table 1. Descriptive statistics for *CK*.

	Minimum points	Maximum points possible	Students' maximum points	Average points	SD	Kortusus	Skewness
Total CK score	1	43.5	40.25	21.21	6.47	0.036	-0.089
Reading of *SMRs* CK score	0	19.0	16.0	10.75	3.25	-0.233	-0.421
Drawing of *SMRs* CK score	0	24.5	24.25	10.46	3.88	0.546	0.082

Table 2. Pearsons' correlation coefficients between students' visualization abilities and success on CK.

	Speed of perception	p	Spatial relations	p
Total *CK* score	0.117	0.021	0.162	0.001
Reading of *SMRs CK* score	0.097	0.058	0.113	0.027
Drawing of *SMRs CK* score	0.114	0.025	0.176	0.001

Table 3. ANOVA between the three groups of students of different intrinsic motivation for learning chemistry and their success on CK.

	df, df	F	p
Total *CK* score *	2, 107.07	17.05	≤ 0.000
Reading of *SMRs CK* score	2, 383	9.99	≤ 0.000
Drawing of *SMRs CK* score **	2, 105.49	17.25	≤ 0.000

* the test of homogeneity of variances was statistically significant F (2, 383) = 3.74; p = 0.025), so the Welch test of equality of means was applied

** the test of homogeneity of variances was statistically significant F (2, 383) = 6.75; p = 0.001), so the Welch test of equality of means was applied

Table 4. ANOVA between the three groups of students of different intrinsic motivation for the macroscopic level of chemical concepts and their success on *CK*.

	df, df	F	p
Total *CS* score	2, 383	5.28	0.005
Reading of *SMRs CS* score	2, 383	1.90	0.151
Drawing of *SMRs CS* score *	2, 106.18	5.38	0.006

* the test of homogeneity of variances was statistically significant F (2, 383) = 3.95; p = 0.020), so the Welch test of equality of means was applied

Table 5. ANOVA between the three groups of students of different intrinsic motivation for the submicroscopic level of chemical concepts and their success on *CK*.

	df, df	F	p
Total *CS* score *	2, 107.40	19.92	0.000
Reading of *SMRs CS* score	2, 383	12.92	0.000
Drawing of *SMRs CS* score **	2, 105.83	19.55	0.000

* The test of homogeneity of variances was statistically significant (F (2, 383) = 3.61; p = 0.028), so the Welch test of equality of means was applied.

** The test of homogeneity of variances was statistically significant (F (2, 383) = 4.98; p = 0.007), so the Welch test of equality of means was applied.

Table 6. ANOVA between the three groups of students of different intrinsic motivation for the symbolic level of chemical concepts and their success on *CK*.

	df, df	F	p
Total *CK* score	2, 383	17.85	0.000
Reading of *SMRs CK* score	2, 383	10.94	0.000
Drawing of *SMRs CK* score *	2, 112.82	14.12	0.000

* The test of homogeneity of variances was statistically significant F (2, 383) = 3.60; p = 0.028), so the Welch test of equality of means was applied.

THE INFLUENCE OF SOME INDEPENDENT VARIABLES ON 16-YEAR-OLD STUDENTS' READING AND DRAWING SUBMICROREPRESENTATIONS ACHIEVEMENTS

Abstract: Submicrorepresentations are a powerful tool for identifying misconceptions of chemical concepts and for generating proper mental models of chemical phenomena in students' long term memory during chemical education. The main purpose of the study was to determine which independent variables (gender, formal reasoning abilities, visualization abilities and intrinsic motivation for learning chemistry) have the most influence on students' reading and drawing submicrorepresentations. 386 secondary school students (aged 16.3 years) participated in the study. The instruments used in the study were: test of Chemical Knowledge, Test of Logical Thinking, two tests of visualization abilities Patterns and Rotations, and Questionnaire on Intrinsic Motivation for Learning Science. The results show moderate, but statistically significant correlations between students' intrinsic motivation, formal reasoning abilities and chemical knowledge at submicroscopic level based on reading and drawing submicrorepresentations. Visualization abilities are not statistically significantly correlated with students' success on items that comprise reading or drawing submicrorepresentations. It can be also concluded that there is a statistically significant difference between male and female students in solving problems that include reading or drawing submicrorepresentations. Based on these results, several educational strategies can be implemented for students to develop adequate mental models of science concepts on all three levels of the model.

Key Words: secondary school students', submicrorepresentations, students' mental abilities, intrinsic motivation.

INTRODUCTION

Learning science is strongly connected with building knowledge through understanding and concepts linking in students' long-term memory by interpreting multi-modal representations of science phenomena (Ainsworth, 1999; Russell & McGuigan, 2001). Students who recognized relationships between different representations demonstrated better conceptual understanding than students who lacked this knowledge (Prain & Waldrip, 2006). Students should be also able to translate one representation into another one and co-ordinate their use in representing scientific knowledge (Ainsworth, 1999). Russell and McGuigan (2001) argued that learners need opportunities to generate various representations of a concept, and to recode these representations in different modes, as they refined and made more explicit their understanding. In the process of science learning, the teacher should therefore incorporate students' "rich pool of representational competence" in creating lessons so that they are motivating for students (diSessa, 2004, p. 298). diSessa (2004) also points out that the quality of the representation ought to be evaluated according to its purpose. Waldrip, Prain, and Carolan (2006) argue that, in order to maximize the effectiveness of designed representational environments, it is necessary to take into account the diversity of learner background knowledge, expectations, preferences, and interpretive skills.

Representations of the chemical concepts could be defined on three levels (i.e. macro, submicro and symbolic level). Adequately merged, these representations can help students to develop a conceptual understanding of chemical phenomena. The *ITLS (Interdependence of Three Levels of Science concepts)* model shows these connections between different representations and the role of visualization methods used in the process of mental model construction of chemical phenomena that students ought to develop. The *ITLS* model draws on different educational theories, such as Paivio's dual coding theory, Mayer's SOI model of meaningful learning and Johnstone's model of information processing, cognitive theory of multimedia learning and Mayer's theory of effective illustrations (see for more details Author; Author).

To illustrate chemical concepts on the level of particles, submicrorepresentations *(SMR)* can be used and can be presented as static or dynamic modes of representations. Research shows (Bunce & Gabel, 2002; Tien, Teichert, & Rickey, 2007; Kelly & Jones, 2008) that those students who were exposed to *SMRs* during the educational process more adequately understand the nature of the particle interactions compared to those who learned the same concepts only by textbooks reading. Studies in the last two decades (Williamson & Abraham, 1995; Johnson, 1998; Chittleborough, Treagust, & Mocerino, 2002; Solsona, Izquierdo, & DeJong, 2003; Papageorgioua & Johnson, 2005; Stains & Talanquer, 2007a; Tien et al, 2007; Kelly & Jones, 2008; Author) also show that students have many difficulties in understanding the submicro and symbolic levels of chemical concepts, and that previous knowledge of a specific topic has an influence on integrating new science concepts into students' mental structure. It is also important to emphasise that a lot of different factors influence students' achievement on different pictorial test questions (Halakova & Prokša, 2007; Sanger & Phelps, 2007; Stains & Talanquer, 2008) and that the students' knowledge evaluation part of the educational process needs further study. Research also shows that teachers use mostly the symbolic level of chemical concepts to teach chemistry (Williamson & Abraham, 1995; Chittleborough et al., 2002). It is important to introduce different visualization abilities to illustrate abstract science concepts to the students at the beginning of science education - age 10 or 11 (Longden, Black, & Solomon, 1991) - thus also the application of submicrorepresentations (Papageorgioua & Johnson, 2005).

For the purpose of this paper some independent variables such as mental abilities (i.e. formal reasoning and visualization abilities) and intrinsic motivation were selected because, according to the research literature, these variables influence chemistry learning.

Thiele and Treagust (1994) report that students who cannot visualise chemical phenomena and/or do not have properly developed formal reasoning abilities cannot properly understand chemical concepts; thus those concepts are hard to understand, unattractive and pointless for them. According to some research results (Wu & Shah, 2003) the significant correlation between spatial ability and chemistry problem solving skills is based on general reasoning abilities or intelligence rather than on visuospatial thinking. Valanides (1996) reported that students aged 12 to 14 years show relatively low developed formal reasoning abilities. 64.6 % of these students show concrete operational abilities. The difference in their levels of formal reasoning abilities is not statistically significant. Similar results were obtained by Shemesh, Eckstein, & Lazarowitz, (1992). Statistically significant correlations were proven between formal reasoning abilities and students' chemical knowledge especially on submicro level (Haidar & Abraham, 1991; Williamson & Abraham, 1995)

It is important to emphasize that Yang, Andre, & Greenbowe (2003) concluded that students with low levels of visualization abilities show greater difficulties in understanding computer animations of chemical phenomena on particulate level. Research (Barke & Engida, 2001) also shows that girls have lower developed visualization abilities than boys, and they propose that students should use different models and visualization material very early in the science education process to stimulate development of visualization abilities. On the other hand, Wu and Shah (2003) reported no statistically significant correlations between students' achievements on the test with static *SMRs* and spatial abilities. They anticipated that the knowledge achievement is more dependent on students' prior knowledge and the general cognitive factor than on visualization abilities.

A negative relationship towards chemistry does not enable proper concept change and/or modification of students' mental model of chemical phenomena. Students often do not have a proper knowledge base that would make it possible to upgrade their knowledge of more and more abstract chemical concepts when they make progress on the educational vertical (Treagust, Harrison, & Venville, 1998).

Learning motivation is defined as a construct which includes different motivational elements (interests, goals, attributes, self-image, external enticements, etc.). Some of these form a more extrinsic stimulus for learning (e.g., learning for grades, praises, avoiding punishment, social acceptance, etc.), while others are manifested more intrinsically (i.e., learning for mastering, learning for knowledge) (Authors).

According to Ryan and Deci (2000), intrinsic motivation is an individual's inherent inclination from which stems his/her tendency to learn about particular areas of life regardless of the presence of external enticements. This construction encourages humans to '… assimilate, control, generate spontaneous interests and to research which makes it essential for the individual's social and cognitive development while on the other hand it represents the fundamental source of personal satisfaction and life energy.' (p. 70).

Highly intrinsically motivated students are more successful in learning new concepts and show better understanding of the learning matter (Stipek, 1998). Rennie (1990), on the basis of the research on science learning, also concluded that higher results in science are related to the learner's active engagement in learning tasks, to his/her positive attitude towards the subject and to a highly positive self-concept in science, which all imply the learner's intrinsic motivation to learn. This is especially important, since many writers (Anderman & Young, 1994; Zusho, Pintrich, & Coppola, 2003) report that the decrease in intrinsic motivation with years of schooling is particularly noticeable in mathematics and science and is at its peak in the period of early adolescence.

Keig and Rubba (1993) pointed out that motivation can be a potential source of variance on students' chemistry knowledge achievements. These claims were confirmed by Tuan et al. (2005). They reported that from 7 to 16% of variance on the science knowledge test could be explained by students' motivation. But on the other hand Nieswandt (2007) reported no statistically significant effect of students' affective variables (situational interest, attitudes towards chemistry and students chemistry-specific self-concept) on their understanding of grade 9 (age 15 to 16) chemistry concepts.

Chittleborough et al. (2002), according to their qualitative research, reported that students are not motivated for learning chemistry more that is necessary for passing the exam. Students' motivation for learning science and chemistry for that matter can be stimulated by using different visualization elements and analogies because this element of the lessons increases students' attention (Theile & Treagust, 1994) and also by different experimental work supported by ICT (Šorgo & Kocijančič, 2006).

Research (Anderman & Young, 1994; Meece & Jones, 1996) also shows that gender differences in motivation for science learning are connected with achievements on the standardized test of science knowledge. It was also established that girls show lower interest in science, that science is boring for them, especially because they just have to learn everything by heart. Results also show that girls possess lower levels of self-confidence in demonstrating their science knowledge (Simpson & Oliver, 1990). On the other hand, Meece and Jones (1996) did not confirm these results; they established that there is no difference between girls and boys regarding the interest in learning science and they also pointed out that gender influence on motivation and in its effect on the manifestation of science knowledge are more complex processes than other researchers try to show.

Purpose and research question

According to the literature review the study of some independent variables that can influence chemistry learning was conducted. In this research the *SMRs* were used as a way for gathering students' chemical knowledge on the higher cognitive level. Submicrorepresentations were defined as tools for determining students' understanding of chemical concepts, and could be used mostly in two different ways. Firstly, students could read them and then use the information given by the specific *SMR* for solving the problem (reading *SMRs*), and secondly they could use the submicrorepresentations for presenting the solution of the science problem (drawing *SMRs*).

Regarding the purpose of this study, the main research question is: How do students' gender, some mental abilities (i.e. logical reasoning and visualization abilities) and intrinsic motivation for learning chemistry influence their achievements in reading and drawing submicrorepresentations?

Hypothesis

From the research question five hypotheses can be stated:

(1) Students' achievement scores on chemistry problems that include reading *SMRs* are statistically significantly higher than scores on problems that include drawing *SMRs.*

(2) There is no statistically significant difference between males and females in solving problems involving reading and drawing *SMRs*.

(3) Students with higher formal reasoning abilities score statistically significantly higher on problems that include drawing *SMRs*.

(4) Students with higher visualization abilities score statistically significantly higher on problems that include drawing *SMRs.*

(5) Students with higher levels of intrinsic motivation for learning chemistry on different levels of chemical representations score statistically significantly higher on problems that include drawing *SMRs* than on those that include reading them.

Method

Participants

A total of 386 secondary school students (60.6 % females; 39.4 % males) participated in the study. On average, the students were 16.3 years old (M= 195.4 months; SD = 5.7 months). All students attended second year of the general type of secondary school (Gymnasium). The chemistry curriculum of the Gymnasium is common to all students. The students attended the fourth year of chemical education in the period that testing occurred (two years in higher primary school - age 13 and 14 and two years in secondary school - age 15 and 16). The sample included 5.5 % of the whole population of the students (N = 7033) in school year 2005/06, throughout Slovenia. Three schools were located in the larger towns (more than 100,000 residents) and three in smaller towns (between 35,000 and 100,000 residents). The sample represented a predominantly urban population with mixed socioeconomic status. Parents' basic educational background was diverse (3.1 % finished primary school; 45.1 % finished secondary school; 43.0 % finished university and 7.3 % finished other formal education) but only 11.6 % of parents had finished some kind of science or technology education.

Instruments

Students' abilities to read and draw the *SMRs* were measured using the diagnostic instrument for determining *Chemical Knowledge (CK)*. The instrument comprises 19 items. Eight items required reading and eleven items drawing *SMRs* in solving the chemistry problems considering the *ITLS* model. The *CK* includes four different contents: pure substances and mixtures (4 items), chemical reactions (6 items), water solutions (4 items) and electrolyte chemistry (5 items). The *CK* showed satisfactory measuring characteristics (i.e. internal consistency reliability - Cronbach's alpha was 0.80; discriminate indexes for every item between 0.21 and 0.80 were all statistically significant). Kortusis and skewness coefficients show normally distributed data (see Table 1). Students had 60 minutes to solve the *CK*. One sample item of each content of *CK* is introduced in Appendix 1.

To determine other independent variables, four different tests and a questionnaire were administered to the students: Test of Logical Thinking (*TOLT*), Rotations (*RO*), Patterns (*PA*), and Intrinsic Motivation for Learning Science questionnaire (*IMLS*).

The level of students' formal reasoning abilities was obtained with the *Test of Logical Thinking (TOLT)* (Tobin & Capie, 1981). The *TOLT* is a ten-item group paper-pencil test. The authors of the test reported a strong correlation ($r = 0.82$; $p < 0.0001$) between performance on tasks during Piagetian clinical interviews that are considered a traditionally preferable method in measuring individuals' formal reasoning abilities and the results on *TOLT*. The *TOLT* has high internal consistency reliability (Cronbach's alpha was 0.85). The test consists of two items designed to measure each of the five modes of reasoning (i.e., controlling variables, proportional, correlational, probabilistic, and combinatorial reasoning). The test scores from 0-1 points (concrete reasoners), 2-3 points (transitional reasoners) and 4-10 points (formal reasoners) were used as a basis for classifying the students. Students had 38 minutes to solve the test.

The students' visualization abilities were measured with two tests: *Patterns (PA)* and *Rotations (RO)* (Pogačnik, 1998; 2000). The *PA* measures students' speed of perception and the *RO* measures students' spatial relations abilities. Both tests were developed based on the Cattell-Horn theory of mental abilities. The *PA* is a 36 item group paper-pencil test. It requires individuals to find and mark exactly the same pattern among the four similar patterns on the right side of the paper to the one on the left part of the paper as quickly as possible. The *PA* has high internal consistency (Cronbach's alpha was 0.86). Correlations between some other instruments for determining individuals' perception abilities (*BTI-Or; BTI-Pr, Beta 6* and *4)* determine that the instruments' validity was higher and statistically significant. Students had 4.5 minutes to solve the test. The *RO* is a 90 item group paper-pencil test. The *RO* requires individuals to find and encircle those patterns on the right side of the paper that are just rotated in comparison with the left pattern. Individuals have to cross those patterns that are not just rotated in the plane but represent a different pattern. Cronbach's alpha for the *RO* was 0.94. Correlations between some other instruments for determining individuals' perception abilities (*BTI-Pr, Beta 4)* were also high and statistically significant. Students had 6 minutes to solve the test. The classifications of students into three groups with regard to their visualization abilities were performed according to the statistical equations. Into Group 1 (poor visualization abilities) were classified students that scored less than M - 1SD points, into Group 2 (average visualization abilities) those that scored between M - 1DS and M + 1SD points, and into Group 3 (superior visualization abilities) students that scored above M + 1SD points on the *PA* and *RO*.

The last independent variable, the intrinsic motivation for learning chemistry was measured by the *IMLS* questionnaire. There are many questionnaires to measure students' attitudes or interests in science and/or chemistry (e.g. Moore & Foy, 1997; Tuan et. al., 2005; Coll et al., 2002; Nieswandt, 2007). All these instruments show a rather general structure of students' attitudes towards science, but they lack the dimension with reference to the *ITLS* model and separately for different science school subjects. These questionnaires do not show enough specific characteristics regarding the research questions asked in this study and would need extensive revision for adapting the instrument to secondary level. For those reasons the new instrument for measuring intrinsic motivation, 125-item *IMLS (Intrinsic Motivation for Learning Science* questionnaire, was developed (Authors). The response to each item is on a five-point Likert-type scale ranging from 1 as strongly disagree to 5 as strongly agree. The internal consistency (Cronbach α) of *IMLS* was 0.78. Students had 20 minutes to complete the questionnaire. The classifications of students into three groups with regard to their intrinsic motivation for learning chemistry were performed according to the statistics. Into Group 1 (poor intrinsically motivated) were classified students that scored less than M - 1SD points, into Group 2 (average intrinsically motivated) those that scored between M - 1DS and M + 1SD points, and into Group 3 (superior intrinsically motivated) students that scored above M + 1SD points on the *IMLS*. Three sample items of each component of intrinsic motivation from the *IMLS* questionnaire are included in Appendix 2.

Research design

The research was a non-experimental, cross-sectional and descriptive study (Bryman, 2004).

The students had received no special teaching about using *SMRs* in the chemistry classroom. The chemical concepts comprised in the *CK* were not instructed using *SMRs* by the teachers that taught the students participating in the study.

CK and *IMLS* were designed specifically for this study. The *CK* was administered to two university chemistry and chemical education professors. Their responses provided scientifically correct answers and content validation for the instrument. The *IMLS* was distributed to two experts in science education and one in educational psychology. Their evaluation of the instrument confirmed that the *IMLS* measures students' intrinsic motivation for learning and their analysis provided validation for the questionnaire. The Slovene translation of the *TOLT* was used for the study. The test was separately translated into the Slovene language by one expert in chemistry and one expert in physics education. The translations were compared and possible modifications were made in preparing the third version of the test. The third expert translated the test back into English. The original and the translated version of the English test were compared and possible modifications were made in designing the final Slovene version of the *TOLT*. Four independent experts in chemistry, physics and mathematics education finally reviewed the test, and their responses provided content validation of the instrument.

After all the instruments had been developed or chosen in relation to the purpose of the study, a pilot study was conducted with 77 students. The *CK*, *TOLT* and *IMLS* were used in the pilot study. Taking into account the statistical analysis of the results obtained in the pilot study, the *SK* and *IMLS* were modified.

All instruments were applied on the research sample at the end of the second school year 2005/06 of the secondary school. The testing took students about 135 minutes on two separate days. Students solved the *IMLS* and *CK* in the first week and in the second one they solved the *TOLT, RO* and *VZ.* The last testing was conducted by a trained psychologist. All instruments were applied in a group and under normal examination conditions.

Descriptive statistics were obtained for illustrating the *CK* characteristics. For determining differences in the means of *CK,* the paired-sample t-test was used. Pearsons' correlation coefficients for determining the correlation between knowledge of chemical concepts and other independent variables were calculated. In addition, the one-way between-groups analysis of variance (*ANOVA*) was conducted to explore the influence of reasoning abilities, visualization abilities and intrinsic motivation for learning chemistry on students' success in solving *CK* tasks. If the test of homogeneity of variances was statistically significant when comparing the means of the groups of students, the more robust test (Welch test) of equality of means was used.

Results

The results show secondary school students' average chemical knowledge of the tested basic chemical concepts (*Table 1*). Students achieved on average 49 % of all points possible on the *CK*.

Students were more successful in reading *SMRs* than drawing them. Students managed to get on average 56.5 % of all points on items that required reading the *SMRs*. On the other hand, students achieved on average 42.4 % of all points available on problems that required drawing the most suitable *SMRs*.

Table 1. Descriptive statistics for *CK*.

The paired samples t-test shows that students score statistically significantly higher in solving problems that require reading *SMRs* than in those that require drawing them ($t (385) = 1.97$, $p = 0.048$).

Students' gender and achievement scores on CK

In the present study statistically significant differences in total *CK* score between males and females were proven by an independent-samples t-test. The results show that males' (M = 22.83; SD = 6.50) scores are statistically significantly higher than females' (M = 20.16; SD = 6.24); t (384) = - 4.04, $p \leq 0.000$). An independent-samples t-test was also conducted to compare the success of males (M = 11.45; SD = 3.29) and females (M = 10.29; SD = 3.16) on items that required reading *SMRs*. Males scored significantly higher than females (t (384) = - 3.48, $p \leq 0.000$). Similar results were obtained by comparing students' scores on items that required drawing *SMRs*. Males (M = 11.38; SD = 3.86) scored significantly higher than females (M = 9.87; SD = 3.78); t (384) = - 3.80, $p \leq 0.000$).

Students' mental abilities and achievement scores on CK

It can be concluded from the results that 86.3 % of students are formal reasoners, 11.1 % of students fall into the group of transitional reasoners and even 2.6 % of the students are still on the concrete level of reasoning. Those students who have better developed formal reasoning abilities are more successful in solving problems that include drawing (r = 0.50; $p \leq 0.000$) and reading (r = 0.53; $p \leq 0.000$) *SMRs*. On average 28.1 % of students' success in solving the items that demand reading *SMRs* can be explained by the *TOLT* score. On the other hand, 25.0 % of students' ability to solve the problems that require drawing *SMRs* can be explained by students' formal reasoning abilities. The correlation between the overall successes in solving problems requiring understanding the *ITLS* model shows, that 31.8 % of students' success on *CK* can be explained by their reasoning abilities (r = 0.56; $p \leq 0.000$). It can be concluded that students need to have developed higher levels of reasoning abilities to solve the CK items more successfully.

For further analysis, the one-way between-groups analysis of variance was conducted to explore the influence of formal reasoning abilities on total success in *CK* and in solving tasks of reading and drawing *SMRs*. Students were divided into three groups according to their reasoning abilities (Group 1: concrete reasoners, Group 2: transitional reasoners and Group 3: formal reasoners).

The differences in overall success in *CK* between the three groups of students of different formal reasoning abilities are statistically significant ($F(2, 383) = 33.39$, $p \leq 0.000$). Post hoc comparisons using Tukey HSD showed that there is a statistically significant difference ($p \leq 0.000$) between the mean scores for Group 1 ($M = 13.43$, $SD = 5.88$) and Group 3 ($M = 22.20$, $SD = 5.99$) and also for Group 2 ($M = 15.38$, $SD = 5.98$) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.622$) between the groups of concrete and transitional reasoners in success in *CK*. There is a statistically significant difference between groups of students with different reasoning abilities in success at reading ($F(2, 383) = 29.81$, $p \leq 0.000$) and drawing ($F(2, 383) = 24.25$, $p \leq 0.000$) *SMRs*. Post hoc comparisons using Tukey HSD indicated that the mean scores for reading *SMRs* between Group 1 ($M = 6.80$, $SD = 3.16$) and Group 3 ($M = 11.22$, $SD = 2.99$) were statistically significantly different ($p \leq 0.000$) and also between Group 2 ($M = 8.02$, $SD = 3.22$) and Group 3 ($p \leq 0.000$). Group 1 did not differ significantly from Group 2 ($p = 0.485$) regarding reading *SMRs*. Similar results were obtained by post hoc comparisons using the Tukey HSD test regarding mean scores for drawing *SMRs*. Group 1 ($M = 6.63$, $SD = 3.57$) was statistically significantly different ($p = 0.001$) from Group 3 ($M = 10.98$, $SD = 3.72$) and also for Group 2 ($M = 7.35$, $SD = 3.25$) and Group 3 ($p \leq 0.000$). Group 1 did not differ significantly from Group 2 ($p = 0.839$).

The next two independent variables include students' visualization abilities.

Table 2. Pearsons' correlation coefficients between students' visualization abilities and success on CK.

Students' visualization abilities are not so highly correlated with *CK* scores as are formal reasoning abilities (*Table 2*). Students' speed of perception is not statistically significant correlated with their success in problem solving regarding reading *SMRs*, on the other hand a very low but statistically significant factor is students' ability for drawing *SMRs* (r = 0.11; p = 0.025). Another students' visualization ability, i.e. spatial relations, is somewhat more highly correlated with drawing *SMRs* (r = 0.18; p = 0.001) than reading (r = 0.11; p = 0.027), but the correlation coefficients are still very low, and the connection between students' *CK* achievements and their visualization abilities could be neglected. It can be summarised that only 2.6 % of students' *CK* scores can be explained by spatial relations and even less - only 1.4 % - by speed of perception.

The *ANOVA* was conducted to explore the influence of visualization abilities on students' success in solving tasks that include reading and drawing *SMRs*. Students were divided into three groups according to their speed of perception and spatial relations abilities (Group 1: poor speed of perception or spatial relations abilities, Group 2: average speed of perception or spatial relations abilities, and Group 3: superior speed of perception or spatial relations abilities). The differences in total scores on *CK*, and problems that demand reading or drawing *SMRs*, between the three groups of students with different speed of perception abilities are not statistically significant.

On the other hand there are statistically significant differences between the groups of students in spatial relations abilities and their success in solving the tasks on *CK* (F(2, 382) =

5.91, p = 0.003). Post hoc comparisons using Tukey HSD showed that there is a statistically significant difference (p = 0.035) between the mean scores for Group 1 (M = 19.08, SD = 5.85) and Group 2 (M = 21.31, SD = 6.63) and also between the mean scores for Group 3 (M = 22.93, SD = 5.90) and Group 1 (p = 0.002). There is no statistically significant difference (p = 0.162) between groups of students with average and superior spatial relations abilities in total success on *CK*.

The one-way analysis of variance shows that there are also statistically significant differences between the groups of students in spatial relations abilities and their success in solving the tasks that demand reading (F(2, 382) = 3.43, p = 0.033) and drawing *SMRs* (F(2, 382) = 6.23, p = 0.002). Post hoc comparisons using the Tukey HSD showed that the mean scores for reading *SMRs* are statistically significantly different (p = 0.027) between Group 1 (M = 9.90, SD = 3.09) and Group 3 (M = 11.38, SD = 2.79). There is no statistically significant difference (p = 0.121) between the groups of students with poor and average spatial relations abilities and also between groups with average and superior spatial relations abilities (p = 0.397) in success in solving items that include reading *SMRs*. Post hoc comparisons showed that there is a statistically significant difference (p = 0.001) between the mean scores for drawing *SMRs* for Group 1 (M = 9.17, SD = 3.46) and Group 3 (M = 11.55, SD = 3.65) and also for Group 2 (M = 10.51, SD = 3.96) and Group 1 (p = 0.035). There is no statistically significant difference (p = 0.125) between Group 2 (average spatial relations abilities) and Group 3 (superior spatial relations abilities) in success in drawing *SMRs*.

Students' intrinsic motivation and CK score

The last set of variables includes intrinsic motivation for learning chemistry, which is statistically significantly correlated to students' success in solving the *CK* (r = 0.31; p ≤

0.000). The results show that there is a lower correlation between learning chemistry in general and students' reading *SMRs* scores ($r = 0.22$; $p \leq 0.000$) than between the same intrinsic motivation and drawing *SMRs* ($r = 0.32$; $p \leq 0.000$). The results seem to indicate that only 9.36 % of the *CK* score variance can be accounted for by students' level of intrinsic motivation for learning chemistry. The even lower percentage of success in solving tasks that require reading *SMRs* (4.93 % variance) can be explained by intrinsic motivation for learning chemistry, but on the other hand the most intrinsically motivated students successfully solve tasks with drawing *SMRs* (10.43 % of variance explained).

Students were divided into three groups according to their level of intrinsic motivation for learning chemistry (Group 1: poor intrinsically motivated, Group 2: average intrinsically motivated, and Group 3: superior intrinsically motivated).

Table 3. ANOVA between the three groups of students of different intrinsic motivation for learning chemistry and their success in *CK*.

It can be concluded from the post hoc analysis using Tamhane (for equal variances not assumed) that there is a statistically significant difference ($p \leq 0.000$) between the mean scores on *CK* for poor (Group 1) intrinsically motivated students for learning chemistry ($M = 19.21$, $SD = 7.11$) and Group 3 – superior intrinsically motivated ($M = 25.61$, $SD = 6.75$) and also between average – Group 2 ($M = 20.63$, $SD = 5.76$) and superior – Group 3 intrinsically motivated students ($p \leq 0.000$). There is no statistically significant difference ($p = 0.373$) between Group 1 and Group 2 in success in solving the tasks on *CK*. The post hoc analysis using Tamhane (for equal variances not assumed) also showed that there is a statistically significant difference ($p \leq 0.000$) between the groups of students with different level of intrinsic motivation and their success in solving the tasks that demand drawing *SMRs* for

Group 1 (M = 9.17, SD = 4.04) and Group 3 (M = 13.27, SD = 4.40) and also for Group 2 (M = 10.09, SD = 3.37) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.270$) between students with poor and average score in the intrinsic motivation questionnaire in success in solving tasks drawing *SMRs*. Post hoc comparisons using the Tukey HSD revealed that there is a statistically significant difference ($p \leq 0.000$) between the mean scores for Group 1 (M = 10.03, SD = 3.57) and Group 3 (M = 12.33, SD = 3.05) and also for Group 2 (M = 10.54, SD = 3.11) and Group 3 ($p \leq 0.000$) in reading *SMRs* achievements. There is no statistically significant difference ($p = 0.493$) between students with poor and average intrinsic motivation for learning chemistry in success at reading *SMRs*.

Students' intrinsic motivation for learning the macro level of chemical concepts is also statistically significantly correlated with the overall *CK* score ($r = 0.24$; $p \leq 0.000$) and with students' ability for reading and drawing *SMRs*. The correlation coefficients extend from ($r = 0.15$; $p \leq 0.000$) for reading and ($r = 0.27$; $p \leq 0.000$) for drawing *SMRs*. The results show that similar low percentages, as obtained regarding students' intrinsic motivation for learning chemistry, of total *CK* score (5.5 %), *CK* reading *SMRs* score (2.3 %) and drawing *SMRs* score (7.0 %) variance can be explained by intrinsic motivation for learning chemistry at the macroscopic level.

Table 4. ANOVA between the three groups of students of different intrinsic motivation for the macroscopic level of chemical concepts and their success on CK.

The *ANOVA* showed that the differences between the three groups of students of different intrinsic motivation for the macroscopic level of chemical concepts and their success on *CK* are statistically significant regarding the total score on *CK* ($p = 0.005$) and drawing *SMRs* ($p = 0.006$) but not reading them ($p = 0.151$). Post hoc comparisons using Tukey HSD showed that there is a statistically significant difference ($p = 0.008$) between the mean total scores on *CK* for poor ($M = 20.27$, $SD = 7.06$) and superior ($M = 23.73$, $SD = 7.15$) intrinsically motivated students for learning chemical concepts on the macroscopic level and also for average ($M = 20.93$, $SD = 6.04$) and superior intrinsically motivated ($p = 0.009$). There is no statistically significant difference ($p = 0.724$) between Group 1 and Group 2 in success on *CK*. Because the test of homogeneity of variances for drawing *SMRs* was statistically significant (*Table 4*), the Welch test of equality of means was used. The Welch test showed that the differences between the three groups of students of different intrinsic motivation for learning the macro level of chemical concepts and their success in drawing *SMRs* are statistically significant ($p = 0.006$). It can be concluded from the post hoc analysis using Tamhane (for equal variances not assumed) that there is a statistically significant difference ($p = 0.006$) between the mean scores for Group 1 ($M = 9.77$, $SD = 3.89$) and Group 3 ($M = 12.20$, $SD = 4.54$) and also for Group 2 ($M = 10.28$, $SD = 3.63$) and Group 3 ($p = 0.013$). There is no statistically significant difference ($p = 0.685$) between Group 1 and Group 2 in success at solving the tasks that include drawing of *SMRs*.

It is important to emphasise that those students who show more interest in learning chemical concepts on submicro level are also more efficient in drawing ($r = 0.36$; $p \leq 0.000$) than in reading ($r = 0.26$; $p \leq 0.000$) *SMRs*. The correlation between the total score on *CK* and interest in learning chemistry on submicroscopic level is moderate ($r = 0.34$) and statistically significant ($p \leq 0.000$). It can be concluded that 12.7 % of variance in drawing, and only 6.5 % respectively of students' ability in reading *SMRs*, can be explained by their intrinsic motivation scores for learning chemistry on submicro level.

Table 5. ANOVA between the three groups of students of different intrinsic motivation for the submicroscopic level of chemical concepts and their success on CK.

Post hoc comparisons using the Tukey HSD showed that there is a statistically significant difference ($p \leq 0.000$) between the mean scores for Group 1 (M = 10.15, SD = 3.58) and Group 3 (M = 12.63, SD = 3.08) and also for Group 2 (M = 10.47, SD = 3.06) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.743$) between the group of students with poor and average intrinsic motivation for learning chemical concepts on submicro level in success in reading *SMRs*.

The post hoc analysis using Tamhane (for equal variances not assumed) shows that there is a statistically significant difference ($p \leq 0.000$) between the mean scores on *CK* for poor (M = 19.22, SD = 6.99) and superior (M = 26.15, SD = 6.80) intrinsically motivated students for learning submicroscopic level of chemical concepts and also for the average (M = 20.58, SD = 5.69) and superior group of students ($p = 0.000$). There is no statistically significant difference ($p = 0.370$) between Group 1 and Group 2 in success in solving the tasks on *CK*. It can be concluded from the post hoc analysis using Tamhane that there is a statistically significant difference ($p \leq 0.000$) between the mean scores regarding success in solving problems with drawing *SMRs* for Group 1 (M = 9.07, SD = 4.02) and Group 3 (M = 13.51, SD = 4.38) and also for Group 2 (M = 10.11, SD = 3.34) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.149$) between Group 1 and Group 2 in success in solving the tasks of drawing *SMRs*.

Students' intrinsic motivation for learning chemistry at the symbolic level of the *ITLS* model is statistically significantly correlated ($r = 0.28$; $p \leq 0.000$) to the students' achievements in *CK* (*i.e.* reading *SMRs* $r = 0.20$; $p = 0.000$, and drawing *SMRs* $r = 0.31$; $p \leq 0.000$). The correlation coefficients show higher correlation for drawing than for reading *SMRs*. It can be summarised that only 4 % of variance on reading *SMRs* scores can be accounted for by students' interest in learning symbolic chemical concepts and 9.6 % of variance on drawing *SMRs*, respectively.

Table 6. ANOVA between the three groups of students of different intrinsic motivation for the symbolic level of chemical concepts and their success on *CK*.

The *ANOVA* showed (*Table 6*) that the differences between the three groups of students of different intrinsic motivation for symbolic level of chemical concepts and their success in *CK* is statistically significant ($p \leq 0.000$). Post hoc comparisons using the Tukey HSD showed that there is a statistically significant difference ($p \leq 0.000$) between the mean total scores on *CK* for Group 1 (poor intrinsic motivation) (M = 19.80, SD = 7.00) and Group 3 (superior intrinsic motivation) (M = 25.59, SD = 6.58) and also for Group 2 (average intrinsic motivation) (M = 20.60, SD = 5.86) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.597$) between Group 1 and Group 2 in success on *CK*. The one-way analysis of variance showed that the differences between the three groups of students of different intrinsic motivation for the symbolic level of chemical concepts and their ability in reading *SMRs* is also statistically significant ($p \leq 0.000$). Post hoc comparisons using Tukey HSD showed that there is a statistically significant difference ($p \leq 0.000$) between the mean scores for Group 1 (M = 10.35, SD = 3.49) and Group 3 (M = 12.53, SD = 2.96) and also for Group 2 (M = 10.45, SD = 3.13) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.970$) between students with low level of intrinsic motivation and those with average motivation in success in reading *SMRs*. The Welch test showed that the differences between the three groups of students of different intrinsic motivation for learning the symbolic level of chemical concepts and their success in problems that include drawing ($p = 0.000$) are statistically significant. The post hoc analysis using Tamhane (for equal variances not assumed) shows that there is a statistically significant difference ($p \leq 0.000$) between the mean scores for Group 1 ($M = 9,45$, $SD = 4.07$) and Group 3 ($M = 13.07$, $SD = 4.27$) and also for Group 2 ($M = 10.15$, $SD = 3.46$) and Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.458$) between Group 1 and Group 2 in success in drawing *SMRs*.

Discussion and implications for education

The first hypothesis relates to the difference in students' achievements between chemistry problems that include reading *SMRs* and those that include drawing them, and can be confirmed. It can be concluded that the average points scored by the students on items that require reading submicrorepresentations are higher (by 14.1%) compared to the average points for items that include drawing the *SMRs*. These results are consistent with some other research (Kelly & Jones, 2008; Margel, Eylon, & Scherz, 2008) which indicate that students have specific problems with drawing the correct submicrorepresentations of the natural phenomena. The results indicate that teachers should devote more of their time in the classroom to introducing to the students the purpose and the meaning of correct drawing of the *SMRs*. These activities should be incorporated in all of the parts of the lessons, from introduction to the new topic to students' evaluating their knowledge at the end. Teachers would collect useful data by analysing students' drawing of *SMRs,* and on the basis of the conclusions could modify future classroom activities to correct the discovered students' misinterpretations of chemical concepts at submicro level. Teachers' view of the instructions and their pedagogical knowledge - especially if they see the teaching as transfer of knowledge or as a process of building the students' knowledge - influence teachers' realization of the chemistry lessons (Valenčič Zuljan, 2007). Students' incomplete comprehension and/or misunderstandings of chemical concepts play an important role in the teaching process. Teachers should carefully analyse such concepts, and their corrected forms should be integrated into the students' learning process.

The difference is statistically significant, and further analysis shows a more detailed picture of some independent variables (i.e. gender, formal reasoning abilities, visualization abilities and intrinsic motivation for learning chemistry) and their influence on students' achievements in solving problems comprising *SMRs.*

The second hypothesis refers to the difference between males and females in solving problems involving reading and drawing *SMRs*, and can not be confirmed. It can be summarised that female students score significantly lower than male students in drawing or reading submicrorepresentations while solving particulate problems. Bunce and Gabel (2002) reported similar findings. They said that females score lower than males on the pre-test, but after implementing the educational strategies that connect all three levels of chemical concepts the significant gender score difference would diminish. The results reported by Barke and Engida (2001) can explain the results found in this research. They anticipated that girls have lower developed visualization abilities than boys, and they propose that students should use different models and visualization material very early in the science education process to stimulate development of visualization abilities. It can be speculated that visualization abilities can influence motivation, and than hence the science problem solving achievements by both males and females. During the educational process teachers should, therefore, pay more attention to female students' progress in developing adequate mental models of chemical concepts regarding submicroscopic level through motivation for learning chemical concepts on all levels, thus stimulating the meaning of such learning for their professional career and everyday life.

The third hypothesis is connected to students' formal reasoning abilities, and it can be confirmed. Results show that students with higher formal reasoning abilities are slightly more successful in problems that require reading than drawing *SMRs*. Drawing *SMRs* seems to be more intellectually demanding than reading them, but results of the present study do not confirm this assumption. It is also evident that students with developed formal reasoning abilities are equally successful in reading or drawing submicrorepresentations as are those students that reach transitional level, but there is a statistically significant difference between concrete and formal reasoners. The difference between concrete and transitional reasoners in reading or drawing *SMRs* is not significant. However, it is important to stress, that even students on the concrete level of reasoning abilities are sufficiently capable of solving some problems on submicro level. It is also evident that those students that fall into the group of concrete or transitional reasoners had more difficulties with solving problems that involve reading or drawing *SMRs* than those that fall into the group of formal reasoners. The lower percent of explained variance was obtained by Gabel, Samuel, & Humm (1987) and Haidar and Abraham (1991), that was attributed to the results on chemical concepts test 22.8 % and 17.5 % respectively of the variance by the students' reasoning abilities. The findings of the present study are consistent with the findings of the study by Williamson and Abraham (1995), who reported that 27 % of variance can be explained by formal reasoning abilities, and Valanides (1998) reported similar results.

The fourth hypothesis is: "Students with higher visualization abilities score statistically significantly higher on the items regarding drawing *SMRs*", but it can not be confirmed. Results shows that, in the contrast with formal reasoning ability and its influence on students' achievements in solving problems on particulate level, it can be concluded that visualization abilities are not so strongly correlated with chemistry knowledge that refers to 2-D submicrorepresentations. This is shown by the results, and only a small portion of variance on the *CK* score can be explained by students' visualization abilities. Further analysis of variance shows, that differences between students with low and average, and average and superior visualization abilities are not statistically significant in most cases. It can, for that reason, be emphasised that students can solve particulate problems even if their visualization abilities are not so highly developed. However it is important to emphasise that there is no statistically significant difference between students with different speeds of perception abilities in solving problems regarding reading or drawing *SMRs*. On the other hand, somewhat bigger differences can be determined regarding the use of 2-D submicrorepresentations between students with different levels of spatial relations. The difference is not statistically significant between students with average and superior spatial relations abilities. The difference between students with poor and average spatial relations abilities is statistically significant in the total *CK* score and reading *SMRs* score. However the difference is also significant on all three levels of *CK* tasks, between students with poor and those with superior spatial relations abilities. It can be concluded that chemical problems which include just 2-D submicrorepresentations do not pose great difficulties in solving them, even for those students with lower visualization abilities. These conclusions ought to encourage teachers to use submicrorepresentations in classrooms, not just for laboratory work explanations, but also for evaluating students' knowledge, without apprehension that students with lower abilities would be discriminated. These results confirmed the predictions of Wu and Shah (2003) and Keig and Rubba (1993) that secondary school students' chemical concepts test scores variance would not be in a very large percentage accounted for by students' visualization abilities, but by more general reasoning abilities. Gabel et al. (1987) also reported no significant correlation between students' visualization abilities and achievements on the chemistry test that comprises items on submicroscopic level. Higher correlations between visualization abilities of secondary school students in Slovenia ($r = 0.472$; $p < 0.01$) were registered by Ferk Vrtačnik, Blejec, & Gril (2003). Similar results were obtained also by Yang et al. (2003).

These results may have their cause in different chemistry conceptual problems (3D model manipulations, computer animations …) that were used for evaluating students' knowledge.

The last hypothesis relates to the students' intrinsic motivation for learning chemistry on different levels of chemical concepts regarding the *ITLS* model, and it can be confirmed. It can be summarised from the results that the correlations between *CK* scores, either in reading, drawing or overall scores and intrinsic motivation for learning chemistry, are the highest regarding motivation for the submicro level of chemical concepts, and the lowest regarding macro level. From the ANOVA results it can be summarised that the differences between the groups of students with different levels of intrinsic motivation is significant almost in all cases, except for reading *SMRs* and intrinsic motivation for the experimental level of chemical education. However it is important to emphasise that on all levels of *ITLS* intrinsic motivation for learning chemistry, the difference between poor and average intrinsically motivated students is not significant. According to these results, students with higher general or specific chemical intrinsic motivation achieve higher scores on the chemistry test comprising reading or drawing submicrorepresentations. Most students on all levels of education do like chemistry at the macro level, so teachers should take advantage of this and extrinsically motivate students through laboratory work. After this activity most students would have the chance to develop intrinsic motivation for the macro level of chemical concepts, and after that the intrinsic motivation for other two more abstract levels of *ITLS* model would evolve. To achieve this goal, teachers encounter a difficult task in achieving a sufficient level of external stimulation for students to become interested in chemistry, because students, at all levels of the educational system, often do not realize the meaning of submicroscopic explanations of the phenomena and their symbolic representations. It can be summarised that the most successful in solving chemistry problems on different levels of the *ITLS* model would be those students that are highly intrinsically motivated for learning chemistry on the particulate level. Similar results of several studies were reported by Tuan et al. (2005), but their research shows a slightly higher correlation between school science achievement and motivation ($r = 0.40$; $p < 0.01$). Previous research (Napier & Riley, 1985) also indicated that motivation has a moderate but significant correlation with students' science achievement. The results obtained in this study can confirm Keigs' and Rubbas' (1993) predictions, i.e. that motivation can be a potential source of variance regarding students' success on the chemical concepts test. On the other hand, Nieswandt (2007) reports the result of her study, that affective variables (students' interest and attitudes for chemistry and their chemistry-specific self-concepts) do not have a statistically significantly effect on conceptual understanding, but the results do reveal the importance of strong and positive self-concept for developing a meaningful understanding of science concepts.

The main implication for teaching chemistry or chemical concepts in science education is that teachers should encourage students and especially females in activities where they are engaged in drawing submicrorepresentations. It is important that teachers at the beginning of using *SMRs* in chemistry teaching use simple *SMRs*, especially when students have to draw them. Teachers should in the process of chemistry teaching emphasise the meaning of correct and accurate reading of the chemistry problem text. They should also stress the meaning of the legends of particles and their names before students start to draw the *SMRs*. Students are going to develop the abilities of drawing *SMRs* also when their formal reasoning abilities or visualization abilities are not highly developed in relation to their age. It is also important to stress, that students show an interest in understanding chemical concepts on a particulate level and that they try to comprehend the bases of chemical phenomena on the level where chemical reactions happen. On the other hand, students who enjoy learning chemistry only on the bases of symbols (chemical symbols of elements, formulae, equations) or observations of the experiments, without deeper understanding of the phenomena on particulate level, could not be very successful in achieving sufficient chemical knowledge. These findings indicate that teachers ought to, nevertheless, encourage students to learn chemistry at the particulate level. These attempts are going to be only external, and for students mostly unnecessary or even discouraging and highly difficult to understand at the beginning of the educational process. But with progress in understanding of the basic chemical concepts (e.g. atom structure, chemical bond, etc), students' interest in understanding chemistry on submicro level will increase and will bring them more success in getting better feedback from the teacher. This type of chemistry teaching ought to result in the increase of intrinsic motivation for deeper learning of chemical concepts on all levels of *ITLS* model. Teachers with adequate chemical and didactical knowledge are able to conduct quality chemistry lessons by transferring scientific knowledge into the classroom. It is important to direct pre-service teacher students into the reflective way of teaching and into developing the constant need for researching their own pedagogical practice (Vogrinc & Valenčič Zuljan, 2009). In-service mentoring of beginning chemistry teachers (Author; Valenčič Zuljan, 2007; Valenčič Zuljan & Vogrinc, 2007) and the provision of quality permanent in-service teacher education (Kalin & Zuljan, 2007) are, beside the pre-graduate study, an important aspect in developing the future teacher as a reflective practician. Permanent in-service teacher education ought to take into account teachers' expectations and needs so that it can offer them the chance to develop competences to implement quality, also in the student oriented instructions model.

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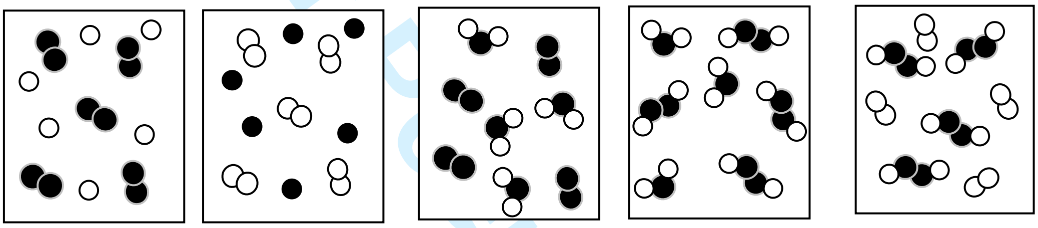
Appendix 1: Sample items from diagnostic instrument for determining *Chemical Knowledge (CK)*.

Reading *SMRs*

Pure substances and mixtures

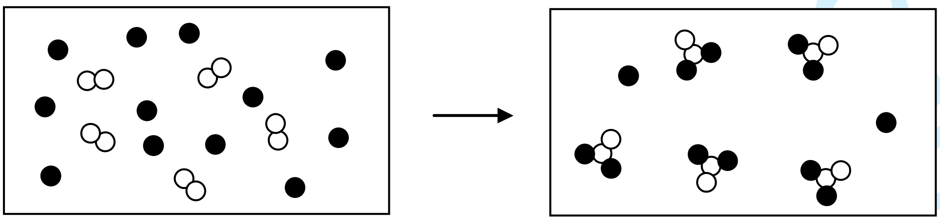
Which scheme represents a mixture of two compounds? One circle represents one atom.



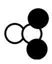
A B C D E

Chemical reactions

The scheme represents the reaction between substance A and B. Which equation correctly represents this reaction?



Mixture before the reaction Mixture after the reaction

Legend:  - Substance A;  - Substance B;  - Product

A $A_2 + 2\ B \rightarrow A_2B_2$

B $12\ A + 10\ B \rightarrow 6\ A_2B_2$

C $2\,A + 2\,B \rightarrow A_2B_2$

D $5\,A + 5\,B_2 \rightarrow 5\,A_2B_2 + 2\,A$

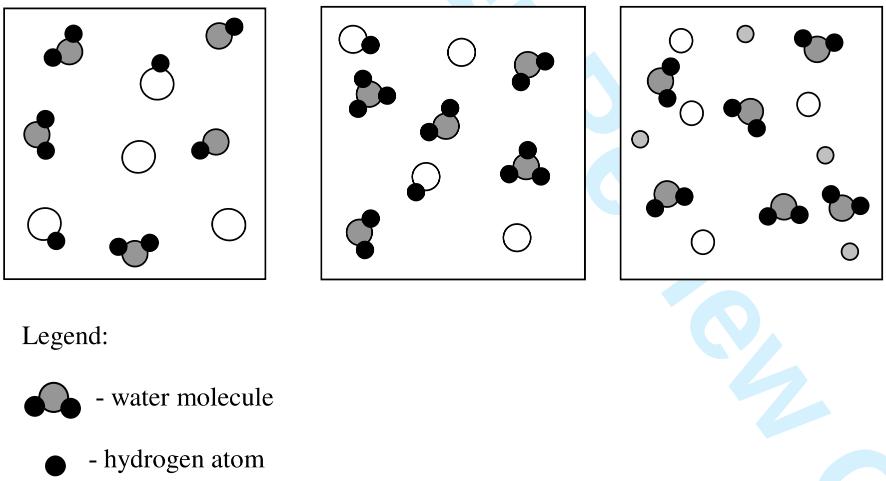
E $2\,A + B_2 \rightarrow A_2B_2$

Which substance was completely used during the reaction? ____________

Elaborate the answer: ____

Electrolyte chemistry

Scheme A to C represents aqueous solutions of three different substances. Most of the water molecules were omitted for clarity.



Answer the following questions.

Which scheme represents an aqueous solution of acid? ____________

Which scheme represents an aqueous solution of base? _____________

Which scheme represents an aqueous solution of soluble salt? ___________

Drawing *SMRs*

Pure substances and mixtures

Water can be found in three states of matter in nature. Draw schemes to show different states of water. Draw ten water molecules in each box represented by ● and on the line write the correct state of matter represented in the box above.

a ________________ b ________________ c ________________

Chemical reactions

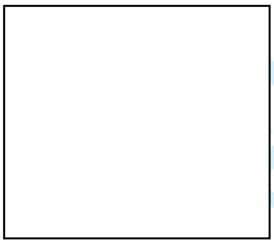
Draw the scheme of a chemical reaction product between two molecules of chlorine and two molecules of hydrogen in the box below.

Legend: ________________________________

Elaborate the answer: ____

Aqueous solutions

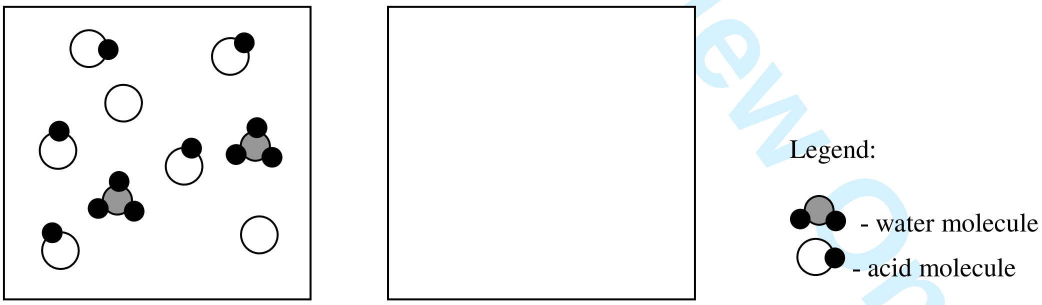
Draw a scheme to show the dissolved potassium bromide with optional concentration in water. Use the legend to illustrate the particles which you have used in the scheme. You need not draw water molecules.



Legend: ________________________

Electrolyte chemistry

Scheme 1 represents aqueous solution of an acid. Water molecules were omitted for clarity. Draw Scheme 2 representing aqueous solution of a stronger acid, but the same concentration. You need not draw water molecules.



Scheme 1 Scheme 2

Elaborate the answer: ____

Appendix 2: Sample items from the questionnaire Intrinsic Motivation for Learning Science (*IMLS*)

1. Emotional component of interest:

I enjoy learning.

I am often bored during:

…chemistry course.

… biology course.

…physics course.

… foreign language course.

… mathematics course.

I enjoy the chemistry course when:

…we observe chemical changes in experiments.

…we learn about particles (atoms, ions, molecules).

…we learn and write chemical symbols, formulae and equations.

2. Cognitive component of interest:

I often look for additional information about school science topics in books, magazines, in the internet, CDs …

The media attract my attention when reporting on:

…chemistry topics.

…biology topics.

…physics topics.

…foreign language topics.

…mathematics topics.

I often think about:

…observation of chemical changes in experiments*, also out of school.*

… particles (atoms, ions, molecules), *also out of school.*

…learning and writing chemical symbols, formulae and equations, *also out of school.*

<u>3. Challenge component of internal motivation:</u>

I persevere with learning.

New problems in:

… chemistry, *challenge me.*

…biology, *challenge me.*

…physics, *challenge me.*

…foreign language, *challenge me.*

…mathematics*, challenge me.*

If I do not understand something, connected with:

…observation of chemical changes in experiments, *I give up.*

…learning about particles (atoms, ions, molecules), *I give up.*

…learning and writing chemical symbols, formulae and equations, *I give up*.

Table 1. Descriptive statistics for *CK*.

	Minimum points	Maximum points possible	Students' maximum points	Average points	SD	Kortusus	Skewness
Total CK score	1	43.5	40.25	21.21	6.47	0.036	-0.089
Reading of *SMRs* CK score	0	19.0	16.0	10.75	3.25	-0.233	-0.421
Drawing of *SMRs* CK score	0	24.5	24.25	10.46	3.88	0.546	0.082

Table 2. Pearsons' correlation coefficients between students' visualization abilities and success on CK.

	Speed of perception	p	Spatial relations	p
Total *CK* score	0.117	0.021	0.162	0.001
Reading of *SMRs CK* score	0.097	0.058	0.113	0.027
Drawing of *SMRs CK* score	0.114	0.025	0.176	0.001

Table 3. ANOVA between the three groups of students of different intrinsic motivation for learning chemistry and their success on CK.

	df, df	F	p
Total *CK* score *	2, 107.07	17.05	≤ 0.000
Reading of *SMRs CK* score	2, 383	9.99	≤ 0.000
Drawing of *SMRs CK* score **	2, 105.49	17.25	≤ 0.000

* the test of homogeneity of variances was statistically significant F (2, 383) = 3.74; p = 0.025), so the Welch test of equality of means was applied

** the test of homogeneity of variances was statistically significant F (2, 383) = 6.75; p = 0.001), so the Welch test of equality of means was applied

Table 4. ANOVA between the three groups of students of different intrinsic motivation for the macroscopic level of chemical concepts and their success on *CK*.

	df, df	F	p
Total *CS* score	2, 383	5.28	0.005
Reading of *SMRs CS* score	2, 383	1.90	0.151
Drawing of *SMRs CS* score *	2, 106.18	5.38	0.006

* the test of homogeneity of variances was statistically significant F (2, 383) = 3.95; p = 0.020), so the Welch test of equality of means was applied

Table 5. ANOVA between the three groups of students of different intrinsic motivation for the submicroscopic level of chemical concepts and their success on *CK*.

	df, df	F	p
Total *CS* score *	2, 107.40	19.92	0.000
Reading of *SMRs CS* score	2, 383	12.92	0.000
Drawing of *SMRs CS* score **	2, 105.83	19.55	0.000

* The test of homogeneity of variances was statistically significant (F (2, 383) = 3.61; p = 0.028), so the Welch test of equality of means was applied.

** The test of homogeneity of variances was statistically significant (F (2, 383) = 4.98; p = 0.007), so the Welch test of equality of means was applied.

Table 6. ANOVA between the three groups of students of different intrinsic motivation for the symbolic level of chemical concepts and their success on *CK*.

	df, df	F	p
Total *CK* score	2, 383	17.85	0.000
Reading of *SMRs CK* score	2, 383	10.94	0.000
Drawing of *SMRs CK* score *	2, 112.82	14.12	0.000

* The test of homogeneity of variances was statistically significant F (2, 383) = 3.60; p = 0.028), so the Welch test of equality of means was applied.