

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

Devetak, Iztok; Glažar, Saša Aleksij

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

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Keywords (user):	submicrorepresentations



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3 **THE INFLUENCE OF 16-YEAR-OLD STUDENTS' GENDER, MENTAL ABILITIES,**
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6 **AND MOTIVATION ON THEIR READING AND DRAWING**
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8 **SUBMICROREPRESENTATIONS ACHIEVEMENTS**
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12 **Abstract:** Submicrorepresentations are a powerful tool for identifying misconceptions of
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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 & Waldrup, 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. Waldrup, 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

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3 representations and the role of visualization methods used in the process of mental model
4 construction of chemical phenomena that students ought to develop. The *ITLS* model draws on
5 different educational theories, such as Paivio's dual coding theory, Mayer's SOI model of
6 meaningful learning and Johnstone's model of information processing, cognitive theory of
7 multimedia learning and Mayer's theory of effective illustrations (see for more details Author;
8 Author).

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20 *Figure 1: Model representing Interdependence of Three Levels of Science concepts*
21 *representations – ITLS model (Author).*
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26 To illustrate chemical concepts on the level of particles, submicrorepresentations (*SMR*)
27 can be used and can be presented as static or dynamic modes of representations. Research
28 shows (Bunce & Gabel, 2002; Tien, Teichert, & Rickey, 2007; Kelly & Jones, 2008) that
29 those students who were exposed to *SMRs* during the educational process more adequately
30 understand the nature of the particle interactions compared to those who learned the same
31 concepts only by textbooks reading. Studies in the last two decades (Williamson & Abraham,
32 1995; Johnson, 1998; Chittleborough, Treagust, & Mocerino, 2002; Solsona, Izquierdo, &
33 DeJong, 2003; Papageorgioua & Johnson, 2005; Stains & Talanquer, 2007; Tien et al, 2007;
34 Kelly & Jones, 2008; Author) also show that students have many difficulties in understanding
35 the submicro and symbolic levels of chemical concepts, and that previous knowledge of a
36 specific topic has an influence on integrating new science concepts into students' mental
37 structure. It is also important to emphasise that a lot of different factors influence students'
38 achievement on different pictorial test questions (Halakova & Prokša, 2007; Sanger & Phelps,
39 2007; Stains & Talanquer, 2008) and that the students' knowledge evaluation part of the
40 educational process needs further study. Research also shows that teachers use mostly the
41 symbolic level of chemical concepts to teach chemistry (Williamson & Abraham, 1995;
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Independent variables and submicrorepresentations

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

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2
3 levels of formal reasoning abilities is not statistically significant. Similar results were obtained
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5 by Shemesh, Eckstein, & Lazarowitz, (1992). Statistically significant correlations were proven
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7 between formal reasoning abilities and students' chemical knowledge especially on submicro
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9 level (Haidar & Abraham, 1991; Williamson & Abraham, 1995)
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13 It is important to emphasize that Yang, Andre, & Greenbowe (2003) concluded that
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15 students with low levels of visualization abilities show greater difficulties in understanding
16
17 computer animations of chemical phenomena on particulate level. Research (Barke & Engida,
18
19 2001) also shows that girls have lower developed visualization abilities than boys, and they
20
21 propose that students should use different models and visualization material very early in the
22
23 science education process to stimulate development of visualization abilities. On the other
24
25 hand, Wu and Shah (2003) reported no statistically significant correlations between students'
26
27 achievements on the test with static *SMRs* and spatial abilities. They anticipated that the
28
29 knowledge achievement is more dependent on students' prior knowledge and the general
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31 cognitive factor than on visualization abilities.
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38 *Students' motivation for chemistry learning*

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44 A negative relationship towards chemistry does not enable proper concept change and/or
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46 modification of students' mental model of chemical phenomena. Students often do not have a
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48 proper knowledge base that would make it possible to upgrade their knowledge of more and
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50 more abstract chemical concepts when they make progress on the educational vertical
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52 (Treagust, Harrison, & Venville, 1998).
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56 Learning motivation is defined as a construct which includes different motivational
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58 elements (interests, goals, attributes, self-image, external enticements, etc.). Some of these
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60 form a more extrinsic stimulus for learning (e.g., learning for grades, praises, avoiding

Independent variables and submicrorepresentations

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3 punishment, social acceptance, etc.), while others are manifested more intrinsically (i.e.,
4
5 learning for mastering, learning for knowledge) (Authors).
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8 According to Ryan and Deci (2000), intrinsic motivation is an individual's inherent
9
10 inclination from which stems his/her tendency to learn about particular areas of life regardless
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12 of the presence of external enticements. This construction encourages humans to '...
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14 assimilate, control, generate spontaneous interests and to research which makes it essential for
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16 the individual's social and cognitive development while on the other hand it represents the
17
18 fundamental source of personal satisfaction and life energy.' (p. 70).
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22 Highly intrinsically motivated students are more successful in learning new concepts and
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24 show better understanding of the learning matter (Stipek, 1998). Rennie (1990), on the basis of
25
26 the research on science learning, also concluded that higher results in science are related to the
27
28 learner's active engagement in learning tasks, to his/her positive attitude towards the subject
29
30 and to a highly positive self-concept in science, which all imply the learner's intrinsic
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32 motivation to learn. This is especially important, since many writers (Anderman & Young,
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34 1994; Zusho, Pintrich, & Coppola, 2003) report that the decrease in intrinsic motivation with
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36 years of schooling is particularly noticeable in mathematics and science and is at its peak in
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38 the period of early adolescence.
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43 Keig and Rubba (1993) pointed out that motivation can be a potential source of variance
44
45 on students' chemistry knowledge achievements. These claims were confirmed by Tuan et al.
46
47 (2005). They reported that from 7 to 16% of variance on the science knowledge test could be
48
49 explained by students' motivation. But on the other hand Nieswandt (2007) reported no
50
51 statistically significant effect of students' affective variables (situational interest, attitudes
52
53 towards chemistry and students chemistry-specific self-concept) on their understanding of
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55 grade 9 (age 15 to 16) chemistry concepts.
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Independent variables and submicrorepresentations

Chittleborough et al. (2002), according to their qualitative research, reported that students are not motivated for learning chemistry more than 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*).

Independent variables and submicrorepresentations

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

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34 A total of 386 secondary school students (60.6 % females; 39.4 % males) participated in
35 the study. On average, the students were 16.3 years old (M= 195.4 months; SD = 5.7 months).
36 All students attended second year of the general type of secondary school (Gymnasium). The
37 chemistry curriculum of the Gymnasium is common to all students. The students attended the
38 fourth year of chemical education in the period that testing occurred (two years in higher
39 primary school - age 13 and 14 and two years in secondary school - age 15 and 16). The
40 sample included 5.5 % of the whole population of the students (N = 7033) in school year
41 2005/06, throughout Slovenia. Three schools were located in the larger towns (more than
42 100,000 residents) and three in smaller towns (between 35,000 and 100,000 residents). The
43 sample represented a predominantly urban population with mixed socioeconomic status.
44 Parents' basic educational background was diverse (3.1 % finished primary school; 45.1 %
45 finished secondary school; 43.0 % finished university and 7.3 % finished other formal
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3 education) but only 11.6 % of parents had finished some kind of science or technology
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5 education.
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10 *Instruments*

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15 Students' abilities to read and draw the *SMRs* were measured using the diagnostic
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17 instrument for determining *Chemical Knowledge (CK)*. The instrument comprises 19 items.
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19 Eight items required reading and eleven items drawing *SMRs* in solving the chemistry
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21 problems considering the *ITLS* model. The *CK* includes four different contents: pure
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23 substances and mixtures (4 items), chemical reactions (6 items), water solutions (4 items) and
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25 electrolyte chemistry (5 items). The *CK* showed satisfactory measuring characteristics (i.e.
26
27 internal consistency reliability - Cronbach's alpha was 0.80; discriminate indexes for every
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29 item between 0.21 and 0.80 were all statistically significant). Kurtosis and skewness
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31 coefficients show normally distributed data (see Table 1). Students had 60 minutes to solve
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33 the *CK*. One sample item of each content of *CK* is introduced in Appendix 1.
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39 To determine other independent variables, four different tests and a questionnaire were
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41 administered to the students: Test of Logical Thinking (*TOLT*), Rotations (*RO*), Patterns (*PA*),
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43 and Intrinsic Motivation for Learning Science questionnaire (*IMLS*).
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45
46 The level of students' formal reasoning abilities was obtained with the *Test of Logical*
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48 *Thinking (TOLT)* (Tobin & Capie, 1981). The *TOLT* is a ten-item group paper-pencil test. The
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50 authors of the test reported a strong correlation ($r = 0.82$; $p < 0.0001$) between performance on
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52 tasks during Piagetian clinical interviews that are considered a traditionally preferable method
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54 in measuring individuals' formal reasoning abilities and the results on *TOLT*. The *TOLT* has
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56 high internal consistency reliability (Cronbach's alpha was 0.85). The test consists of two
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58 items designed to measure each of the five modes of reasoning (i.e., controlling variables,
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Independent variables and submicrorepresentations

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3 proportional, correlational, probabilistic, and combinatorial reasoning). The test scores from 0-
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5 1 points (concrete reasoners), 2-3 points (transitional reasoners) and 4-10 points (formal
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7 reasoners) were used as a basis for classifying the students. Students had 38 minutes to solve
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9 the test.
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12 The students' visualization abilities were measured with two tests: *Patterns (PA)* and
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14 *Rotations (RO)* (Pogačnik, 1998; 2000). The *PA* measures students' speed of perception and
15
16 the *RO* measures students' spatial relations abilities. Both tests were developed based on the
17
18 Cattell-Horn theory of mental abilities. The *PA* is a 36 item group paper-pencil test. It requires
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20 individuals to find and mark exactly the same pattern among the four similar patterns on the
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22 right side of the paper to the one on the left part of the paper as quickly as possible. The *PA*
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24 has high internal consistency (Cronbach's alpha was 0.86). Correlations between some other
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26 instruments for determining individuals' perception abilities (*BTI-Or*; *BTI-Pr*, *Beta 6* and *4*)
27
28 determine that the instrument's validity was higher and statistically significant. Students had
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30 4.5 minutes to solve the test. The *RO* is a 90 item group paper-pencil test. The *RO* requires
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32 individuals to find and encircle those patterns on the right side of the paper that are just rotated
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34 in comparison with the left pattern. Individuals have to cross those patterns that are not just
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36 rotated in the plane but represent a different pattern. Cronbach's alpha for the *RO* was 0.94.
37
38 Correlations between some other instruments for determining individuals' perception abilities
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40 (*BTI-Pr*, *Beta 4*) were also high and statistically significant. Students had 6 minutes to solve
41
42 the test. The classifications of students into three groups with regard to their visualization
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44 abilities were performed according to the statistical equations. Into Group 1 (poor visualization
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46 abilities) were classified students that scored less than $M - 1SD$ points, into Group 2 (average
47
48 visualization abilities) those that scored between $M - 1SD$ and $M + 1SD$ points, and into
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50 Group 3 (superior visualization abilities) students that scored above $M + 1SD$ points on the *PA*
51
52 and *RO*.
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Independent variables and submicrorepresentations

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).

Independent variables and submicrorepresentations

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3 The students had received no special teaching about using *SMRs* in the chemistry
4 classroom. The chemical concepts comprised in the *CK* were not instructed using *SMRs* by
5 the teachers that taught the students participating in the study.
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10 *CK* and *IMLS* were designed specifically for this study. The *CK* was administered to two
11 university chemistry and chemical education professors. Their responses provided
12 scientifically correct answers and content validation for the instrument. The *IMLS* was
13 distributed to two experts in science education and one in educational psychology. Their
14 evaluation of the instrument confirmed that the *IMLS* measures students' intrinsic motivation
15 for learning and their analysis provided validation for the questionnaire. The Slovene
16 translation of the *TOLT* was used for the study. The test was separately translated into the
17 Slovene language by one expert in chemistry and one expert in physics education. The
18 translations were compared and possible modifications were made in preparing the third
19 version of the test. The third expert translated the test back into English. The original and the
20 translated version of the English test were compared and possible modifications were made in
21 designing the final Slovene version of the *TOLT*. Four independent experts in chemistry,
22 physics and mathematics education finally reviewed the test, and their responses provided
23 content validation of the instrument.
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43 After all the instruments had been developed or chosen in relation to the purpose of the
44 study, a pilot study was conducted with 77 students. The *CK*, *TOLT* and *IMLS* were used in
45 the pilot study. Taking into account the statistical analysis of the results obtained in the pilot
46 study, the *SK* and *IMLS* were modified.
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53 All instruments were applied on the research sample at the end of the second school
54 year 2005/06 of the secondary school. The testing took students about 135 minutes on two
55 separate days. Students solved the *IMLS* and *CK* in the first week and in the second one they
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2
3 solved the *TOLT*, *RO* and *PA*. The last testing was conducted by a trained psychologist. All
4
5 instruments were applied in a group and under normal examination conditions.
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8 Descriptive statistics were obtained for illustrating the *CK* characteristics. For
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10 determining differences in the means of *CK*, the paired-sample t-test was used. Pearsons'
11
12 correlation coefficients for determining the correlation between knowledge of chemical
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14 concepts and other independent variables were calculated. The percentage of variance two
15
16 variables share is referred to as the coefficient of determination. The coefficient of
17
18 determination is calculated by square the correlation coefficient (r^2) value and then converted
19
20 into percentage of variance by multiplying it by 100 (Pallant, 2005). In other words, the
21
22 square of correlation coefficient (r^2) is the fraction of the variation in the values of
23
24 independent variable that is explained by the least-squares regression of independent on
25
26 dependent variable (Moore & McCabe, 1997).
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31 In addition, the one-way between-groups analysis of variance (*ANOVA*) was conducted
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33 to explore the influence of reasoning abilities, visualization abilities and intrinsic motivation
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35 for learning chemistry on students' success in solving *CK* tasks. If the test of homogeneity of
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37 variances was statistically significant when comparing the means of the groups of students,
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39 the more robust test (Welch test) of equality of means was used.
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43 The 5% cut off was used in presenting the most frequent misconceptions detected by
44
45 analysing the students' sample problem solving achievements. The decision was made
46
47 according to the statistical significance of results. It tells us something about the degree to
48
49 which the result is "true" in the sense of being "representative of the population": 5% is
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51 customarily treated as a "border-line acceptable" error level (Moore & McCabe, 1997).
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57 Results

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Independent variables and submicrorepresentations

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3 The *CK* analysis shows secondary school students' average chemical knowledge of the
4 tested basic chemical concepts (*Table 1*). Students achieved on average 49 % of all points
5 possible on the *CK*.
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10 Students were more successful in reading *SMRs* than drawing them. Students managed to
11 get on average 56.5 % of all points on items that required reading the *SMRs*. On the other
12 hand, students achieved on average 42.4 % of all points available on problems that required
13 drawing the most suitable *SMRs*.
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22 Table 1. Descriptive statistics for *CK*.
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27 The paired samples t-test shows that students score statistically significantly higher in
28 solving problems that require reading *SMRs* than in those that require drawing them ($t(385) =$
29 $1.97, p = 0.048$). More detailed presentation of students' achievements in solving specific
30 sample problems (See Appendix 1) is presented in Chart 1.
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39 Chart 1. Students' achievements at sample chemistry problems (PSM – Pure substances and
40 mixtures; CR – Chemical reactions; EC – Electrolyte chemistry; and SC – Solution
41 chemistry).
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48 Some results of the detailed analysis of students' responses to the sample *SMRs*
49 chemistry problems are presented below in the same order as in Chart 1.
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55 *Pure substances and mixtures (PSM Reading SMRs)*
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3 Results of the analysis of Problem 1 (See Appendix 1) show, that 34.8% of students
4 incorrectly select the *SMRs* representing the mixture of two compounds (Chart 1). Some
5 students correctly selected one of them, out of two possible solutions.
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10 13.4% and 13.7% of students think that a mixture of molecules with the same atoms and
11 molecules with different atoms, presented on *SMR C* and *SMR E* respectively, is also a
12 mixture of two compounds. 9.6 % of students selected the *SMR A* as a correct answer. These
13 results show that about 10% of students after three years of chemical education do not
14 adequately understand the differences between a molecule of element and compound at the
15 particulate level. There were other mistakes which were less frequent (less than 5% cases).
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27 *Chemical reaction (CR reading SMRs)*

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

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

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17 57.8% of students correctly assigned all three *SMRs* to the aqueous solution of base,
18 acid and soluble salt in Problem 3 (See Appendix 1). 6.1% of students did not solve the
19 problem and 33.1 % of them incorrectly assigned one or more *SMRs* to the correct aqueous
20 solution. These students tried to answer the question by guessing the right answer so they
21 didn't understand the submicroscopic properties of electrolyte. Other mistakes represent less
22 than 5% of all cases.
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Pure substances and mixtures (PSM drawing SMRs)

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36 87.3% of students didn't draw the correct *SMRs* of all three states of water (Chart 1) in
37 Problem 4 (See Appendix 1). Only 7.8% of students drew the *SMRs* correctly. Students were
38 the most successful at drawing water in a gaseous state (65.2%) whilst only 7.8% of students
39 correctly represented liquid water. 29.2% of students draw water molecules too far apart
40 (Figure 2a) and 23.9% of them represent liquid water as a gas (large distances between the
41 molecules). Students also didn't take into account that the distances between water molecules
42 during freezing increases (ice has about 9 % lower density as liquid water), but they just
43 adopted the general characteristic of substances that there are larger distances between
44 particles in liquid than in solid state.
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59 Figure 2. Incorrectly presented states of water; original students' drawing, where written on a
60 line means: a liquid; b solid; c liquid and d gas.

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6 26.7% of students present an ordered structure of water molecules in liquid (Figure
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8 3.2a) and 6.1% of students draw ice on submicroscopic level with molecules too apart and not
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10 ordered (Figure 3.1b.). There were also other misconceptions (some are presented in Figure 3)
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12 which were less frequent (less than 5% cases).
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17 Figure 3. *SMRs* of different states of water presenting different sizes of molecules and their
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19 organisation in a specific state of water; original students' drawing, written on a line means: 1
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21 - a gas; b solid; c liquid and 2 - a liquid; b solid; c gas).
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25 26 27 *Chemical reaction (CR drawing SMRs)*

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29 Only 18.4% of students correctly presented the chemical reaction between chlorine and
30
31 hydrogen molecules on submicroscopic level (See Chart 1). The Problem 5 (See Appendix 1)
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33 was three-parted. In the first part students had to write the *SMR* (18.4 % correct drawings and
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35 75.2 incorrect), in the second part they had to present the drawn particles in a legend with
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37 their nemeses or formulas (39.1% sufficient legends and 55.3% with some sort of
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39 incorrectness) and in the third part students had to elaborate their solution of the problem.
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44 34.3% of students did not take into account the different size of chlorine and hydrogen
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46 atoms and they just drew the *SMR* as shown in Figure 4.
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51 Figure 4. The same size of hydrogen and chlorine atoms in the molecule of hydrogen chloride.
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56 38% of students did not consider the correct number of product molecules according to
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58 the problem text, so they illustrated only two molecules of hydrogen chloride.
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Independent variables and submicrorepresentations

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3 Analysis of the legend shows, that 27.2% of students who correctly presented the legend
4 used symbols of elements to illustrate the drawn particles, but in only 2.7% of cases students
5 used a correct name of the particle (e.g. hydrogen atom and chlorine atom). In average more
6 than 27% of students just wrote the name (hydrogen – 28.2%; chlorine – 27.5%) of an
7 element in the legend and not the name of the particles.
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15 48.2% of the students elaborate their *SMR* using some part of submicroscopic level of
16 chemical concepts: (e.g. »In two molecules of each element are 4 atoms, and so 4 molecules
17 of HCl are formed.« »HCl is composed from 1 atom H and 1 atom Cl.«). It is also important to
18 take into account that 20.8% of students did not write any elaboration. There were other less
19 frequent mistakes, less than 5% of all cases.
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30 *Solution chemistry (SC drawing SMRs)*

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32 7.6% of students otherwise drew the *SMR* correctly (See Problem 6 in Appendix 1), but
33 made some mistake in the legend or vice versa. Only 2.9% of students correctly named the
34 particles in the solution as bromide and potassium ions. Only 0.7% of students correctly solve
35 both parts of the problem (see Chart 1).
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41 The most frequent misconception (46.1% of students) of potassium bromide aqueous
42 solution is that students draw molecules of the solute (Figure 5). Almost half of these students
43 did not consider the different ionic (atomic) radius of the ions (atoms) and drew the solution
44 (Figure 5).
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53 Figure 5: *SMR* illustrating misconceptions of aqueous solution of potassium bromide.
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58 10.7% of students did also not know that the mol ratio between potassium and bromide
59 ions is 1:1, so they attribute usually two bromide ions to one potassium ion.
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3 Only 2.9% of all students correctly named the particles presented in the *SMR* in the
4 legend. Most (28.2%) students wrote the symbol of an element to represent the particle, or
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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).

Independent variables and submicrorepresentations

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3 There were other mistakes which represent less than 5% of all cases and they are not
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5 presented at this point.
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10 Figure 6: *SMR* illustrating misconceptions of an acid aqueous solution drawn by the students
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12 using the *Scheme 1*.
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17 44.1% of students did not elaborate their *SMR*, 35.5% did try to discuss their decision
18 connecting macroscopic and submicroscopic level of chemical concepts, but they show
19 numerous misconceptions, that additionally confirmed misconceptions discovered by drawn
20 *SMRs* (e.g. »There are more hydronium ions in scheme 2, so the acid is stronger«; »There is
21 more acid molecules in the stronger acid.«; »The acid is stronger, because water molecules
22 are smaller.«). It can be concluded from the content analysis of the students' elaborations that
23 24.5% of them tried to illustrate their *SMR* by saying that they had drawn larger number of
24 hydronium ions, lower number of acid molecules or they mentioned higher number of
25 dissociated acid molecules, and 12.3% of students associated the acid strength with its
26 concentration.
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41 Content analysis of selected chemistry *SMRs* reading and drawing problems suggests
42 that different variables may influence students' problem solving achievements, so a more
43 detailed analysis of some selected independent variables (students' gender, reasoning abilities
44 and motivation) was conducted in an attempt to explain these influences.
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54 *Students' gender and achievement scores on CK*
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58 In the present study statistically significant differences in total *CK* score between males
59 and females were proven by an independent-samples t-test. The results show that males' ($M =$
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Independent variables and submicrorepresentations

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3 22.83; SD = 6.50) scores are statistically significantly higher than females' (M = 20.16; SD =
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5 6.24); $t(384) = -4.04, p \leq 0.000$. An independent-samples t-test was also conducted to
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7 compare the success of males (M = 11.45; SD = 3.29) and females (M = 10.29; SD = 3.16) on
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9 items that required reading *SMRs*. Males scored significantly higher than females ($t(384) = -$
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11 3.48, $p \leq 0.000$). Similar results were obtained by comparing students' scores on items that
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13 required drawing *SMRs*. Males (M = 11.38; SD = 3.86) scored significantly higher than
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15 females (M = 9.87; SD = 3.78); $t(384) = -3.80, p \leq 0.000$.
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Students' mental abilities and achievement scores on CK

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27 It can be concluded from the results that 86.3 % of students are formal reasoners, 11.1 %
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29 of students fall into the group of transitional reasoners and even 2.6 % of the students are still
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31 on the concrete level of reasoning. Those students who have better developed formal
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33 reasoning abilities are more successful in solving problems that include drawing ($r = 0.50; p \leq$
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35 0.000) and reading ($r = 0.53; p \leq 0.000$) *SMRs*. On average 28.1 % of students' success in
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37 solving the items that demand reading *SMRs* can be explained by the *TOLT* score. On the other
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39 hand, 25.0 % of students' ability to solve the problems that require drawing *SMRs* can be
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41 explained by students' formal reasoning abilities. The correlation between the overall
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43 successes in solving problems requiring understanding the *ITLS* model shows, that 31.8 % of
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45 students' success on *CK* can be explained by their reasoning abilities ($r = 0.56; p \leq 0.000$). It
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47 can be concluded that students need to have developed higher levels of reasoning abilities to
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49 solve the *CK* items more successfully.
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56 For further analysis, the one-way between-groups analysis of variance was conducted to
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58 explore the influence of formal reasoning abilities on total success in *CK* and in solving tasks
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60 of reading and drawing *SMRs*. Students were divided into three groups according to their

Independent variables and submicrorepresentations

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3 reasoning abilities (Group 1: concrete reasoners, Group 2: transitional reasoners and Group 3:
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5 formal reasoners).
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8 The differences in overall success in *CK* between the three groups of students of
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10 different formal reasoning abilities are statistically significant ($F(2, 383) = 33.39, p \leq 0.000$).
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12 Post hoc comparisons using Tukey HSD showed that there is a statistically significant
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14 difference ($p \leq 0.000$) between the mean scores for Group 1 ($M = 13.43, SD = 5.88$) and
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16 Group 3 ($M = 22.20, SD = 5.99$) and also for Group 2 ($M = 15.38, SD = 5.98$) and Group 3 (p
17
18 ≤ 0.000). There is no statistically significant difference ($p = 0.622$) between the groups of
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20 concrete and transitional reasoners in success in *CK*. There is a statistically significant
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22 difference between groups of students with different reasoning abilities in success at reading
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24 ($F(2, 383) = 29.81, p \leq 0.000$) and drawing ($F(2, 383) = 24.25, p \leq 0.000$) *SMRs*. Post hoc
25
26 comparisons using Tukey HSD indicated that the mean scores for reading *SMRs* between
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28 Group 1 ($M = 6.80, SD = 3.16$) and Group 3 ($M = 11.22, SD = 2.99$) were statistically
29
30 significantly different ($p \leq 0.000$) and also between Group 2 ($M = 8.02, SD = 3.22$) and Group
31
32 3 ($p \leq 0.000$). Group 1 did not differ significantly from Group 2 ($p = 0.485$) regarding reading
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34 *SMRs*. Similar results were obtained by post hoc comparisons using the Tukey HSD test
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36 regarding mean scores for drawing *SMRs*. Group 1 ($M = 6.63, SD = 3.57$) was statistically
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38 significantly different ($p = 0.001$) from Group 3 ($M = 10.98, SD = 3.72$) and also for Group 2
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40 ($M = 7.35, SD = 3.25$) and Group 3 ($p \leq 0.000$). Group 1 did not differ significantly from
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42 Group 2 ($p = 0.839$).
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51 The next two independent variables include students' visualization abilities.
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56 Table 2. Pearsons' correlation coefficients between students' visualization abilities and
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58 success on *CK*.
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Independent variables and submicrorepresentations

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3 Students' visualization abilities are not so highly correlated with *CK* scores as are formal
4 reasoning abilities (*Table 2*). Students' speed of perception is not statistically significant
5 correlated with their success in problem solving regarding reading *SMRs*, on the other hand a
6 very low but statistically significant factor is students' ability for drawing *SMRs* ($r = 0.11$; $p =$
7 0.025). Another students' visualization ability, i.e. spatial relations, is somewhat more highly
8 correlated with drawing *SMRs* ($r = 0.18$; $p = 0.001$) than reading ($r = 0.11$; $p = 0.027$), but the
9 correlation coefficients are still very low, and the connection between students' *CK*
10 achievements and their visualization abilities could be neglected. It can be summarised that
11 only 2.6 % of students' *CK* scores can be explained by spatial relations and even less - only
12 1.4 % - by speed of perception.
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27 The *ANOVA* was conducted to explore the influence of visualization abilities on
28 students' success in solving tasks that include reading and drawing *SMRs*. Students were
29 divided into three groups according to their speed of perception and spatial relations abilities
30 (Group 1: poor speed of perception or spatial relations abilities, Group 2: average speed of
31 perception or spatial relations abilities, and Group 3: superior speed of perception or spatial
32 relations abilities). The differences in total scores on *CK*, and problems that demand reading or
33 drawing *SMRs*, between the three groups of students with different speed of perception
34 abilities are not statistically significant.
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46 On the other hand there are statistically significant differences between the groups of
47 students in spatial relations abilities and their success in solving the tasks on *CK* ($F(2, 382) =$
48 5.91 , $p = 0.003$). Post hoc comparisons using Tukey HSD showed that there is a statistically
49 significant difference ($p = 0.035$) between the mean scores for Group 1 ($M = 19.08$, $SD =$
50 5.85) and Group 2 ($M = 21.31$, $SD = 6.63$) and also between the mean scores for Group 3 (M
51 $= 22.93$, $SD = 5.90$) and Group 1 ($p = 0.002$). There is no statistically significant difference (p
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Independent variables and submicrorepresentations

= 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

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3 motivation for learning chemistry. The even lower percentage of success in solving tasks that
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5 require reading *SMRs* (4.93 % variance) can be explained by intrinsic motivation for learning
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7 chemistry, but on the other hand the most intrinsically motivated students successfully solve
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9 tasks with drawing *SMRs* (10.43 % of variance explained).
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13 Students were divided into three groups according to their level of intrinsic motivation
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15 for learning chemistry (Group 1: poor intrinsically motivated, Group 2: average intrinsically
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17 motivated, and Group 3: superior intrinsically motivated).
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22 Table 3. ANOVA between the three groups of students of different intrinsic motivation for
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24 learning chemistry and their success in *CK*.
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30 It can be concluded from the post hoc analysis using Tamhane (for equal variances not
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32 assumed) that there is a statistically significant difference ($p \leq 0.000$) between the mean scores
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34 on *CK* for poor (Group 1) intrinsically motivated students for learning chemistry ($M = 19.21$,
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36 $SD = 7.11$) and Group 3 – superior intrinsically motivated ($M = 25.61$, $SD = 6.75$) and also
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38 between average – Group 2 ($M = 20.63$, $SD = 5.76$) and superior – Group 3 intrinsically
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40 motivated students ($p \leq 0.000$). There is no statistically significant difference ($p = 0.373$)
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42 between Group 1 and Group 2 in success in solving the tasks on *CK*. The post hoc analysis
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44 using Tamhane (for equal variances not assumed) also showed that there is a statistically
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46 significant difference ($p \leq 0.000$) between the groups of students with different level of
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48 intrinsic motivation and their success in solving the tasks that demand drawing *SMRs* for
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50 Group 1 ($M = 9.17$, $SD = 4.04$) and Group 3 ($M = 13.27$, $SD = 4.40$) and also for Group 2 (M
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52 $= 10.09$, $SD = 3.37$) and Group 3 ($p \leq 0.000$). There is no statistically significant difference (p
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54 $= 0.270$) between students with poor and average score in the intrinsic motivation
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56 questionnaire in success in solving tasks drawing *SMRs*. Post hoc comparisons using the
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Independent variables and submicrorepresentations

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 ($p = 0.009$).

Independent variables and submicrorepresentations

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3 There is no statistically significant difference ($p = 0.724$) between Group 1 and Group 2 in
4 success on *CK*. Because the test of homogeneity of variances for drawing *SMRs* was
5 statistically significant (*Table 4*), the Welch test of equality of means was used. The Welch
6 test showed that the differences between the three groups of students of different intrinsic
7 motivation for learning the macro level of chemical concepts and their success in drawing
8 *SMRs* are statistically significant ($p = 0.006$). It can be concluded from the post hoc analysis
9 using Tamhane (for equal variances not assumed) that there is a statistically significant
10 difference ($p = 0.006$) between the mean scores for Group 1 ($M = 9.77$, $SD = 3.89$) and Group
11 3 ($M = 12.20$, $SD = 4.54$) and also for Group 2 ($M = 10.28$, $SD = 3.63$) and Group 3 ($p =$
12 0.013). There is no statistically significant difference ($p = 0.685$) between Group 1 and Group
13 2 in success at solving the tasks that include drawing of *SMRs*.

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

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

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56 Post hoc comparisons using the Tukey HSD showed that there is a statistically
57 significant difference ($p \leq 0.000$) between the mean scores for Group 1 ($M = 10.15$, $SD =$
58 3.58) and Group 3 ($M = 12.63$, $SD = 3.08$) and also for Group 2 ($M = 10.47$, $SD = 3.06$) and
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Independent variables and submicrorepresentations

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*.

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6 The ANOVA showed (Table 6) that the differences between the three groups of students
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8 of different intrinsic motivation for symbolic level of chemical concepts and their success in
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10 CK is statistically significant ($p \leq 0.000$). Post hoc comparisons using the Tukey HSD showed
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12 that there is a statistically significant difference ($p \leq 0.000$) between the mean total scores on
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14 CK for Group 1 (poor intrinsic motivation) ($M = 19.80$, $SD = 7.00$) and Group 3 (superior
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16 intrinsic motivation) ($M = 25.59$, $SD = 6.58$) and also for Group 2 (average intrinsic
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18 motivation) ($M = 20.60$, $SD = 5.86$) and Group 3 ($p \leq 0.000$). There is no statistically
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20 significant difference ($p = 0.597$) between Group 1 and Group 2 in success on CK. The one-
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22 way analysis of variance showed that the differences between the three groups of students of
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24 different intrinsic motivation for the symbolic level of chemical concepts and their ability in
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26 reading SMRs is also statistically significant ($p \leq 0.000$). Post hoc comparisons using Tukey
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28 HSD showed that there is a statistically significant difference ($p \leq 0.000$) between the mean
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30 scores for Group 1 ($M = 10.35$, $SD = 3.49$) and Group 3 ($M = 12.53$, $SD = 2.96$) and also for
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32 Group 2 ($M = 10.45$, $SD = 3.13$) and Group 3 ($p \leq 0.000$). There is no statistically significant
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34 difference ($p = 0.970$) between students with low level of intrinsic motivation and those with
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36 average motivation in success in reading SMRs. The Welch test showed that the differences
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38 between the three groups of students of different intrinsic motivation for learning the symbolic
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40 level of chemical concepts and their success in problems that include drawing ($p = 0.000$) are
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42 statistically significant. The post hoc analysis using Tamhane (for equal variances not
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44 assumed) shows that there is a statistically significant difference ($p \leq 0.000$) between the mean
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46 scores for Group 1 ($M = 9.45$, $SD = 4.07$) and Group 3 ($M = 13.07$, $SD = 4.27$) and also for
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48 Group 2 ($M = 10.15$, $SD = 3.46$) and Group 3 ($p \leq 0.000$). There is no statistically significant
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50 difference ($p = 0.458$) between Group 1 and Group 2 in success in drawing SMRs.
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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

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3 the connections between the macroscopic and the submicroscopic levels of concepts, because
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5 they attribute the macroscopic name of an element to the substance particle.
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8 It can be recommended that teachers can help students to develop adequate mental
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10 models of chemical reaction also by using *SMR*, where the correct quantity of matter and
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12 correct molecule geometry can be stressed with the support of the legends of the particles
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14 used in *SMRs* with their names. It is also important to suggest that teachers try to encourage
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16 precise reading of the scientific text, because students' success in solving the chemistry
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18 problems is dependent on that. They must not encourage students to learn chemical equations
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20 by heart because it has a negative influence on students' motivation for learning chemistry,
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22 because just memorizing the formulae is meaningless to students. Emphasizing the
23
24 importance of putting the symbolic chemical language into the context and breaking it down
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26 into meaningful parts – not overloading students working memory capacity – has been shown
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28 to be an important aspect of effective chemistry learning also by other researchers (Bunce, &
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30 Gabel, 2002; Chittleborough et al., 2002).
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36 Thirdly, it can be summarised that students had difficulties correctly representing the
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38 ionic substance water solutions in particulate level (Item 6). This shows that the majority of
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40 students after four years of chemical education do not understand what happens with soluble
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42 ionic substances when added into water. Students ought to use their knowledge acquired
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44 during chemistry lessons on a more theoretical level (ionic bonding, solubility, atomic and
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46 ionic radii) on concrete samples. Students' transfers between macroscopic and
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48 submicroscopic level of chemical concepts during problem solving processes are not
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50 satisfactory.
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54 The analysis of the last set of concepts (acids and bases) showed that only slightly more
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56 than half of the students correctly recognise the *SMRs* of acid, base and salt aqueous solutions
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58 (Item 3) but a lot more students had problems representing acidic solution on a
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Independent variables and submicrorepresentations

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3 submicroscopic level, especially when they had to consider more than one variable to solve
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5 the problem (Item 7). It can be concluded that students do not associate the acid strength with
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7 acid dissociation ability, but often with the concentration of acid particles in the aqueous
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9 solution. It is important to emphasize that teachers have to use *SMRs* also to illustrate acid or
10
11 base dissociation and connect this concept with acid or base strength and pH value, because
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13 the most frequent misconception presented by students is that stronger acid has more
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15 molecules of acid in water solution, and they do not connect this concept with the hydronium
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17 or hydroxide and conjugated base or acid ions.
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24 *Research question 2: Do male and female students achieve significantly different scores*
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26 *on problems that include reading and drawing SMRs?*
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30 It can be summarized that female students score significantly lower than male students in
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32 drawing or reading submicrorepresentations while solving particulate problems. Bunce and
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34 Gabel (2002) reported similar findings. They said that females score lower than males on the
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36 pre-test, but after implementing the educational strategies that connect all three levels of
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38 chemical concepts the significant gender score difference would diminish. The results reported
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40 by Barke and Engida (2001) can explain the results found in this research. They anticipated
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42 that girls have lower developed visualization abilities than boys, and they propose that
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44 students should use different models and visualization material very early in the science
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46 education process to stimulate development of visualization abilities. It can be speculated that
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48 visualization abilities can influence motivation, and then hence the science problem solving
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50 achievements by both males and females.
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55 During the educational process teachers should, therefore, pay more attention to female
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57 students' progress in developing adequate mental models of chemical concepts especially at
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59 submicroscopic and symbolic.
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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'

Independent variables and submicrorepresentations

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3 achievements in solving problems on particulate level, it can be concluded that visualization
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5 abilities are not so strongly correlated with chemistry knowledge that refers to 2-D
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7 submicrorepresentations. This is shown by the results, and only a small portion of variance on
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9 the *CK* score can be explained by students' visualization abilities. Further analysis of variance
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11 shows, that differences between students with low and average, and average and superior
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13 visualization abilities are not statistically significant in most cases. It can, for that reason, be
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15 emphasised that students can solve particulate problems even if their visualization abilities are
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17 not so highly developed. However it is important to emphasise that there is no statistically
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19 significant difference between students with different speeds of perception abilities in solving
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21 problems regarding reading or drawing *SMRs*. On the other hand, somewhat bigger
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23 differences can be determined regarding the use of 2-D submicrorepresentations between
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25 students with different levels of spatial relations. The difference is not statistically significant
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27 between students with average and superior spatial relations abilities. The difference between
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29 students with poor and average spatial relations abilities is statistically significant in the total
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31 *CK* score and reading *SMRs* score. However the difference is also significant on all three
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33 levels of *CK* tasks, between students with poor and those with superior spatial relations
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35 abilities. It can be concluded that chemical problems which include just 2-D
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37 submicrorepresentations do not pose great difficulties in solving them, even for those students
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39 with lower visualization abilities.
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48 These conclusions indicate that teachers should be encouraged to use
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50 submicrorepresentations in classrooms for evaluating students' knowledge, without
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52 apprehension that students with lower abilities would be discriminated.
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55 These results confirmed the predictions of Wu and Shah (2003) and Keig and Rubba
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57 (1993) that secondary school students' chemical concepts test scores variance would not be in
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59 a very large percentage accounted for by students' visualization abilities, but by more general
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3 reasoning abilities. Gabel et al. (1987) also reported no significant correlation between
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5 students' visualization abilities and achievements on the chemistry test that comprises items
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7 on submicroscopic level. Higher correlations between visualization abilities of secondary
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9 school students in Slovenia ($r = 0.472$; $p < 0.01$) were registered by Ferik Vrtačnik, Blejec, &
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11 Gril (2003). Similar results were obtained also by Yang et al. (2003). These results may have
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13 their cause in different chemistry conceptual problems (3D model manipulations, computer
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15 animations ...) that were used for evaluating students' knowledge.
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22 *Research question 4: Do students with higher levels of intrinsic motivation score*
23 *significantly higher on problems that include drawing SMRs than on those that include*
24 *reading them?*
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30 It can be concluded from the results that the correlations between *CK* scores, either in
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32 reading, drawing or overall scores and intrinsic motivation for learning chemistry, are the
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34 highest regarding motivation for the submicro level of chemical concepts, and the lowest
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36 regarding macro level. From the ANOVA results it can be summarised that the differences
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38 between the groups of students with different levels of intrinsic motivation is significant
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40 almost in all cases, except for reading *SMRs* and intrinsic motivation for the experimental level
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42 of chemical education. However it is important to emphasise that on all levels of *ITLS* intrinsic
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44 motivation for learning chemistry, the difference between poor and average intrinsically
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46 motivated students is not significant. According to these results, students with higher general
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48 or specific chemical intrinsic motivation achieve higher scores on the chemistry test
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50 comprising reading or drawing submicrorepresentations.
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56 Most students do like chemistry at the macro level, so teachers should take advantage of
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58 this and after experimental work could have the chance to develop intrinsic motivation also for
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60 the submicroscopic and symbolic level of chemical concepts. To achieve this goal, teachers

Independent variables and submicrorepresentations

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3 encounter a difficult task in achieving a sufficient level of external stimulation for students to
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5 become interested in submicro level of chemistry, because students often do not realize the
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7 meaning of these explanations of the phenomena and their symbolic representations. It can be
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9 concluded that the most successful in solving chemistry problems on different levels of the
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11 *ITLS* model would be those students that are highly intrinsically motivated for learning
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13 chemistry at the particulate level.
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17 Similar results of several studies were reported by Tuan et al. (2005), but their research
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19 shows a slightly higher correlation between school science achievement and motivation ($r =$
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21 0.40 ; $p < 0.01$). Previous research (Napier & Riley, 1985) also indicated that motivation has a
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23 moderate but significant correlation with students' science achievement. The results obtained
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25 in this study can confirm Keigs' and Rubbas' (1993) predictions, i.e. that motivation can be a
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27 potential source of variance regarding students' success on the chemical concepts test. On the
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29 other hand, Nieswandt (2007) reports the result of her study, that affective variables (students'
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31 interest and attitudes for chemistry and their chemistry-specific self-concepts) do not have a
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33 statistically significant effect on conceptual understanding, but the results do reveal the
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35 importance of strong and positive self-concept for developing a meaningful understanding of
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37 science concepts.
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44 The overall conclusions indicate that teachers should devote more time to the activities
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46 where students, and especially females, are engaged in drawing submicrorepresentations and
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48 explaining their meaning (e.g using particles names). They should also emphasise the
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50 meaning of correct and accurate reading of the chemistry problem text. Teachers should be
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52 aware that students can develop the understanding of *SMRs* also when their formal reasoning
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54 abilities and/or visualization abilities are not highly developed in relation to their age.
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56 Teachers can collect useful data about students' incomplete comprehension and/or
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58 misunderstandings of chemical concepts by analyzing students' drawing of *SMRs*, and also by
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3 analysing their own classroom instructions and their pedagogical knowledge obtained through
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5 action research; especially if they see the teaching as transfer of knowledge or as a process of
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7 building the students' knowledge (Vogrinc & Valenčič Zuljan, 2009). These conclusions can
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9 influence teachers' realization of the classroom activities and could modify their future
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11 educational strategies implemented in the classroom. It should be emphasised, indicated by
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13 the findings that teachers should, nevertheless, encourage students to learn chemistry at the
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15 particulate level. Such attempts are going to be only external, and for students mostly
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17 unnecessary or even discouraging and highly difficult to understand at the beginning, but with
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19 the progress in understanding of the basic chemical concepts (e.g. atom structure, chemical
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21 bond, etc.) in context, students' interest in understanding chemistry at submicro level will
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23 increase and deeper knowledge with understanding would develop.
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6 and Cognition in the Learning of College Chemistry. *International Journal of Science*
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8 *Education*, 25, 1081-1094.
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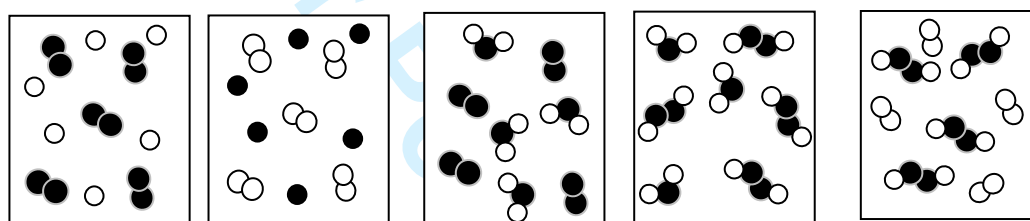
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Appendix 1: Sample items from diagnostic instrument for determining *Chemical Knowledge (CK)*.

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

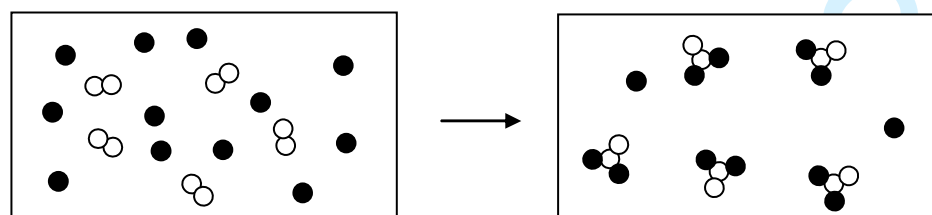
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Chemical reactions (CR reading SMRs)

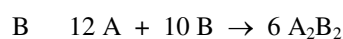
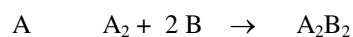
2. The scheme represents the reaction between substance A and B. Which equation correctly represents this reaction?

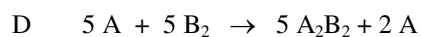
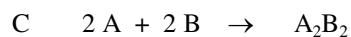


Mixture before the reaction

Mixture after the reaction

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



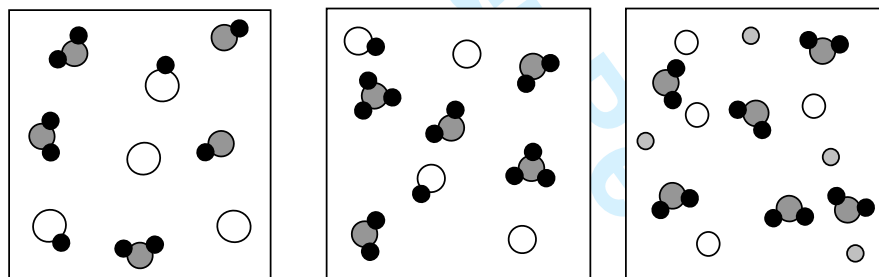


Which substance was completely used during the reaction? _____

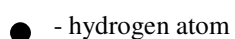
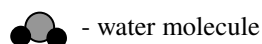
Elaborate the answer: _____

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? _____

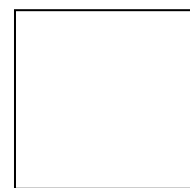
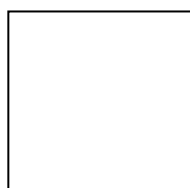
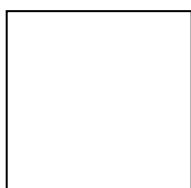
Independent variables and submicrorepresentations

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)

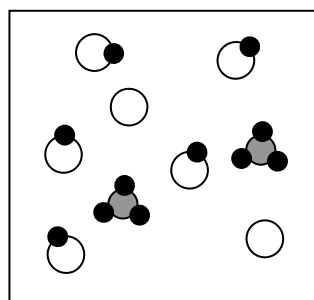
6. Draw a scheme to show the dissolved potassium bromide with optional concentration in water. Use the legend to illustrate the particles which you have used in the scheme. You need not draw water molecules.



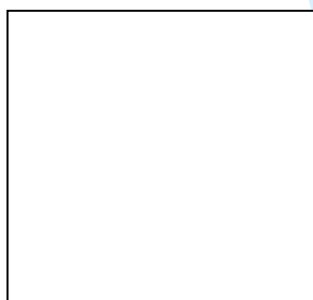
Legend: _____

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.

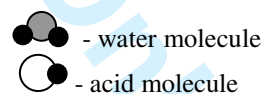


Scheme 1



Scheme 2

Legend:



Elaborate the answer: _____

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3 **Appendix 2: Sample items from the questionnaire Intrinsic Motivation for Learning**
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5 **Science (IMLS)**
6
7

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9
10 1. Emotional component of interest:
11

12
13
14
15 *I enjoy learning.*
16

17
18
19 *I am often bored during:*
20

21
22 ...chemistry course.
23

24 ... biology course.
25

26 ...physics course.
27

28 ... foreign language course.
29

30 ... mathematics course.
31
32
33

34
35
36 *I enjoy the chemistry course when:*
37

38 ...we observe chemical changes in experiments.
39

40 ...we learn about particles (atoms, ions, molecules).
41

42 ...we learn and write chemical symbols, formulae and equations.
43
44
45
46
47

48 2. Cognitive component of interest:
49

50
51
52
53 *I often look for additional information about school science topics in books, magazines, in the*
54
55 *internet, CDs ...*
56

57
58
59
60 *The media attract my attention when reporting on:*

1
2
3 ...chemistry topics.

4
5 ...biology topics.

6
7 ...physics topics.

8
9 ...foreign language topics.

10
11 ...mathematics topics.

12
13
14
15
16
17
18 *I often think about:*

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

20
21 ... particles (atoms, ions, molecules), *also out of school.*

22
23 ...learning and writing chemical symbols, formulae and equations, *also out of school.*

24
25
26
27
28
29 3. Challenge component of internal motivation:

30
31
32
33
34 *I persevere with learning.*

35
36
37
38 *New problems in:*

39 ... chemistry, *challenge me.*

40
41 ...biology, *challenge me.*

42
43 ...physics, *challenge me.*

44
45 ...foreign language, *challenge me.*

46
47 ...mathematics, *challenge me.*

48
49
50
51
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53
54
55 *If I do not understand something, connected with:*

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

57
58 ...learning about particles (atoms, ions, molecules), *I give up.*

Independent variables and submicrorepresentations

1
2
3 ...learning and writing chemical symbols, formulae and equations, *I give up*.
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Independent variables and submicrorepresentations

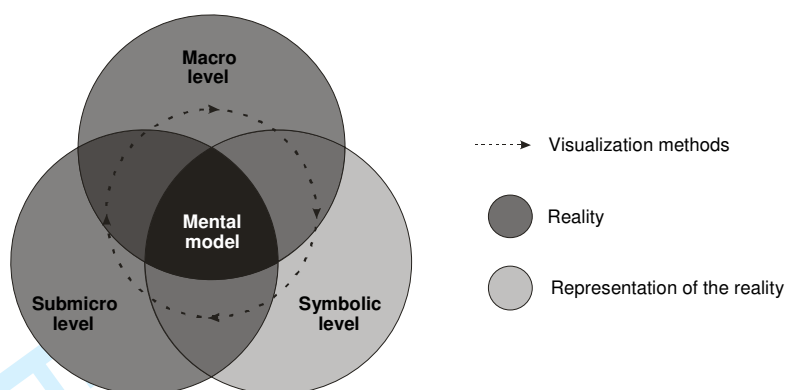


Figure 1: Model representing Interdependence of Three Levels of Science concepts representations – ITLS model (Author).

Independent variables and submicrorepresentations

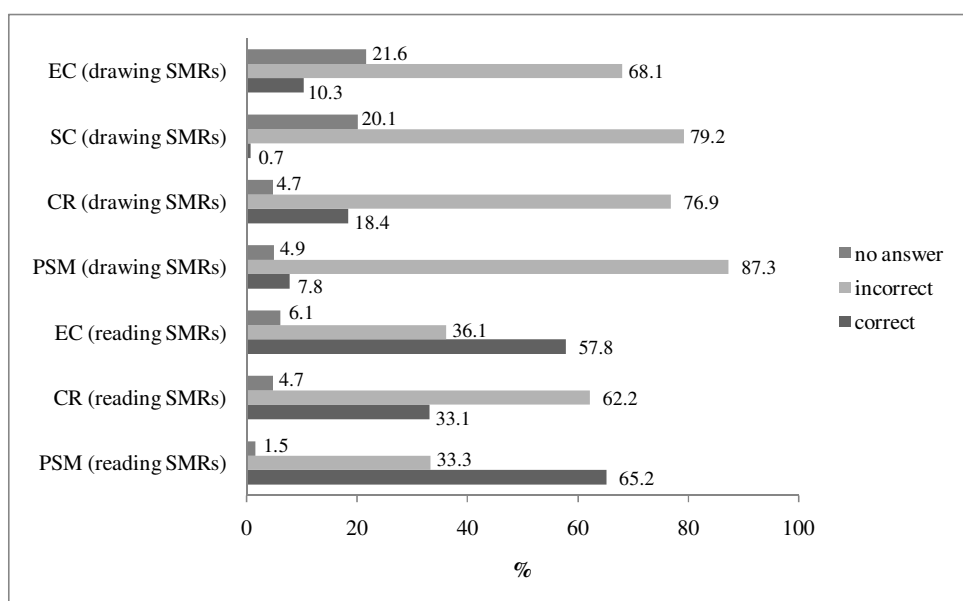


Chart 1. Students' achievements at sample chemistry problems (PSM – Pure substances and mixtures; CR – Chemical reactions; EC – Electrolyte chemistry; and SC – Solution chemistry).

Independent variables and submicrorepresentations

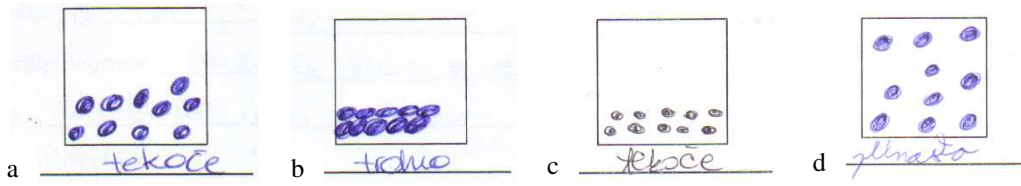


Figure 2. Incorrectly presented all three states of water; original students' drawing, written on a line means: a liquid; b solid; c liquid and d gas.

Independent variables and submicrorepresentations

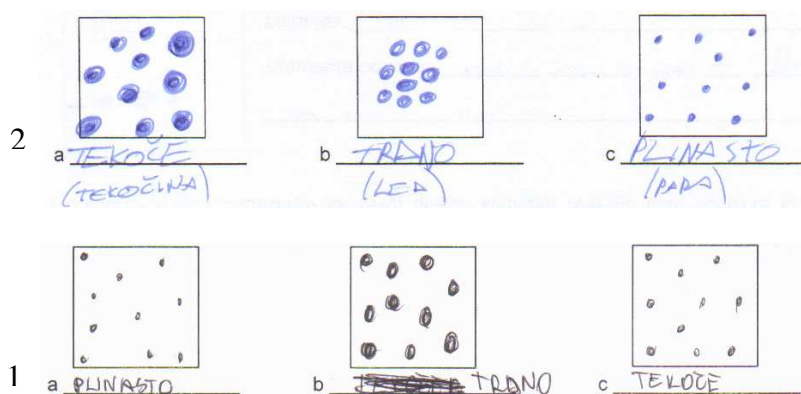


Figure 3. SMRs of different states of water presenting different sizes of molecules and their organisation in a specific state of water; original students' drawing, written on a line means: 1 - a gas; b solid; c liquid and 2 - a liquid; b solid; c gas).

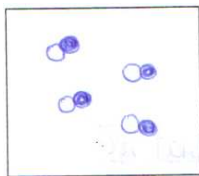


Figure 4. The same size of hydrogen and chlorine atoms in the molecule of hydrogen chloride.

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Independent variables and submicrorepresentations



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

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Independent variables and submicrorepresentations

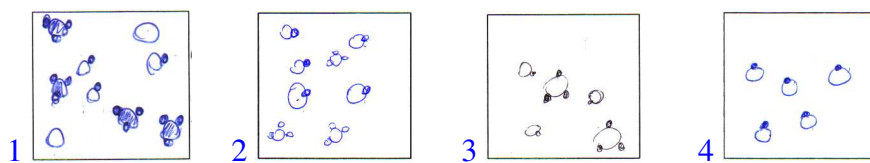


Figure 6: SMR illustrating misconceptions of an acid aqueous solution.

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Independent variables and submicrorepresentations

Table 1. Descriptive statistics for CK.

	Minimum points	Maximum points possible	Students' maximum points	Average points	SD	Kurtosis	Skewness
Total CK score	1	43.5	40.25	21.21	6.47	0.036	-0.089
Reading of <i>SMRs</i> CK score	0	19.0	16.0	10.75	3.25	-0.233	-0.421
Drawing of <i>SMRs</i> 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 <i>CK</i> score	0.117	0.021	0.162	0.001
Reading of <i>SMRs CK</i> score	0.097	0.058	0.113	0.027
Drawing of <i>SMRs CK</i> score	0.114	0.025	0.176	0.001

Independent variables and submicrorepresentations

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 <i>CK</i> score *	2, 107.07	17.05	≤ 0.000
Reading of <i>SMRs CK</i> score	2, 383	9.99	≤ 0.000
Drawing of <i>SMRs CK</i> 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

Independent variables and submicrorepresentations

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 <i>CS</i> score	2, 383	5.28	0.005
Reading of <i>SMRs CS</i> score	2, 383	1.90	0.151
Drawing of <i>SMRs CS</i> 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

Independent variables and submicrorepresentations

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 <i>CS</i> score *	2, 107.40	19.92	0.000
Reading of <i>SMRs CS</i> score	2, 383	12.92	0.000
Drawing of <i>SMRs CS</i> 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.

Independent variables and submicrorepresentations

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 <i>CK</i> score	2, 383	17.85	0.000
Reading of <i>SMRs CK</i> score	2, 383	10.94	0.000
Drawing of <i>SMRs CK</i> 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.

Independent variables and submicrorepresentations

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3 **THE INFLUENCE OF 16-YEAR-OLD STUDENTS' GENDER, MENTAL ABILITIES,**
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6 **AND MOTIVATION ON THEIR READING AND DRAWING**
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8 **SUBMICROREPRESENTATIONS ACHIEVEMENTS**
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12 **Abstract:** Submicrorepresentations are a powerful tool for identifying misconceptions of
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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 & Waldrup, 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. Waldrup, 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

Independent variables and submicrorepresentations

1
2
3 meaningful learning and Johnstone's model of information processing, cognitive theory of
4
5 multimedia learning and Mayer's theory of effective illustrations (see for more details Author;
6
7 Author).

8
9
10 To illustrate chemical concepts on the level of particles, submicrorepresentations (*SMR*)
11
12 can be used and can be presented as static or dynamic modes of representations. Research
13
14 shows (Bunce & Gabel, 2002; Tien, Teichert, & Rickey, 2007; Kelly & Jones, 2008) that
15
16 those students who were exposed to *SMRs* during the educational process more adequately
17
18 understand the nature of the particle interactions compared to those who learned the same
19
20 concepts only by textbooks reading. Studies in the last two decades (Williamson & Abraham,
21
22 1995; Johnson, 1998; Chittleborough, Treagust, & Mocerino, 2002; Solsona, Izquierdo, &
23
24 DeJong, 2003; Papageorgioua & Johnson, 2005; Stains & Talanquer, 2007a; Tien et al, 2007;
25
26 Kelly & Jones, 2008; Author) also show that students have many difficulties in understanding
27
28 the submicro and symbolic levels of chemical concepts, and that previous knowledge of a
29
30 specific topic has an influence on integrating new science concepts into students' mental
31
32 structure. It is also important to emphasise that a lot of different factors influence students'
33
34 achievement on different pictorial test questions (Halakova & Prokša, 2007; Sanger & Phelps,
35
36 2007; Stains & Talanquer, 2008) and that the students' knowledge evaluation part of the
37
38 educational process needs further study. Research also shows that teachers use mostly the
39
40 symbolic level of chemical concepts to teach chemistry (Williamson & Abraham, 1995;
41
42 Chittleborough et al., 2002). It is important to introduce different visualization abilities to
43
44 illustrate abstract science concepts to the students at the beginning of science education - age
45
46 10 or 11 (Longden, Black, & Solomon, 1991) - thus also the application of
47
48 submicrorepresentations (Papageorgioua & Johnson, 2005).
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Independent variables and submicrorepresentations

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3 For the purpose of this paper some independent variables such as mental abilities (i.e.
4 formal reasoning and visualization abilities) and intrinsic motivation were selected because,
5 according to the research literature, these variables influence chemistry learning.
6
7

8
9
10 Piaget defined four stages of individuals' cognitive reasoning development:
11 sensorimotor (from birth to about age 2), preoperational (begins about the time the child starts
12 to talk to about age 7), concrete (about first grade to early adolescence) and formal operations
13 (adolescence). Five modes of reasoning (i.e., controlling variables, proportional, correlational,
14 probabilistic, and combinatorial reasoning) were defined and according to those modes
15 subjects can be differentiated into three groups: concrete reasoners, transitional reasoners and
16 formal reasoners (Tobin & Capie, 1981).
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27 Thiele and Treagust (1994) report that students who cannot visualise chemical
28 phenomena and/or do not have properly developed formal reasoning abilities cannot properly
29 understand chemical concepts; thus those concepts are hard to understand, unattractive and
30 pointless for them. According to some research results (Wu & Shah, 2003) the significant
31 correlation between spatial ability and chemistry problem solving skills is based on general
32 reasoning abilities or intelligence rather than on visuospatial thinking. Valanides (1996)
33 reported that students aged 12 to 14 years show relatively low developed formal reasoning
34 abilities. 64.6 % of these students show concrete operational abilities. The difference in their
35 levels of formal reasoning abilities is not statistically significant. Similar results were obtained
36 by Shemesh, Eckstein, & Lazarowitz, (1992). Statistically significant correlations were proven
37 between formal reasoning abilities and students' chemical knowledge especially on submicro
38 level (Haidar & Abraham, 1991; Williamson & Abraham, 1995)
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55 It is important to emphasize that Yang, Andre, & Greenbowe (2003) concluded that
56 students with low levels of visualization abilities show greater difficulties in understanding
57 computer animations of chemical phenomena on particulate level. Research (Barke & Engida,
58
59
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Independent variables and submicrorepresentations

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

1
2
3 the research on science learning, also concluded that higher results in science are related to the
4
5 learner's active engagement in learning tasks, to his/her positive attitude towards the subject
6
7 and to a highly positive self-concept in science, which all imply the learner's intrinsic
8
9 motivation to learn. This is especially important, since many writers (Anderman & Young,
10
11 1994; Zusho, Pintrich, & Coppola, 2003) report that the decrease in intrinsic motivation with
12
13 years of schooling is particularly noticeable in mathematics and science and is at its peak in
14
15 the period of early adolescence.
16
17

18
19
20 Keig and Rubba (1993) pointed out that motivation can be a potential source of variance
21
22 on students' chemistry knowledge achievements. These claims were confirmed by Tuan et al.
23
24 (2005). They reported that from 7 to 16% of variance on the science knowledge test could be
25
26 explained by students' motivation. But on the other hand Nieswandt (2007) reported no
27
28 statistically significant effect of students' affective variables (situational interest, attitudes
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30 towards chemistry and students chemistry-specific self-concept) on their understanding of
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32 grade 9 (age 15 to 16) chemistry concepts.
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36 Chittleborough et al. (2002), according to their qualitative research, reported that
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38 students are not motivated for learning chemistry more than is necessary for passing the exam.
39
40 Students' motivation for learning science and chemistry for that matter can be stimulated by
41
42 using different visualization elements and analogies because this element of the lessons
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44 increases students' attention (Theile & Treagust, 1994) and also by different experimental
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46 work supported by ICT (Šorgo & Kocijančič, 2006).
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50 Research (Anderman & Young, 1994; Meece & Jones, 1996) also shows that gender
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52 differences in motivation for science learning are connected with achievements on the
53
54 standardized test of science knowledge. It was also established that girls show lower interest in
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56 science, that science is boring for them, especially because they just have to learn everything
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58 by heart. Results also show that girls possess lower levels of self-confidence in demonstrating
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Independent variables and submicrorepresentations

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3 their science knowledge (Simpson & Oliver, 1990). On the other hand, Meece and Jones
4
5 (1996) did not confirm these results; they established that there is no difference between girls
6
7 and boys regarding the interest in learning science and they also pointed out that gender
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9 influence on motivation and in its effect on the manifestation of science knowledge are more
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11 complex processes than other researchers try to show.
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17 Purpose and research questions

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20 According to the literature review the study of some independent variables that can
21
22 influence chemistry learning was conducted. In this research the *SMRs* were used as a way for
23
24 gathering students' chemical knowledge on the higher cognitive level.
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26 Submicrorepresentations were defined as tools for determining students' understanding of
27
28 chemical concepts, and could be used mostly in two different ways. Firstly, students could
29
30 read them and then use the information given by the specific *SMR* for solving the problem
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32 (reading *SMRs*), and secondly they could use the submicrorepresentations for presenting the
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34 solution of the science problem (drawing *SMRs*).
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39 Regarding the purpose of this study four research questions can be addressed: (1) Are
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41 students' achievement scores significantly higher on problems that include reading *SMRs* than
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43 on those that include drawing them?, (2) Do male and female students achieve significantly
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45 different scores on problems that include reading and drawing *SMRs*?, (3) Do students with
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47 higher mental abilities (i.e. formal reasoning and visualization abilities) achieve significantly
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49 higher scores on problems that include drawing *SMRs* than on those that include reading
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51 them?, and (4) Do students with higher levels of intrinsic motivation score significantly higher
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53 on problems that include drawing *SMRs* than on those that include reading them?
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60 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

Independent variables and submicrorepresentations

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2
3 100,000 residents) and three in smaller towns (between 35,000 and 100,000 residents). The
4
5 sample represented a predominantly urban population with mixed socioeconomic status.
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7 Parents' basic educational background was diverse (3.1 % finished primary school; 45.1 %
8
9 finished secondary school; 43.0 % finished university and 7.3 % finished other formal
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11 education) but only 11.6 % of parents had finished some kind of science or technology
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13 education.
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Instruments

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25 Students' abilities to read and draw the *SMRs* were measured using the diagnostic
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27 instrument for determining *Chemical Knowledge (CK)*. The instrument comprises 19 items.
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29 Eight items required reading and eleven items drawing *SMRs* in solving the chemistry
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31 problems considering the *ITLS* model. The *CK* includes four different contents: pure
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33 substances and mixtures (4 items), chemical reactions (6 items), water solutions (4 items) and
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35 electrolyte chemistry (5 items). The *CK* showed satisfactory measuring characteristics (i.e.
36
37 internal consistency reliability - Cronbach's alpha was 0.80; discriminate indexes for every
38
39 item between 0.21 and 0.80 were all statistically significant). Kurtosis and skewness
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41 coefficients show normally distributed data (see Table 1). Students had 60 minutes to solve
42
43 the *CK*. One sample item of each content of *CK* is introduced in Appendix 1.
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48
49 To determine other independent variables, four different tests and a questionnaire were
50
51 administered to the students: Test of Logical Thinking (*TOLT*), Rotations (*RO*), Patterns (*PA*),
52
53 and Intrinsic Motivation for Learning Science questionnaire (*IMLS*).
54

55
56 The level of students' formal reasoning abilities was obtained with the *Test of Logical*
57
58 *Thinking (TOLT)* (Tobin & Capie, 1981). The *TOLT* is a ten-item group paper-pencil test. The
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60 authors of the test reported a strong correlation ($r = 0.82$; $p < 0.0001$) between performance on

Independent variables and submicrorepresentations

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3 tasks during Piagetian clinical interviews that are considered a traditionally preferable method
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5 in measuring individuals' formal reasoning abilities and the results on *TOLT*. The *TOLT* has
6
7 high internal consistency reliability (Cronbach's alpha was 0.85). The test consists of two
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9 items designed to measure each of the five modes of reasoning (i.e., controlling variables,
10
11 proportional, correlational, probabilistic, and combinatorial reasoning). The test scores from 0-
12
13 1 points (concrete reasoners), 2-3 points (transitional reasoners) and 4-10 points (formal
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15 reasoners) were used as a basis for classifying the students. Students had 38 minutes to solve
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17 the test.
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22 The students' visualization abilities were measured with two tests: *Patterns (PA)* and
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24 *Rotations (RO)* (Pogačnik, 1998; 2000). The *PA* measures students' speed of perception and
25
26 the *RO* measures students' spatial relations abilities. Both tests were developed based on the
27
28 Cattell-Horn theory of mental abilities. The *PA* is a 36 item group paper-pencil test. It requires
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30 individuals to find and mark exactly the same pattern among the four similar patterns on the
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32 right side of the paper to the one on the left part of the paper as quickly as possible. The *PA*
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34 has high internal consistency (Cronbach's alpha was 0.86). Correlations between some other
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36 instruments for determining individuals' perception abilities (*BTI-Or*; *BTI-Pr*, *Beta 6* and *4*)
37
38 determine that the instruments' validity was higher and statistically significant. Students had
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40 4.5 minutes to solve the test. The *RO* is a 90 item group paper-pencil test. The *RO* requires
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42 individuals to find and encircle those patterns on the right side of the paper that are just rotated
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44 in comparison with the left pattern. Individuals have to cross those patterns that are not just
45
46 rotated in the plane but represent a different pattern. Cronbach's alpha for the *RO* was 0.94.
47
48 Correlations between some other instruments for determining individuals' perception abilities
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50 (*BTI-Pr*, *Beta 4*) were also high and statistically significant. Students had 6 minutes to solve
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52 the test. The classifications of students into three groups with regard to their visualization
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54 abilities were performed according to the statistical equations. Into Group 1 (poor visualization
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Independent variables and submicrorepresentations

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3 abilities) were classified students that scored less than $M - 1SD$ points, into Group 2 (average
4 visualization abilities) those that scored between $M - 1SD$ and $M + 1SD$ points, and into
5
6 Group 3 (superior visualization abilities) students that scored above $M + 1SD$ points on the *PA*
7
8 and *RO*.
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10

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12 The last independent variable, the intrinsic motivation for learning chemistry was
13 measured by the *IMLS* questionnaire. There are many questionnaires to measure students'
14 attitudes or interests in science and/or chemistry (e.g. Moore & Foy, 1997; Tuan et. al., 2005;
15 Coll et al., 2002; Nieswandt, 2007). All these instruments show a rather general structure of
16 students' attitudes towards science, but they lack the dimension with reference to the *ITLS*
17 model and separately for different science school subjects. These questionnaires do not show
18 enough specific characteristics regarding the research questions asked in this study and would
19 need extensive revision for adapting the instrument to secondary level. For those reasons the
20 new instrument for measuring intrinsic motivation, 125-item *IMLS (Intrinsic Motivation for*
21 *Learning Science* questionnaire, was developed (Authors). The response to each item is on a
22 five-point Likert-type scale ranging from 1 as strongly disagree to 5 as strongly agree. The
23 internal consistency (Cronbach α) of *IMLS* was 0.78. Students had 20 minutes to complete the
24 questionnaire. The classifications of students into three groups with regard to their intrinsic
25 motivation for learning chemistry were performed according to the statistics. Into Group 1
26 (poor intrinsically motivated) were classified students that scored less than $M - 1SD$ points,
27 into Group 2 (average intrinsically motivated) those that scored between $M - 1SD$ and $M +$
28 $1SD$ points, and into Group 3 (superior intrinsically motivated) students that scored above $M +$
29 $1SD$ points on the *IMLS*. Three sample items of each component of intrinsic motivation from
30 the *IMLS* questionnaire are included in Appendix 2.
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Research design

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6 The research was a non-experimental, cross-sectional and descriptive study (Bryman,
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8 2004).

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10 The students had received no special teaching about using *SMRs* in the chemistry
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12 classroom. The chemical concepts comprised in the *CK* were not instructed using *SMRs* by
13
14 the teachers that taught the students participating in the study.

15
16
17 *CK* and *IMLS* were designed specifically for this study. The *CK* was administered to two
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19 university chemistry and chemical education professors. Their responses provided
20
21 scientifically correct answers and content validation for the instrument. The *IMLS* was
22
23 distributed to two experts in science education and one in educational psychology. Their
24
25 evaluation of the instrument confirmed that the *IMLS* measures students' intrinsic motivation
26
27 for learning and their analysis provided validation for the questionnaire. The Slovene
28
29 translation of the *TOLT* was used for the study. The test was separately translated into the
30
31 Slovene language by one expert in chemistry and one expert in physics education. The
32
33 translations were compared and possible modifications were made in preparing the third
34
35 version of the test. The third expert translated the test back into English. The original and the
36
37 translated version of the English test were compared and possible modifications were made in
38
39 designing the final Slovene version of the *TOLT*. Four independent experts in chemistry,
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41 physics and mathematics education finally reviewed the test, and their responses provided
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43 content validation of the instrument.

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

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3 All instruments were applied on the research sample at the end of the second school
4 year 2005/06 of the secondary school. The testing took students about 135 minutes on two
5 separate days. Students solved the *IMLS* and *CK* in the first week and in the second one they
6 solved the *TOLT*, *RO* and *VZ*. The last testing was conducted by a trained psychologist. All
7 instruments were applied in a group and under normal examination conditions.
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15 Descriptive statistics were obtained for illustrating the *CK* characteristics. For
16 determining differences in the means of *CK*, the paired-sample t-test was used. Pearsons'
17 correlation coefficients for determining the correlation between knowledge of chemical
18 concepts and other independent variables were calculated. The percentage of variance two
19 variables share is referred to as the coefficient of determination. The coefficient of
20 determination is calculated by square the correlation coefficient (r^2) value and then converted
21 into percentage of variance by multiplying it by 100 (Pallant, 2005). In other words, the
22 square of correlation coefficient (r^2) is the fraction of the variation in the values of
23 independent variable that is explained by the least-squares regression of independent on
24 dependent variable (Moore & McCabe, 1997).
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39 In addition, the one-way between-groups analysis of variance (*ANOVA*) was conducted
40 to explore the influence of reasoning abilities, visualization abilities and intrinsic motivation
41 for learning chemistry on students' success in solving *CK* tasks. If the test of homogeneity of
42 variances was statistically significant when comparing the means of the groups of students,
43 the more robust test (Welch test) of equality of means was used.
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51 The 5% cut off was used in presenting the most frequent misconceptions detected by
52 analysing the students' sample problem solving achievements. The decision was made
53 according to the statistical significance of results. It tells us something about the degree to
54 which the result is "true" in the sense of being "representative of the population": 5% is
55 customarily treated as a "border-line acceptable" error level (Moore & McCabe, 1997).
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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)

Independent variables and submicrorepresentations

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

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3 reaction is written as a product into the chemical equation. 32 % of students wrote in
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5 elaborating their answer, that substance B was completely used in the reaction, and 24 %
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7 wrote vice versa, that substance A remains after the reaction. 7.4% of students did not
8
9 elaborate their answer adequately. 22.5% of students elaborate their answer at the
10
11 submicroscopic level (e.g. »All atoms (A) were used in the reaction.«) but almost 44% of the
12
13 students elaborated their answer on the macroscopic level (e.g. »Substance A didn't
14
15 completely react.»; »There is still substance A after the reaction.«; »Remains only substance
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17 A.«; »At the end there is no substance B only A.«). It is also interesting to note out that 19.9%
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19 of students did not elaborate their answer. There were other mistakes which were less frequent
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21 (less than 5% cases).
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28 *Electrolyte chemistry (EC reading SMRs)*

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31 57.8% of students correctly assigned all three SMRs to the aqueous solution of base,
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33 acid and soluble salt in Problem 3 (See Appendix 1). 6.1% of students did not solve the
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35 problem and 33.1 % of them incorrectly assigned one or more SMRs to the correct aqueous
36
37 solution. These students tried to answer the question by guessing the right answer so they
38
39 didn't understand the submicroscopic properties of electrolyte. Other mistakes represent less
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41 than 5% of all cases.
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48 *Pure substances and mixtures (PSM drawing SMRs)*

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50 87.3% of students didn't draw the correct SMRs of all three states of water (Chart 1) in
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52 Problem 4 (See Appendix 1). Only 7.8% of students drew the SMRs similar to those presented
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54 in Figure 1.
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Independent variables and submicrorepresentations

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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)

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3 Only 18.4% of students correctly presented the chemical reaction between chlorine and
4 hydrogen molecules on submicroscopic level (See Chart 1). The Problem 5 (See Appendix 1)
5 was three-parted. In the first part students had to write the *SMR* (18.4 % correct drawings and
6 75.2 incorrect), in the second part they had to present the drawn particles in a legend with
7 their nemeses or formulas (39.1% sufficient legends and 55.3% with some sort of
8 incorrectness) and in the third part students had to elaborate their solution of the problem.
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17 34.3% of students did not take into account the different size of chlorine and hydrogen
18 atoms and they just drew the *SMR* as shown in Figure 4.
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24 *Figure 4.* The same size of hydrogen and chlorine atoms in the molecule of hydrogen
25 chloride.
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32 38% of students did not consider the correct number of product molecules according to
33 the problem text, so they illustrated only two molecules of hydrogen chloride.
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37 Analysis of the legend shows, that 27.2% of students who correctly presented the legend
38 used symbols of elements to illustrate the drawn particles, but in only 2.7% of cases students
39 used a correct name of the particle (e.g. hydrogen atom and chlorine atom). In average more
40 than 27% (hydrogen – 28.2%; chlorine – 27.5%) of students just wrote the name of an
41 element in the legend and not the name of the particles.
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48 48.2% of the students elaborate their *SMR* using some part of submicroscopic level of
49 chemical concepts; this means that they try to incorporate the particulate description into their
50 elaboration (e.g. »1 atom Cl and 1 atom H is needed for HCl«; »One atom H is bonded with
51 one atom Cl; in two molecules of each element are 4 atoms, and so 4 molecules of HCl are
52 formed.« »HCl is composed from 1atom H and 1 atom Cl.«). It is also important to take into
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3 account that 20.8% of students did not write any elaboration. There were other less frequent
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5 mistakes, less than 5% of all cases.
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10 11 *Solution chemistry (SC drawing SMRs)*

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13 Students had a lot of problems drawing the correct *SMR* of aqueous solution of
14 potassium bromide and presented the drawn particles in the legend while solving problem 6
15 (See Appendix 1). 7.6% of students otherwise drew the *SMR* correctly, but made the same
16 mistake in the legend or vice versa, because only 2.9% of students correctly named the
17 particles in the solution as bromide and potassium ions. Only 0.7% of students correctly solve
18 both parts of the problem, and more than 20 % did not even attempt to solve it (see Chart 1).
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27 The most frequent misconception (46.1% of students) of potassium bromide aqueous
28 solution is that students draw molecules of the solute. Almost half of these students did not
29 consider the different ionic (atomic) radius of the ions (atoms) and drew the solution as shown
30 on Figure 5.
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39 *Figure 5: SMR illustrating misconceptions of aqueous solution of potassium bromide (i.e.*
40 *represented molecules of potassium bromide and also not taking into account that potassium*
41 *and bromide particles differ in their radii).*
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50 10.7% of students did also not know that is the mol ration between potassium and
51 bromide ions 1:1, so they attribute usually two bromide ions to one potassium ion.
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53 Only 2.9% of all students correctly named the particles presented in the *SMR* in the
54 legend. Most (28.2%) students wrote the symbol of an element to represent the particle, which
55 was not requested by the problem. 13.5% of students also wrote the names of both elements
56 and not names of the ions.
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3 There were other mistakes which represent less than 5% of all cases. For more detailed
4 analysis see Authors (...). But the overall conclusion is that a majority of students were
5 unable to correctly represent the aqueous solution of an ionic substance on a submicroscopic
6 level.
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15 *Electrolyte chemistry (EC drawing SMRs)*

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17 A lot of students participating in the study also had problems drawing the
18 submicrorepresentation of the aqueous solution of the stronger acid as was represented by the
19 given *SMR*, but with the same concentration. For the correct solution to Problem 7 (See
20 Appendix 1) students should take into consideration five variables (i.e. represented the same
21 acid concentration; higher number of hydronium ions and conjugated base ions like on the
22 given *SMR* but the number of each should be the same; and the complete dissociation should
23 be represented). The analysis of their *SMRs* shows, that 35.3% of students represent the same
24 number of acid molecules as on given *SMR*. 34.1% of them associate the acid strength with
25 the concentration of acid molecules in the aqueous solution and 25.7% of them with the level
26 of dissociation. The same number of hydronium ions and conjugated base ions was given only
27 by 21.6% of the students. All variables were considered in the process of problem solving
28 only by 10.3% of the students and 21.6% did not even attempt to draw the *SMR*.
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45 The most frequent mistake (30.6%) was that students represented lower concentrations
46 of the strongest acid. 20.8% of the students did not draw the hydronium and conjugated base
47 ions, and 12.5% of the students represented also the water molecules (the problem text
48 specifically addressed that this was not requested). Other misconceptions are: (1) the same
49 number of conjugate base ions as on *Scheme 1* (11.8%) (Figure 6.1); (2) lower concentration
50 of an acid as on *Scheme 1* (11.5%) (Figure 6.1-6.4); (3) no conjugated base ions in the
51 drawing, only hydronium ions (10.5%) (Figure 6.2-6.3); (4) the same number of hydronium
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Independent variables and submicrorepresentations

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' ($M = 20.16$; $SD = 6.24$); $t(384) = -4.04$, $p \leq 0.000$. 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

Independent variables and submicrorepresentations

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3 hand, 25.0 % of students' ability to solve the problems that require drawing *SMRs* can be
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5 explained by students' formal reasoning abilities. The correlation between the overall
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7 successes in solving problems requiring understanding the *ITLS* model shows, that 31.8 % of
8
9 students' success on *CK* can be explained by their reasoning abilities ($r = 0.56$; $p \leq 0.000$). It
10
11 can be concluded that students need to have developed higher levels of reasoning abilities to
12
13 solve the *CK* items more successfully.
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17 For further analysis, the one-way between-groups analysis of variance was conducted to
18
19 explore the influence of formal reasoning abilities on total success in *CK* and in solving tasks
20
21 of reading and drawing *SMRs*. Students were divided into three groups according to their
22
23 reasoning abilities (Group 1: concrete reasoners, Group 2: transitional reasoners and Group 3:
24
25 formal reasoners).
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29 The differences in overall success in *CK* between the three groups of students of
30
31 different formal reasoning abilities are statistically significant ($F(2, 383) = 33.39$, $p \leq 0.000$).
32
33 Post hoc comparisons using Tukey HSD showed that there is a statistically significant
34
35 difference ($p \leq 0.000$) between the mean scores for Group 1 ($M = 13.43$, $SD = 5.88$) and
36
37 Group 3 ($M = 22.20$, $SD = 5.99$) and also for Group 2 ($M = 15.38$, $SD = 5.98$) and Group 3 (p
38
39 ≤ 0.000). There is no statistically significant difference ($p = 0.622$) between the groups of
40
41 concrete and transitional reasoners in success in *CK*. There is a statistically significant
42
43 difference between groups of students with different reasoning abilities in success at reading
44
45 ($F(2, 383) = 29.81$, $p \leq 0.000$) and drawing ($F(2, 383) = 24.25$, $p \leq 0.000$) *SMRs*. Post hoc
46
47 comparisons using Tukey HSD indicated that the mean scores for reading *SMRs* between
48
49 Group 1 ($M = 6.80$, $SD = 3.16$) and Group 3 ($M = 11.22$, $SD = 2.99$) were statistically
50
51 significantly different ($p \leq 0.000$) and also between Group 2 ($M = 8.02$, $SD = 3.22$) and Group
52
53 3 ($p \leq 0.000$). Group 1 did not differ significantly from Group 2 ($p = 0.485$) regarding reading
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55 *SMRs*. Similar results were obtained by post hoc comparisons using the Tukey HSD test
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Independent variables and submicrorepresentations

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3 regarding mean scores for drawing *SMRs*. Group 1 ($M = 6.63$, $SD = 3.57$) was statistically
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5 significantly different ($p = 0.001$) from Group 3 ($M = 10.98$, $SD = 3.72$) and also for Group 2
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7 ($M = 7.35$, $SD = 3.25$) and Group 3 ($p \leq 0.000$). Group 1 did not differ significantly from
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9 Group 2 ($p = 0.839$).
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12 The next two independent variables include students' visualization abilities.
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17 Table 2. Pearsons' correlation coefficients between students' visualization abilities and
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19 success on CK.
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24 Students' visualization abilities are not so highly correlated with *CK* scores as are formal
25
26 reasoning abilities (Table 2). Students' speed of perception is not statistically significant
27
28 correlated with their success in problem solving regarding reading *SMRs*, on the other hand a
29
30 very low but statistically significant factor is students' ability for drawing *SMRs* ($r = 0.11$; $p =$
31
32 0.025). Another students' visualization ability, i.e. spatial relations, is somewhat more highly
33
34 correlated with drawing *SMRs* ($r = 0.18$; $p = 0.001$) than reading ($r = 0.11$; $p = 0.027$), but the
35
36 correlation coefficients are still very low, and the connection between students' *CK*
37
38 achievements and their visualization abilities could be neglected. It can be summarised that
39
40 only 2.6 % of students' *CK* scores can be explained by spatial relations and even less - only
41
42 1.4 % - by speed of perception.
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48 The *ANOVA* was conducted to explore the influence of visualization abilities on
49
50 students' success in solving tasks that include reading and drawing *SMRs*. Students were
51
52 divided into three groups according to their speed of perception and spatial relations abilities
53
54 (Group 1: poor speed of perception or spatial relations abilities, Group 2: average speed of
55
56 perception or spatial relations abilities, and Group 3: superior speed of perception or spatial
57
58 relations abilities). The differences in total scores on *CK*, and problems that demand reading or
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Independent variables and submicrorepresentations

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3 drawing *SMRs*, between the three groups of students with different speed of perception
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5 abilities are not statistically significant.
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8 On the other hand there are statistically significant differences between the groups of
9
10 students in spatial relations abilities and their success in solving the tasks on *CK* ($F(2, 382) =$
11
12 $5.91, p = 0.003$). Post hoc comparisons using Tukey HSD showed that there is a statistically
13
14 significant difference ($p = 0.035$) between the mean scores for Group 1 ($M = 19.08, SD =$
15
16 5.85) and Group 2 ($M = 21.31, SD = 6.63$) and also between the mean scores for Group 3 (M
17
18 $= 22.93, SD = 5.90$) and Group 1 ($p = 0.002$). There is no statistically significant difference (p
19
20 $= 0.162$) between groups of students with average and superior spatial relations abilities in
21
22 total success on *CK*.
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25

26
27 The one-way analysis of variance shows that there are also statistically significant
28
29 differences between the groups of students in spatial relations abilities and their success in
30
31 solving the tasks that demand reading ($F(2, 382) = 3.43, p = 0.033$) and drawing *SMRs* ($F(2,$
32
33 $382) = 6.23, p = 0.002$). Post hoc comparisons using the Tukey HSD showed that the mean
34
35 scores for reading *SMRs* are statistically significantly different ($p = 0.027$) between Group 1
36
37 ($M = 9.90, SD = 3.09$) and Group 3 ($M = 11.38, SD = 2.79$). There is no statistically
38
39 significant difference ($p = 0.121$) between the groups of students with poor and average spatial
40
41 relations abilities and also between groups with average and superior spatial relations abilities
42
43 ($p = 0.397$) in success in solving items that include reading *SMRs*. Post hoc comparisons
44
45 showed that there is a statistically significant difference ($p = 0.001$) between the mean scores
46
47 for drawing *SMRs* for Group 1 ($M = 9.17, SD = 3.46$) and Group 3 ($M = 11.55, SD = 3.65$)
48
49 and also for Group 2 ($M = 10.51, SD = 3.96$) and Group 1 ($p = 0.035$). There is no statistically
50
51 significant difference ($p = 0.125$) between Group 2 (average spatial relations abilities) and
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53 Group 3 (superior spatial relations abilities) in success in drawing *SMRs*.
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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 ($p = 0.373$)

Independent variables and submicrorepresentations

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2
3 between Group 1 and Group 2 in success in solving the tasks on *CK*. The post hoc analysis
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5 using Tamhane (for equal variances not assumed) also showed that there is a statistically
6
7 significant difference ($p \leq 0.000$) between the groups of students with different level of
8
9 intrinsic motivation and their success in solving the tasks that demand drawing *SMRs* for
10
11 Group 1 ($M = 9.17$, $SD = 4.04$) and Group 3 ($M = 13.27$, $SD = 4.40$) and also for Group 2 (M
12
13 $= 10.09$, $SD = 3.37$) and Group 3 ($p \leq 0.000$). There is no statistically significant difference (p
14
15 $= 0.270$) between students with poor and average score in the intrinsic motivation
16
17 questionnaire in success in solving tasks drawing *SMRs*. Post hoc comparisons using the
18
19 Tukey HSD revealed that there is a statistically significant difference ($p \leq 0.000$) between the
20
21 mean scores for Group 1 ($M = 10.03$, $SD = 3.57$) and Group 3 ($M = 12.33$, $SD = 3.05$) and
22
23 also for Group 2 ($M = 10.54$, $SD = 3.11$) and Group 3 ($p \leq 0.000$) in reading *SMRs*
24
25 achievements. There is no statistically significant difference ($p = 0.493$) between students with
26
27 poor and average intrinsic motivation for learning chemistry in success at reading *SMRs*.
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35 Students' intrinsic motivation for learning the macro level of chemical concepts is also
36
37 statistically significantly correlated with the overall *CK* score ($r = 0.24$; $p \leq 0.000$) and with
38
39 students' ability for reading and drawing *SMRs*. The correlation coefficients extend from ($r =$
40
41 0.15 ; $p \leq 0.000$) for reading and ($r = 0.27$; $p \leq 0.000$) for drawing *SMRs*. The results show that
42
43 similar low percentages, as obtained regarding students' intrinsic motivation for learning
44
45 chemistry, of total *CK* score (5.5 %), *CK* reading *SMRs* score (2.3 %) and drawing *SMRs* score
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47 (7.0 %) variance can be explained by intrinsic motivation for learning chemistry at the
48
49 macroscopic level.
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56 Table 4. ANOVA between the three groups of students of different intrinsic motivation for the
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58 macroscopic level of chemical concepts and their success on *CK*.
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Independent variables and submicrorepresentations

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 %

Independent variables and submicrorepresentations

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3 respectively of students' ability in reading *SMRs*, can be explained by their intrinsic
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5 motivation scores for learning chemistry on submicro level.
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10 Table 5. ANOVA between the three groups of students of different intrinsic motivation for the
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12 submicroscopic level of chemical concepts and their success on CK.
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16
17 Post hoc comparisons using the Tukey HSD showed that there is a statistically
18
19 significant difference ($p \leq 0.000$) between the mean scores for Group 1 ($M = 10.15$, $SD =$
20
21 3.58) and Group 3 ($M = 12.63$, $SD = 3.08$) and also for Group 2 ($M = 10.47$, $SD = 3.06$) and
22
23 Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.743$) between the
24
25 group of students with poor and average intrinsic motivation for learning chemical concepts on
26
27 submicro level in success in reading *SMRs*.
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32 The post hoc analysis using Tamhane (for equal variances not assumed) shows that there
33
34 is a statistically significant difference ($p \leq 0.000$) between the mean scores on CK for poor (M
35
36 $= 19.22$, $SD = 6.99$) and superior ($M = 26.15$, $SD = 6.80$) intrinsically motivated students for
37
38 learning submicroscopic level of chemical concepts and also for the average ($M = 20.58$, $SD =$
39
40 5.69) and superior group of students ($p = 0.000$). There is no statistically significant difference
41
42 ($p = 0.370$) between Group 1 and Group 2 in success in solving the tasks on CK. It can be
43
44 concluded from the post hoc analysis using Tamhane that there is a statistically significant
45
46 difference ($p \leq 0.000$) between the mean scores regarding success in solving problems with
47
48 drawing *SMRs* for Group 1 ($M = 9.07$, $SD = 4.02$) and Group 3 ($M = 13.51$, $SD = 4.38$) and
49
50 also for Group 2 ($M = 10.11$, $SD = 3.34$) and Group 3 ($p \leq 0.000$). There is no statistically
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52 significant difference ($p = 0.149$) between Group 1 and Group 2 in success in solving the tasks
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54 of drawing *SMRs*.
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3 Students' intrinsic motivation for learning chemistry at the symbolic level of the *ITLS*
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5 model is statistically significantly correlated ($r = 0.28$; $p \leq 0.000$) to the students'
6
7 achievements in *CK* (*i.e.* reading *SMRs* $r = 0.20$; $p = 0.000$, and drawing *SMRs* $r = 0.31$; $p \leq$
8
9 0.000). The correlation coefficients show higher correlation for drawing than for reading
10
11 *SMRs*. It can be summarised that only 4 % of variance on reading *SMRs* scores can be
12
13 accounted for by students' interest in learning symbolic chemical concepts and 9.6 % of
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15 variance on drawing *SMRs*, respectively.
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22 Table 6. ANOVA between the three groups of students of different intrinsic motivation for the
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24 symbolic level of chemical concepts and their success on *CK*.
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30 The ANOVA showed (*Table 6*) that the differences between the three groups of students
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32 of different intrinsic motivation for symbolic level of chemical concepts and their success in
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34 *CK* is statistically significant ($p \leq 0.000$). Post hoc comparisons using the Tukey HSD showed
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36 that there is a statistically significant difference ($p \leq 0.000$) between the mean total scores on
37
38 *CK* for Group 1 (poor intrinsic motivation) ($M = 19.80$, $SD = 7.00$) and Group 3 (superior
39
40 intrinsic motivation) ($M = 25.59$, $SD = 6.58$) and also for Group 2 (average intrinsic
41
42 motivation) ($M = 20.60$, $SD = 5.86$) and Group 3 ($p \leq 0.000$). There is no statistically
43
44 significant difference ($p = 0.597$) between Group 1 and Group 2 in success on *CK*. The one-
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46 way analysis of variance showed that the differences between the three groups of students of
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48 different intrinsic motivation for the symbolic level of chemical concepts and their ability in
49
50 reading *SMRs* is also statistically significant ($p \leq 0.000$). Post hoc comparisons using Tukey
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52 HSD showed that there is a statistically significant difference ($p \leq 0.000$) between the mean
53
54 scores for Group 1 ($M = 10.35$, $SD = 3.49$) and Group 3 ($M = 12.53$, $SD = 2.96$) and also for
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56 Group 2 ($M = 10.45$, $SD = 3.13$) and Group 3 ($p \leq 0.000$). There is no statistically significant
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Independent variables and submicrorepresentations

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3 difference ($p = 0.970$) between students with low level of intrinsic motivation and those with
4
5 average motivation in success in reading *SMRs*. The Welch test showed that the differences
6
7 between the three groups of students of different intrinsic motivation for learning the symbolic
8
9 level of chemical concepts and their success in problems that include drawing ($p = 0.000$) are
10
11 statistically significant. The post hoc analysis using Tamhane (for equal variances not
12
13 assumed) shows that there is a statistically significant difference ($p \leq 0.000$) between the mean
14
15 scores for Group 1 ($M = 9.45$, $SD = 4.07$) and Group 3 ($M = 13.07$, $SD = 4.27$) and also for
16
17 Group 2 ($M = 10.15$, $SD = 3.46$) and Group 3 ($p \leq 0.000$). There is no statistically significant
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19 difference ($p = 0.458$) between Group 1 and Group 2 in success in drawing *SMRs*.
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Discussion and implications for education

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32 The first hypothesis relates to the difference in students' achievements between
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34 chemistry problems that include reading *SMRs* and those that include drawing them, and can
35
36 be confirmed. It can be concluded that the average points scored by the students on items that
37
38 require reading submicrorepresentations are higher (by 14.1%) compared to the average points
39
40 for items that include drawing the *SMRs*. These results are consistent with some other research
41
42 (Kelly & Jones, 2008; Margel, Eylon, & Scherz, 2008) which indicate that students have
43
44 specific problems with drawing the correct submicrorepresentations of the natural phenomena.
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49 Results in our study show specific misconceptions that are presented by the students
50
51 while transferring the submicro world of particles into the symbolic level. Students
52
53 demonstrate difficulties also trying to describe the submicrorepresentations or they just try to
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55 illustrate the phenomena on the particulate level.
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59 Firstly, students also have difficulties in representing different states of matter (See
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sample item 4 in Appendix 1). They express the most misconceptions representing the liquid

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3 state of water (molecules too far apart, incorrect arrangement of molecules), and they were the
4 most successful in presenting the gas state of water. A lot of students also had difficulties in
5 illustrating ice on a submicroscopic level. Students also struggle to distinguish between pure
6 substances and mixtures, because they anticipate that those particles that are represented by
7 two circles represent a compound, no matter what sort of atoms are bonded in the molecule
8 (See sample item 1 in Appendix 1). It can be concluded that students connect elements only
9 with separate atoms and compounds with multiple atoms molecules. According to these
10 results teachers should place more emphasise on the application of submicroscopic levels of
11 chemical concepts connecting them with macroscopic properties of the substances and using
12 *SMRs* for introducing new concepts and evaluating students' understanding.
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27 Secondly, it is important to be aware that almost half of the students aged 16 think that
28 the reactant that is not used completely in the chemical reaction, is written into the chemical
29 equation (See sample item 2 in Appendix 1). The analysis of the students' drawing *SMRs* of
30 chemical reaction products (See sample item 5 in Appendix 1) show that students are also
31 imprecise in reading the text of the problem, because they draw the wrong number of product
32 molecules or do not consider the differences in atomic radius of different elements. Legend
33 analysis also showed that students do not develop the connections between the macroscopic
34 and the submicroscopic levels of concepts, because they attribute the macroscopic name of an
35 element to the substance particle. It can be recommended that teachers can help students to
36 develop adequate mental models of chemical reaction also by using *SMR*, where the correct
37 number of moles and correct molecule geometry can be stressed with the support of the
38 legends of the particles used in *SMRs* with their names. It is also important to suggest that
39 teachers try to encourage precise reading of the scientific text, because students' success in
40 solving the chemistry problems is dependent on that. They must not encourage students to
41 learn chemical equations by heart because the results of this study show that doing so has a
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Independent variables and submicrorepresentations

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3 negative influence on students' motivation for learning chemistry, because just memorizing
4 the formulae is meaningless to students. Once again, as emphasized by other researchers
5 (Bunce, & Gabel, 2002; Chittleborough et al., 2002) the importance of putting the symbolic
6 chemical language into the context and breaking it down into meaningful parts – not
7 overloading students working memory capacity with it – has been shown to be an important
8 aspect of effective chemistry learning. This can help students to understand formulae and
9 equations in a way that is more meaningful to the students. This aspect is also important from
10 the teachers' point of view. Students progressing on the educational vertical would have more
11 information stored in their long-term memory and teachers wouldn't have to repeat the
12 explanation of the same basic concepts all over again on the higher level of students'
13 schooling. The findings suggest that students only try to describe chemical reactions on
14 macroscopic level, and the submicroscopic level is neglected or they don't even try to
15 describe it with their own words. According to these results teachers should emphasize
16 students' discussion about chemical phenomena individually to the teacher, in pairs or in
17 specially designed group work and evaluate their ability to elaborate their decisions in
18 problem solving strategies.

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41 Thirdly, it can be summarised that students had difficulties correctly representing the
42 ionic substance water solutions in particulate level (See sample item 6 in Appendix 1),
43 because less than one tenth of students correctly drew their *SMR*. This shows that the majority
44 of students after four years of chemical education do not understand what happens with
45 soluble ionic substances when added into water. Students ought to use their knowledge
46 acquired during chemistry lessons on a more theoretical level (ionic bonding, solubility,
47 atomic and ionic radii) on concrete samples. According to the results presented here the
48 students' transfers between macroscopic and submicroscopic level of chemical concepts
49 during problem solving processes are not satisfactory. Because of these results teachers
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3 should devote more of their time to teaching students proper problem solving strategies using
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5 *SMRs* and their prior knowledge.
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8 The last set of concepts assessed in sample items were acids and bases. Only more than
9
10 half of the students correctly recognise the *SMRs* of acid, base and salt aqueous solutions (See
11
12 sample item 3 in Appendix 1) but a lot more students had problems representing acidic
13
14 solution on a submicroscopic level, especially when they had to consider more than one
15
16 variable to solve the problem (See sample item 7 in Appendix 1). It can be concluded that
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18 students do not associate the acid strength with acid dissociation ability, but often with the
19
20 concentration of acid particles in the aqueous solution. From the analysis of the students'
21
22 *SMRs* representing acid in an aqueous solution, it is important to emphasize that teachers have
23
24 to use *SMRs* also to illustrate acid or base dissociation and connect this concept with acid or
25
26 base strength and pH value, because the most frequent misconception presented by students is
27
28 that stronger acid has more molecules of acid in water solution, and they do not connect this
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30 concept with the hydronium or hydroxide and conjugated base or acid ions.
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36 The overall conclusion of the content analysis of sample problems indicate, that
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38 teachers should devote more of their time in the classroom to introducing to the students the
39
40 purpose and the meaning of correct drawing of the *SMRs*. These activities should be
41
42 incorporated in all of the parts of the lessons, from introduction to the new topic to students'
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44 evaluating their knowledge at the end. Teachers would collect useful data by analyzing
45
46 students' drawing of *SMRs*, and on the basis of the conclusions could modify future
47
48 classroom activities to correct the discovered students' misinterpretations of chemical
49
50 concepts at submicro level. Teachers' view of the instructions and their pedagogical
51
52 knowledge - especially if they see the teaching as transfer of knowledge or as a process of
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54 building the students' knowledge - influence teachers' realization of the chemistry lessons
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56 (Valenčič Zuljan, 2007). Students' incomplete comprehension and/or misunderstandings of
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Independent variables and submicrorepresentations

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3 chemical concepts play an important role in the teaching process. Teachers should carefully
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5 analyze such concepts, and their corrected forms should be integrated into the students'
6
7 learning process.
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10 The difference is statistically significant, and further analysis shows a more detailed
11
12 picture of some independent variables (i.e. gender, formal reasoning abilities, visualization
13
14 abilities and intrinsic motivation for learning chemistry) and their influence on students'
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16 achievements in solving problems comprising *SMRs*.
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20 The second hypothesis refers to the difference between males and females in solving
21
22 problems involving reading and drawing *SMRs*, and cannot be confirmed. It can be
23
24 summarized that female students score significantly lower than male students in drawing or
25
26 reading submicrorepresentations while solving particulate problems. Bunce and Gabel (2002)
27
28 reported similar findings. They said that females score lower than males on the pre-test, but
29
30 after implementing the educational strategies that connect all three levels of chemical concepts
31
32 the significant gender score difference would diminish. The results reported by Barke and
33
34 Engida (2001) can explain the results found in this research. They anticipated that girls have
35
36 lower developed visualization abilities than boys, and they propose that students should use
37
38 different models and visualization material very early in the science education process to
39
40 stimulate development of visualization abilities. It can be speculated that visualization abilities
41
42 can influence motivation, and then hence the science problem solving achievements by both
43
44 males and females. During the educational process teachers should, therefore, pay more
45
46 attention to female students' progress in developing adequate mental models of chemical
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48 concepts regarding submicroscopic level through motivation for learning chemical concepts
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50 on all levels, thus stimulating the meaning of such learning for their professional career and
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52 everyday life.
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3 The third hypothesis is connected to students' formal reasoning abilities, and it can be
4 confirmed. Results show that students with higher formal reasoning abilities are slightly more
5 successful in problems that require reading than drawing *SMRs*. Drawing *SMRs* seems to be
6 more intellectually demanding than reading them, but results of the present study do not
7 confirm this assumption. It is also evident that students with developed formal reasoning
8 abilities are equally successful in reading or drawing submicrorepresentations as are those
9 students that reach transitional level, but there is a statistically significant difference between
10 concrete and formal reasoners. The difference between concrete and transitional reasoners in
11 reading or drawing *SMRs* is not significant. However, it is important to stress, that even
12 students on the concrete level of reasoning abilities are sufficiently capable of solving some
13 problems on submicro level. It is also evident that those students that fall into the group of
14 concrete or transitional reasoners had more difficulties with solving problems that involve
15 reading or drawing *SMRs* than those that fall into the group of formal reasoners. The lower
16 percent of explained variance was obtained by Gabel, Samuel, & Humm (1987) and Haidar
17 and Abraham (1991), that was attributed to the results on chemical concepts test 22.8 % and
18 17.5 % respectively of the variance by the students' reasoning abilities. The findings of the
19 present study are consistent with the findings of the study by Williamson and Abraham (1995),
20 who reported that 27 % of variance can be explained by formal reasoning abilities, and
21 Valanides (1998) reported similar results.

22
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24 The fourth hypothesis is: "Students with higher visualization abilities score statistically
25 significantly higher on the items regarding drawing *SMRs*", but it can not be confirmed.
26 Results shows that, in the contrast with formal reasoning ability and its influence on students'
27 achievements in solving problems on particulate level, it can be concluded that visualization
28 abilities are not so strongly correlated with chemistry knowledge that refers to 2-D
29 submicrorepresentations. This is shown by the results, and only a small portion of variance on
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Independent variables and submicrorepresentations

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3 the *CK* score can be explained by students' visualization abilities. Further analysis of variance
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5 shows, that differences between students with low and average, and average and superior
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7 visualization abilities are not statistically significant in most cases. It can, for that reason, be
8
9 emphasised that students can solve particulate problems even if their visualization abilities are
10
11 not so highly developed. However it is important to emphasise that there is no statistically
12
13 significant difference between students with different speeds of perception abilities in solving
14
15 problems regarding reading or drawing *SMRs*. On the other hand, somewhat bigger
16
17 differences can be determined regarding the use of 2-D submicrorepresentations between
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19 students with different levels of spatial relations. The difference is not statistically significant
20
21 between students with average and superior spatial relations abilities. The difference between
22
23 students with poor and average spatial relations abilities is statistically significant in the total
24
25 *CK* score and reading *SMRs* score. However the difference is also significant on all three
26
27 levels of *CK* tasks, between students with poor and those with superior spatial relations
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29 abilities. It can be concluded that chemical problems which include just 2-D
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31 submicrorepresentations do not pose great difficulties in solving them, even for those students
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33 with lower visualization abilities. These conclusions indicate that teachers should be
34
35 encouraged to use submicrorepresentations in classrooms, not just for laboratory work
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37 explanations, but also for evaluating students' knowledge, without apprehension that students
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39 with lower abilities would be discriminated. These results confirmed the predictions of Wu
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41 and Shah (2003) and Keig and Rubba (1993) that secondary school students' chemical
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43 concepts test scores variance would not be in a very large percentage accounted for by
44
45 students' visualization abilities, but by more general reasoning abilities. Gabel et al. (1987)
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47 also reported no significant correlation between students' visualization abilities and
48
49 achievements on the chemistry test that comprises items on submicroscopic level. Higher
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51 correlations between visualization abilities of secondary school students in Slovenia ($r =$
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3 0.472; $p < 0.01$) were registered by Ferik Vrtačnik, Blejec, & Gril (2003). Similar results were
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5 obtained also by Yang et al. (2003). These results may have their cause in different chemistry
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7 conceptual problems (3D model manipulations, computer animations ...) that were used for
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9 evaluating students' knowledge.
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13 The last hypothesis relates to the students' intrinsic motivation for learning chemistry on
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15 different levels of chemical concepts regarding the *ITLS* model, and it can be confirmed. It can
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17 be summarised from the results that the correlations between *CK* scores, either in reading,
18
19 drawing or overall scores and intrinsic motivation for learning chemistry, are the highest
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21 regarding motivation for the submicro level of chemical concepts, and the lowest regarding
22
23 macro level. From the ANOVA results it can be summarised that the differences between the
24
25 groups of students with different levels of intrinsic motivation is significant almost in all
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27 cases, except for reading *SMRs* and intrinsic motivation for the experimental level of chemical
28
29 education. However it is important to emphasise that on all levels of *ITLS* intrinsic motivation
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31 for learning chemistry, the difference between poor and average intrinsically motivated
32
33 students is not significant. According to these results, students with higher general or specific
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35 chemical intrinsic motivation achieve higher scores on the chemistry test comprising reading
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37 or drawing submicrorepresentations. Most students on all levels of education do like chemistry
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39 at the macro level, so teachers should take advantage of this and extrinsically motivate
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41 students through laboratory work. After this activity most students would have the chance to
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43 develop intrinsic motivation for the macro level of chemical concepts, and after that the
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45 intrinsic motivation for other two more abstract levels of *ITLS* model would evolve. To
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47 achieve this goal, teachers encounter a difficult task in achieving a sufficient level of external
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49 stimulation for students to become interested in chemistry, because students, at all levels of the
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51 educational system, often do not realize the meaning of submicroscopic explanations of the
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53 phenomena and their symbolic representations. It can be summarised that the most successful
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Independent variables and submicrorepresentations

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3 in solving chemistry problems on different levels of the *ITLS* model would be those students
4 that are highly intrinsically motivated for learning chemistry on the particulate level. Similar
5 results of several studies were reported by Tuan et al. (2005), but their research shows a
6 slightly higher correlation between school science achievement and motivation ($r = 0.40$; $p <$
7 0.01). Previous research (Napier & Riley, 1985) also indicated that motivation has a moderate
8 but significant correlation with students' science achievement. The results obtained in this
9 study can confirm Keigs' and Rubbas' (1993) predictions, i.e. that motivation can be a
10 potential source of variance regarding students' success on the chemical concepts test. On the
11 other hand, Nieswandt (2007) reports the result of her study, that affective variables (students'
12 interest and attitudes for chemistry and their chemistry-specific self-concepts) do not have a
13 statistically significantly effect on conceptual understanding, but the results do reveal the
14 importance of strong and positive self-concept for developing a meaningful understanding of
15 science concepts.

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34 The main implication for teaching chemistry or chemical concepts in science education
35 is that teachers should encourage students and especially females in activities where they are
36 engaged in drawing submicrorepresentations. It is important that teachers at the beginning of
37 using *SMRs* in chemistry teaching use simple *SMRs*, especially when students have to draw
38 them. Teachers should in the process of chemistry teaching emphasise the meaning of correct
39 and accurate reading of the chemistry problem text. They should stress the meaning of
40 the legends of particles and their names before students start to draw the *SMRs*. Students are
41 going to develop the abilities of drawing *SMRs* also when their formal reasoning abilities or
42 visualization abilities are not highly developed in relation to their age. It is also important to
43 stress, that students show an interest in understanding chemical concepts on a particulate level
44 and that they try to comprehend the bases of chemical phenomena on the level where
45 chemical reactions happen. On the other hand, students who enjoy learning chemistry only on
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3 the bases of symbols (chemical symbols of elements, formulae, equations) or observations of
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5 the experiments, without deeper understanding of the phenomena on particulate level, could
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7 not be very successful in achieving sufficient chemical knowledge. These findings indicate
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9 that teachers **should**, nevertheless, encourage students to learn chemistry at the particulate
10
11 level. These attempts are going to be only external, and for students mostly unnecessary or
12
13 even discouraging and highly difficult to understand at the beginning of the educational
14
15 process. But with progress in understanding of the basic chemical concepts (e.g. atom
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17 structure, chemical bond, etc), students' interest in understanding chemistry on submicro level
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19 will increase and will bring them more success in getting better feedback from the teacher.
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21 This type of chemistry teaching **should** result in the increase of intrinsic motivation for deeper
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23 learning of chemical concepts on all levels of *ITLS* model.
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29 Teachers with adequate chemical and didactical knowledge are able to conduct quality
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31 chemistry lessons by transferring scientific knowledge into the classroom. It is important to
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33 direct pre-service teacher students into the reflective way of teaching and into developing the
34
35 constant need for researching their own pedagogical practice (Vogrinc & Valenčič Zuljan,
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37 2009). In-service mentoring of beginning chemistry teachers (Author; Valenčič Zuljan, 2007;
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39 Valenčič Zuljan & Vogrinc, 2007) and the provision of quality permanent in-service teacher
40
41 education (Kalin & Zuljan, 2007) are, beside the pre-graduate study, an important aspect in
42
43 developing the future teacher as a reflective practitioner. **On the basis of the results it is**
44
45 **suggested that permanent in-service teacher education take into** account teachers' expectations
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47 and needs so that it can offer them the chance to develop competences to implement quality,
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49 also in the student oriented instructions model.
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Independent variables and submicrorepresentations

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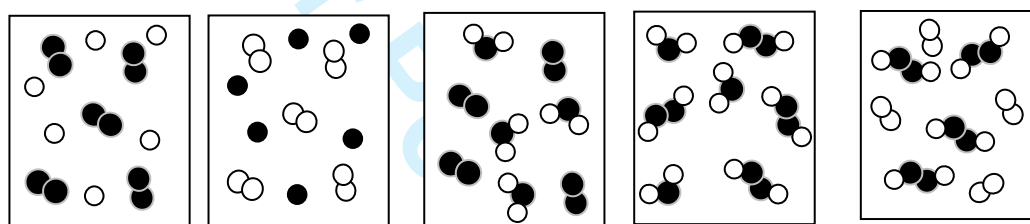
For Peer Review Only

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.



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B

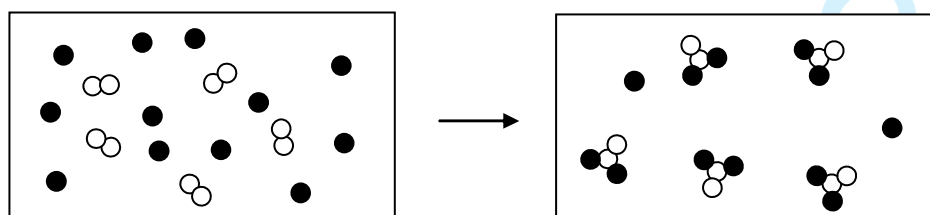
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Chemical reactions (CR reading SMRs)

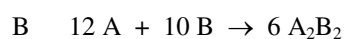
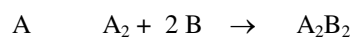
2. The scheme represents the reaction between substance A and B. Which equation correctly represents this reaction?



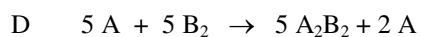
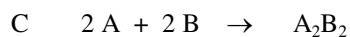
Mixture before the reaction

Mixture after the reaction

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



Independent variables and submicrorepresentations

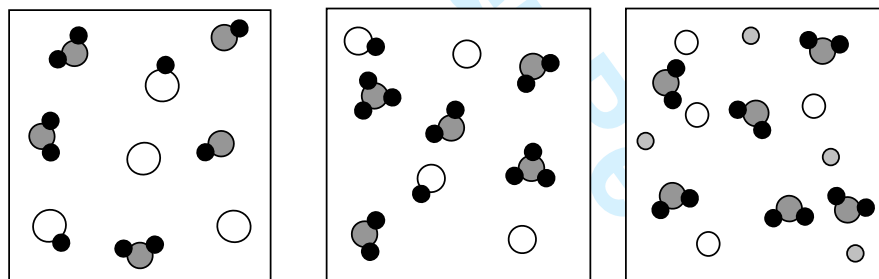


Which substance was completely used during the reaction? _____

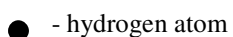
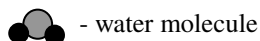
Elaborate the answer: _____

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? _____

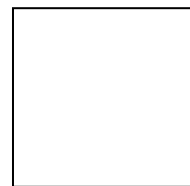
Which scheme represents an aqueous solution of soluble salt? _____

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: _____

Independent variables and submicrorepresentations

Solution Chemistry (SC drawing SMRs)

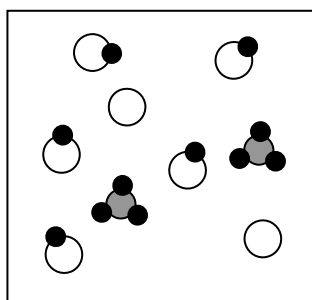
6. Draw a scheme to show the dissolved potassium bromide with optional concentration in water. Use the legend to illustrate the particles which you have used in the scheme. You need not draw water molecules.



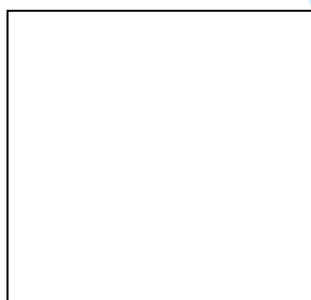
Legend: _____

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.

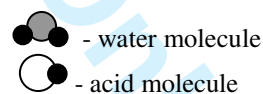


Scheme 1



Scheme 2

Legend:



Elaborate the answer: _____

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2
3 **Appendix 2: Sample items from the questionnaire Intrinsic Motivation for Learning**
4
5 **Science (IMLS)**
6
7
8
9

10 1. Emotional component of interest:
11
12

13
14
15 *I enjoy learning.*
16

17
18
19 *I am often bored during:*
20

21
22 ...chemistry course.
23

24 ... biology course.
25

26 ...physics course.
27

28 ... foreign language course.
29

30 ... mathematics course.
31
32
33

34
35
36 *I enjoy the chemistry course when:*
37

38 ...we observe chemical changes in experiments.
39

40 ...we learn about particles (atoms, ions, molecules).
41

42 ...we learn and write chemical symbols, formulae and equations.
43
44
45
46
47

48 2. Cognitive component of interest:
49
50

51
52
53 *I often look for additional information about school science topics in books, magazines, in the*
54 *internet, CDs ...*
55
56

57
58
59 *The media attract my attention when reporting on:*
60

Independent variables and submicrorepresentations

1
2
3 ...chemistry topics.

4
5 ...biology topics.

6
7 ...physics topics.

8
9 ...foreign language topics.

10
11 ...mathematics topics.

12
13
14
15
16
17
18 *I often think about:*

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

20
21 ... particles (atoms, ions, molecules), *also out of school.*

22
23 ...learning and writing chemical symbols, formulae and equations, *also out of school.*

24
25
26
27
28
29 3. Challenge component of internal motivation:

30
31
32
33
34 *I persevere with learning.*

35
36
37
38 *New problems in:*

39 ... chemistry, *challenge me.*

40
41 ...biology, *challenge me.*

42
43 ...physics, *challenge me.*

44
45 ...foreign language, *challenge me.*

46
47 ...mathematics, *challenge me.*

48
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54
55 *If I do not understand something, connected with:*

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

57
58 ...learning about particles (atoms, ions, molecules), *I give up.*

1
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3 ...learning and writing chemical symbols, formulae and equations, *I give up*.
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For Peer Review Only

Independent variables and submicrorepresentations

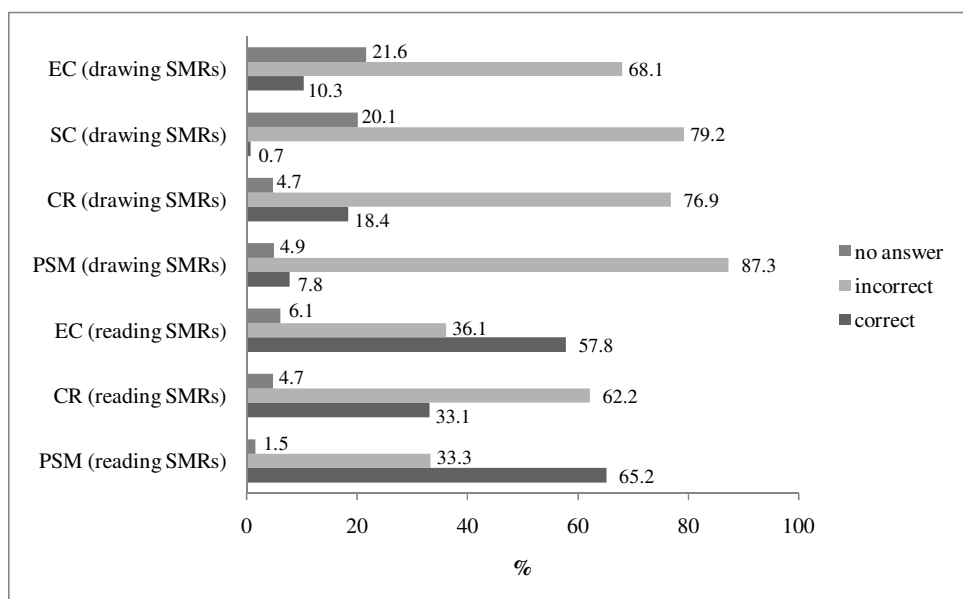


Chart 1. Students' achievements at sample chemistry problems (PSM – Pure substances and mixtures; CR – Chemical reactions; EC – Electrolyte chemistry; and SC – Solution chemistry).

Independent variables and submicrorepresentations

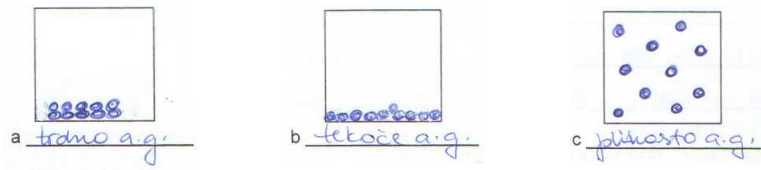


Figure 1. Correctly presented all three states of water; original students' drawing, written on a line means: a solid; b liquid and c gas.

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Independent variables and submicrorepresentations

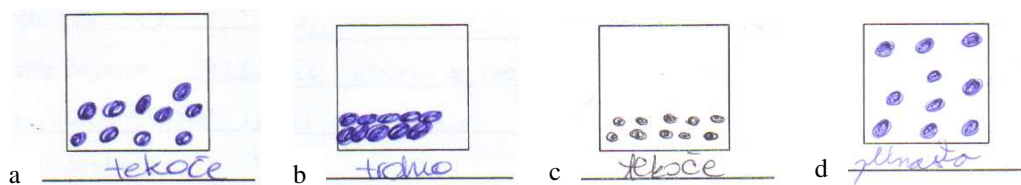


Figure 2. Incorrectly presented all three states of water; original students' drawing, written on a line means : a liquid; b solid; c liquid and d gas.

Independent variables and submicrorepresentations

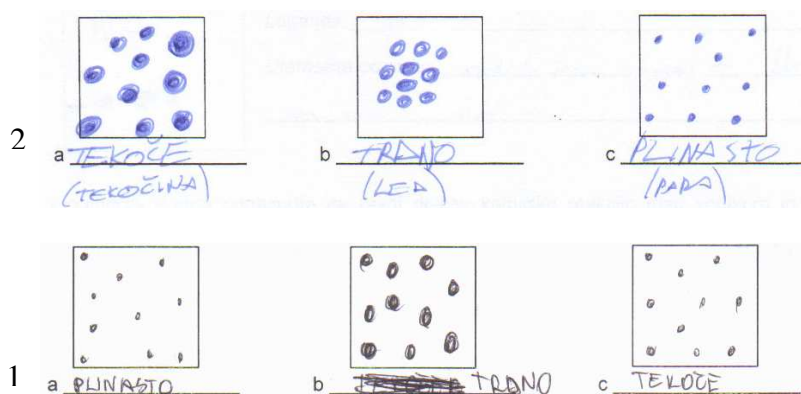


Figure 3. SMRs of different states of water presenting different sizes of molecules in a specific state of water; original students' drawing, written on a line means: 1 - a gas; b solid; c liquid and 2 - a liquid; b solid; c gas).

Independent variables and submicrorepresentations

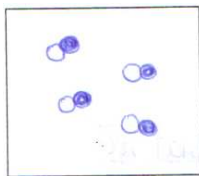


Figure 4. The same size of hydrogen and chlorine atoms in the molecule of hydrogen chloride.

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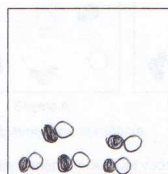


Figure 5: SMR illustrating misconceptions of aqueous solution of potassium bromide (i.e. molecules of potassium bromide and not taking into account the potassium and bromide atoms different atomic radii).

Independent variables and submicrorepresentations

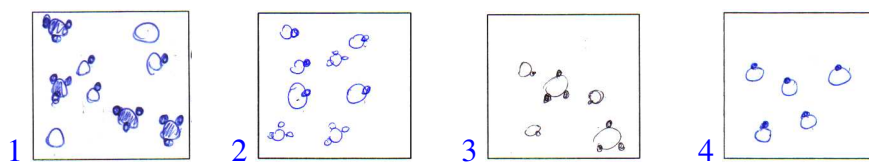


Figure 5: SMR illustrating misconceptions of an acid aqueous solution.

For Peer Review Only

Table 1. Descriptive statistics for CK.

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

Independent variables and submicrorepresentations

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

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

Independent variables and submicrorepresentations

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 <i>CK</i> score *	2, 107.07	17.05	≤ 0.000
Reading of <i>SMRs CK</i> score	2, 383	9.99	≤ 0.000
Drawing of <i>SMRs CK</i> 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

Independent variables and submicrorepresentations

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 <i>CS</i> score	2, 383	5.28	0.005
Reading of <i>SMRs CS</i> score	2, 383	1.90	0.151
Drawing of <i>SMRs CS</i> 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

Independent variables and submicrorepresentations

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 <i>CS</i> score *	2, 107.40	19.92	0.000
Reading of <i>SMRs CS</i> score	2, 383	12.92	0.000
Drawing of <i>SMRs CS</i> 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.

Independent variables and submicrorepresentations

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 <i>CK</i> score	2, 383	17.85	0.000
Reading of <i>SMRs CK</i> score	2, 383	10.94	0.000
Drawing of <i>SMRs CK</i> 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.

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2
3 **THE INFLUENCE OF SOME INDEPENDENT VARIABLES ON 16-YEAR-OLD**
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5 **STUDENTS' READING AND DRAWING SUBMICROREPRESENTATIONS**
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8 **ACHIEVEMENTS**
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15 **Abstract:** Submicrorepresentations are a powerful tool for identifying misconceptions of
16
17 chemical concepts and for generating proper mental models of chemical phenomena in
18
19 students' long term memory during chemical education. The main purpose of the study was
20
21 to determine which independent variables (gender, formal reasoning abilities, visualization
22
23 abilities and intrinsic motivation for learning chemistry) have the most influence on students'
24
25 reading and drawing submicrorepresentations. 386 secondary school students (aged 16.3
26
27 years) participated in the study. The instruments used in the study were: test of Chemical
28
29 Knowledge, Test of Logical Thinking, two tests of visualization abilities Patterns and
30
31 Rotations, and Questionnaire on Intrinsic Motivation for Learning Science. The results show
32
33 moderate, but statistically significant correlations between students' intrinsic motivation,
34
35 formal reasoning abilities and chemical knowledge at submicroscopic level based on reading
36
37 and drawing submicrorepresentations. Visualization abilities are not statistically significantly
38
39 correlated with students' success on items that comprise reading or drawing
40
41 submicrorepresentations. It can be also concluded that there is a statistically significant
42
43 difference between male and female students in solving problems that include reading or
44
45 drawing submicrorepresentations. Based on these results, several educational strategies can
46
47 be implemented for students to develop adequate mental models of science concepts on all
48
49 three levels of the model.
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57 **Key Words:** secondary school students', submicrorepresentations, students' mental abilities,
58
59 intrinsic motivation.
60

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 & Waldrup, 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. Waldrup, 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

1
2
3 different educational theories, such as Paivio's dual coding theory, Mayer's SOI model of
4
5 meaningful learning and Johnstone's model of information processing, cognitive theory of
6
7 multimedia learning and Mayer's theory of effective illustrations (see for more details Author;
8
9 Author).

10
11
12 To illustrate chemical concepts on the level of particles, submicrorepresentations (*SMR*)
13
14 can be used and can be presented as static or dynamic modes of representations. Research
15
16 shows (Bunce & Gabel, 2002; Tien, Teichert, & Rickey, 2007; Kelly & Jones, 2008) that
17
18 those students who were exposed to *SMRs* during the educational process more adequately
19
20 understand the nature of the particle interactions compared to those who learned the same
21
22 concepts only by textbooks reading. Studies in the last two decades (Williamson & Abraham,
23
24 1995; Johnson, 1998; Chittleborough, Treagust, & Mocerino, 2002; Solsona, Izquierdo, &
25
26 DeJong, 2003; Papageorgiou & Johnson, 2005; Stains & Talanquer, 2007a; Tien et al, 2007;
27
28 Kelly & Jones, 2008; Author) also show that students have many difficulties in understanding
29
30 the submicro and symbolic levels of chemical concepts, and that previous knowledge of a
31
32 specific topic has an influence on integrating new science concepts into students' mental
33
34 structure. It is also important to emphasise that a lot of different factors influence students'
35
36 achievement on different pictorial test questions (Halakova & Prokša, 2007; Sanger & Phelps,
37
38 2007; Stains & Talanquer, 2008) and that the students' knowledge evaluation part of the
39
40 educational process needs further study. Research also shows that teachers use mostly the
41
42 symbolic level of chemical concepts to teach chemistry (Williamson & Abraham, 1995;
43
44 Chittleborough et al., 2002). It is important to introduce different visualization abilities to
45
46 illustrate abstract science concepts to the students at the beginning of science education - age
47
48 10 or 11 (Longden, Black, & Solomon, 1991) - thus also the application of
49
50 submicrorepresentations (Papageorgiou & Johnson, 2005).
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Independent variables and submicrorepresentations

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3 For the purpose of this paper some independent variables such as mental abilities (i.e.
4 formal reasoning and visualization abilities) and intrinsic motivation were selected because,
5
6 according to the research literature, these variables influence chemistry learning.
7
8

9
10 Thiele and Treagust (1994) report that students who cannot visualise chemical
11 phenomena and/or do not have properly developed formal reasoning abilities cannot properly
12 understand chemical concepts; thus those concepts are hard to understand, unattractive and
13 pointless for them. According to some research results (Wu & Shah, 2003) the significant
14 correlation between spatial ability and chemistry problem solving skills is based on general
15 reasoning abilities or intelligence rather than on visuospatial thinking. Valanides (1996)
16 reported that students aged 12 to 14 years show relatively low developed formal reasoning
17 abilities. 64.6 % of these students show concrete operational abilities. The difference in their
18 levels of formal reasoning abilities is not statistically significant. Similar results were obtained
19 by Shemesh, Eckstein, & Lazarowitz, (1992). Statistically significant correlations were proven
20 between formal reasoning abilities and students' chemical knowledge especially on submicro
21 level (Haidar & Abraham, 1991; Williamson & Abraham, 1995)
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38 It is important to emphasize that Yang, Andre, & Greenbowe (2003) concluded that
39 students with low levels of visualization abilities show greater difficulties in understanding
40 computer animations of chemical phenomena on particulate level. Research (Barke & Engida,
41 2001) also shows that girls have lower developed visualization abilities than boys, and they
42 propose that students should use different models and visualization material very early in the
43 science education process to stimulate development of visualization abilities. On the other
44 hand, Wu and Shah (2003) reported no statistically significant correlations between students'
45 achievements on the test with static *SMRs* and spatial abilities. They anticipated that the
46 knowledge achievement is more dependent on students' prior knowledge and the general
47 cognitive factor than on visualization abilities.
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3 A negative relationship towards chemistry does not enable proper concept change and/or
4
5 modification of students' mental model of chemical phenomena. Students often do not have a
6
7 proper knowledge base that would make it possible to upgrade their knowledge of more and
8
9 more abstract chemical concepts when they make progress on the educational vertical
10
11 (Treagust, Harrison, & Venville, 1998).
12
13

14
15 Learning motivation is defined as a construct which includes different motivational
16
17 elements (interests, goals, attributes, self-image, external enticements, etc.). Some of these
18
19 form a more extrinsic stimulus for learning (e.g., learning for grades, praises, avoiding
20
21 punishment, social acceptance, etc.), while others are manifested more intrinsically (i.e.,
22
23 learning for mastering, learning for knowledge) (Authors).
24
25

26
27 According to Ryan and Deci (2000), intrinsic motivation is an individual's inherent
28
29 inclination from which stems his/her tendency to learn about particular areas of life regardless
30
31 of the presence of external enticements. This construction encourages humans to '...
32
33 assimilate, control, generate spontaneous interests and to research which makes it essential for
34
35 the individual's social and cognitive development while on the other hand it represents the
36
37 fundamental source of personal satisfaction and life energy.' (p. 70).
38
39
40

41 Highly intrinsically motivated students are more successful in learning new concepts and
42
43 show better understanding of the learning matter (Stipek, 1998). Rennie (1990), on the basis of
44
45 the research on science learning, also concluded that higher results in science are related to the
46
47 learner's active engagement in learning tasks, to his/her positive attitude towards the subject
48
49 and to a highly positive self-concept in science, which all imply the learner's intrinsic
50
51 motivation to learn. This is especially important, since many writers (Anderman & Young,
52
53 1994; Zusho, Pintrich, & Coppola, 2003) report that the decrease in intrinsic motivation with
54
55 years of schooling is particularly noticeable in mathematics and science and is at its peak in
56
57 the period of early adolescence.
58
59
60

Independent variables and submicrorepresentations

1
2
3 Keig and Rubba (1993) pointed out that motivation can be a potential source of variance
4 on students' chemistry knowledge achievements. These claims were confirmed by Tuan et al.
5 (2005). They reported that from 7 to 16% of variance on the science knowledge test could be
6 explained by students' motivation. But on the other hand Nieswandt (2007) reported no
7 statistically significant effect of students' affective variables (situational interest, attitudes
8 towards chemistry and students chemistry-specific self-concept) on their understanding of
9 grade 9 (age 15 to 16) chemistry concepts.

10
11 Chittleborough et al. (2002), according to their qualitative research, reported that
12 students are not motivated for learning chemistry more that is necessary for passing the exam.
13 Students' motivation for learning science and chemistry for that matter can be stimulated by
14 using different visualization elements and analogies because this element of the lessons
15 increases students' attention (Theile & Treagust, 1994) and also by different experimental
16 work supported by ICT (Šorgo & Kocijančič, 2006).

17
18 Research (Anderman & Young, 1994; Meece & Jones, 1996) also shows that gender
19 differences in motivation for science learning are connected with achievements on the
20 standardized test of science knowledge. It was also established that girls show lower interest in
21 science, that science is boring for them, especially because they just have to learn everything
22 by heart. Results also show that girls possess lower levels of self-confidence in demonstrating
23 their science knowledge (Simpson & Oliver, 1990). On the other hand, Meece and Jones
24 (1996) did not confirm these results; they established that there is no difference between girls
25 and boys regarding the interest in learning science and they also pointed out that gender
26 influence on motivation and in its effect on the manifestation of science knowledge are more
27 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*.

Independent variables and submicrorepresentations

- 1
2
3 (5) Students with higher levels of intrinsic motivation for learning chemistry on
4
5 different levels of chemical representations score statistically significantly higher on
6
7 problems that include drawing *SMRs* than on those that include reading them.
8
9

Method*Participants*

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22 A total of 386 secondary school students (60.6 % females; 39.4 % males) participated in
23
24 the study. On average, the students were 16.3 years old (M= 195.4 months; SD = 5.7 months).
25
26 All students attended second year of the general type of secondary school (Gymnasium). The
27
28 chemistry curriculum of the Gymnasium is common to all students. The students attended the
29
30 fourth year of chemical education in the period that testing occurred (two years in higher
31
32 primary school - age 13 and 14 and two years in secondary school - age 15 and 16). The
33
34 sample included 5.5 % of the whole population of the students (N = 7033) in school year
35
36 2005/06, throughout Slovenia. Three schools were located in the larger towns (more than
37
38 100,000 residents) and three in smaller towns (between 35,000 and 100,000 residents). The
39
40 sample represented a predominantly urban population with mixed socioeconomic status.
41
42 Parents' basic educational background was diverse (3.1 % finished primary school; 45.1 %
43
44 finished secondary school; 43.0 % finished university and 7.3 % finished other formal
45
46 education) but only 11.6 % of parents had finished some kind of science or technology
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48 education.
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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). Kurtosis 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

Independent variables and submicrorepresentations

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3 reasoners) were used as a basis for classifying the students. Students had 38 minutes to solve
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5 the test.
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8 The students' visualization abilities were measured with two tests: *Patterns (PA)* and
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10 *Rotations (RO)* (Pogačnik, 1998; 2000). The *PA* measures students' speed of perception and
11
12 the *RO* measures students' spatial relations abilities. Both tests were developed based on the
13
14 Cattell-Horn theory of mental abilities. The *PA* is a 36 item group paper-pencil test. It requires
15
16 individuals to find and mark exactly the same pattern among the four similar patterns on the
17
18 right side of the paper to the one on the left part of the paper as quickly as possible. The *PA*
19
20 has high internal consistency (Cronbach's alpha was 0.86). Correlations between some other
21
22 instruments for determining individuals' perception abilities (*BTI-Or*; *BTI-Pr*, *Beta 6* and *4*)
23
24 determine that the instruments' validity was higher and statistically significant. Students had
25
26 4.5 minutes to solve the test. The *RO* is a 90 item group paper-pencil test. The *RO* requires
27
28 individuals to find and encircle those patterns on the right side of the paper that are just rotated
29
30 in comparison with the left pattern. Individuals have to cross those patterns that are not just
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32 rotated in the plane but represent a different pattern. Cronbach's alpha for the *RO* was 0.94.
33
34 Correlations between some other instruments for determining individuals' perception abilities
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36 (*BTI-Pr*, *Beta 4*) were also high and statistically significant. Students had 6 minutes to solve
37
38 the test. The classifications of students into three groups with regard to their visualization
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40 abilities were performed according to the statistical equations. Into Group 1 (poor visualization
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42 abilities) were classified students that scored less than $M - 1SD$ points, into Group 2 (average
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44 visualization abilities) those that scored between $M - 1SD$ and $M + 1SD$ points, and into
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46 Group 3 (superior visualization abilities) students that scored above $M + 1SD$ points on the *PA*
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48 and *RO*.
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57 The last independent variable, the intrinsic motivation for learning chemistry was
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59 measured by the *IMLS* questionnaire. There are many questionnaires to measure students'
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3 attitudes or interests in science and/or chemistry (e.g. Moore & Foy, 1997; Tuan et. al., 2005;
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5 Coll et al., 2002; Nieswandt, 2007). All these instruments show a rather general structure of
6
7 students' attitudes towards science, but they lack the dimension with reference to the *ITLS*
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9 model and separately for different science school subjects. These questionnaires do not show
10
11 enough specific characteristics regarding the research questions asked in this study and would
12
13 need extensive revision for adapting the instrument to secondary level. For those reasons the
14
15 new instrument for measuring intrinsic motivation, 125-item *IMLS* (*Intrinsic Motivation for*
16
17 *Learning Science* questionnaire, was developed (Authors). The response to each item is on a
18
19 five-point Likert-type scale ranging from 1 as strongly disagree to 5 as strongly agree. The
20
21 internal consistency (Cronbach α) of *IMLS* was 0.78. Students had 20 minutes to complete the
22
23 questionnaire. The classifications of students into three groups with regard to their intrinsic
24
25 motivation for learning chemistry were performed according to the statistics. Into Group 1
26
27 (poor intrinsically motivated) were classified students that scored less than $M - 1SD$ points,
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29 into Group 2 (average intrinsically motivated) those that scored between $M - 1SD$ and $M +$
30
31 $1SD$ points, and into Group 3 (superior intrinsically motivated) students that scored above $M +$
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33 $1SD$ points on the *IMLS*. Three sample items of each component of intrinsic motivation from
34
35 the *IMLS* questionnaire are included in Appendix 2.
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46 *Research design*

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51 The research was a non-experimental, cross-sectional and descriptive study (Bryman,
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53 2004).
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55 The students had received no special teaching about using *SMRs* in the chemistry
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57 classroom. The chemical concepts comprised in the *CK* were not instructed using *SMRs* by
58
59 the teachers that taught the students participating in the study.
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Independent variables and submicrorepresentations

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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'

1
2
3 correlation coefficients for determining the correlation between knowledge of chemical
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5 concepts and other independent variables were calculated. In addition, the one-way between-
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7 groups analysis of variance (*ANOVA*) was conducted to explore the influence of reasoning
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9 abilities, visualization abilities and intrinsic motivation for learning chemistry on students'
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11 success in solving *CK* tasks. If the test of homogeneity of variances was statistically
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13 significant when comparing the means of the groups of students, the more robust test (Welch
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15 test) of equality of means was used.
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24 Results

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29 The results show secondary school students' average chemical knowledge of the tested
30
31 basic chemical concepts (*Table 1*). Students achieved on average 49 % of all points possible
32
33 on the *CK*.
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36 Students were more successful in reading *SMRs* than drawing them. Students managed to
37
38 get on average 56.5 % of all points on items that required reading the *SMRs*. On the other
39
40 hand, students achieved on average 42.4 % of all points available on problems that required
41
42 drawing the most suitable *SMRs*.
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48 Table 1. Descriptive statistics for *CK*.
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53 The paired samples t-test shows that students score statistically significantly higher in
54
55 solving problems that require reading *SMRs* than in those that require drawing them ($t(385) =$
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57 $1.97, p = 0.048$).
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Independent variables and submicrorepresentations

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

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2
3 can be concluded that students need to have developed higher levels of reasoning abilities to
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5 solve the CK items more successfully.
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8 For further analysis, the one-way between-groups analysis of variance was conducted to
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10 explore the influence of formal reasoning abilities on total success in *CK* and in solving tasks
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12 of reading and drawing *SMRs*. Students were divided into three groups according to their
13
14 reasoning abilities (Group 1: concrete reasoners, Group 2: transitional reasoners and Group 3:
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16 formal reasoners).
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20 The differences in overall success in *CK* between the three groups of students of
21
22 different formal reasoning abilities are statistically significant ($F(2, 383) = 33.39, p \leq 0.000$).
23
24 Post hoc comparisons using Tukey HSD showed that there is a statistically significant
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26 difference ($p \leq 0.000$) between the mean scores for Group 1 ($M = 13.43, SD = 5.88$) and
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28 Group 3 ($M = 22.20, SD = 5.99$) and also for Group 2 ($M = 15.38, SD = 5.98$) and Group 3 (p
29
30 ≤ 0.000). There is no statistically significant difference ($p = 0.622$) between the groups of
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32 concrete and transitional reasoners in success in *CK*. There is a statistically significant
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34 difference between groups of students with different reasoning abilities in success at reading
35
36 ($F(2, 383) = 29.81, p \leq 0.000$) and drawing ($F(2, 383) = 24.25, p \leq 0.000$) *SMRs*. Post hoc
37
38 comparisons using Tukey HSD indicated that the mean scores for reading *SMRs* between
39
40 Group 1 ($M = 6.80, SD = 3.16$) and Group 3 ($M = 11.22, SD = 2.99$) were statistically
41
42 significantly different ($p \leq 0.000$) and also between Group 2 ($M = 8.02, SD = 3.22$) and Group
43
44 3 ($p \leq 0.000$). Group 1 did not differ significantly from Group 2 ($p = 0.485$) regarding reading
45
46 *SMRs*. Similar results were obtained by post hoc comparisons using the Tukey HSD test
47
48 regarding mean scores for drawing *SMRs*. Group 1 ($M = 6.63, SD = 3.57$) was statistically
49
50 significantly different ($p = 0.001$) from Group 3 ($M = 10.98, SD = 3.72$) and also for Group 2
51
52 ($M = 7.35, SD = 3.25$) and Group 3 ($p \leq 0.000$). Group 1 did not differ significantly from
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54 Group 2 ($p = 0.839$).
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Independent variables and submicrorepresentations

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* ($F(2, 382) =$

Independent variables and submicrorepresentations

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3 5.91, $p = 0.003$). Post hoc comparisons using Tukey HSD showed that there is a statistically
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5 significant difference ($p = 0.035$) between the mean scores for Group 1 ($M = 19.08$, $SD =$
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7 5.85) and Group 2 ($M = 21.31$, $SD = 6.63$) and also between the mean scores for Group 3 (M
8
9 $= 22.93$, $SD = 5.90$) and Group 1 ($p = 0.002$). There is no statistically significant difference (p
10
11 $= 0.162$) between groups of students with average and superior spatial relations abilities in
12
13 total success on *CK*.
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17 The one-way analysis of variance shows that there are also statistically significant
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19 differences between the groups of students in spatial relations abilities and their success in
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21 solving the tasks that demand reading ($F(2, 382) = 3.43$, $p = 0.033$) and drawing *SMRs* ($F(2,$
22
23 $382) = 6.23$, $p = 0.002$). Post hoc comparisons using the Tukey HSD showed that the mean
24
25 scores for reading *SMRs* are statistically significantly different ($p = 0.027$) between Group 1
26
27 ($M = 9.90$, $SD = 3.09$) and Group 3 ($M = 11.38$, $SD = 2.79$). There is no statistically
28
29 significant difference ($p = 0.121$) between the groups of students with poor and average spatial
30
31 relations abilities and also between groups with average and superior spatial relations abilities
32
33 ($p = 0.397$) in success in solving items that include reading *SMRs*. Post hoc comparisons
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35 showed that there is a statistically significant difference ($p = 0.001$) between the mean scores
36
37 for drawing *SMRs* for Group 1 ($M = 9.17$, $SD = 3.46$) and Group 3 ($M = 11.55$, $SD = 3.65$)
38
39 and also for Group 2 ($M = 10.51$, $SD = 3.96$) and Group 1 ($p = 0.035$). There is no statistically
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41 significant difference ($p = 0.125$) between Group 2 (average spatial relations abilities) and
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43 Group 3 (superior spatial relations abilities) in success in drawing *SMRs*.
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53 *Students' intrinsic motivation and CK score*

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

Independent variables and submicrorepresentations

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

Independent variables and submicrorepresentations

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

Independent variables and submicrorepresentations

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3 showed that there is a statistically significant difference ($p = 0.008$) between the mean total
4 scores on *CK* for poor ($M = 20.27$, $SD = 7.06$) and superior ($M = 23.73$, $SD = 7.15$)
5 intrinsically motivated students for learning chemical concepts on the macroscopic level and
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8 also for average ($M = 20.93$, $SD = 6.04$) and superior intrinsically motivated ($p = 0.009$).
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12 There is no statistically significant difference ($p = 0.724$) between Group 1 and Group 2 in
13 success on *CK*. Because the test of homogeneity of variances for drawing *SMRs* was
14 statistically significant (*Table 4*), the Welch test of equality of means was used. The Welch
15 test showed that the differences between the three groups of students of different intrinsic
16 motivation for learning the macro level of chemical concepts and their success in drawing
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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*.

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6 Post hoc comparisons using the Tukey HSD showed that there is a statistically
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8 significant difference ($p \leq 0.000$) between the mean scores for Group 1 ($M = 10.15$, $SD =$
9
10 3.58) and Group 3 ($M = 12.63$, $SD = 3.08$) and also for Group 2 ($M = 10.47$, $SD = 3.06$) and
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12 Group 3 ($p \leq 0.000$). There is no statistically significant difference ($p = 0.743$) between the
13
14 group of students with poor and average intrinsic motivation for learning chemical concepts on
15
16 submicro level in success in reading *SMRs*.
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20 The post hoc analysis using Tamhane (for equal variances not assumed) shows that there
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22 is a statistically significant difference ($p \leq 0.000$) between the mean scores on *CK* for poor (M
23
24 $= 19.22$, $SD = 6.99$) and superior ($M = 26.15$, $SD = 6.80$) intrinsically motivated students for
25
26 learning submicroscopic level of chemical concepts and also for the average ($M = 20.58$, $SD =$
27
28 5.69) and superior group of students ($p = 0.000$). There is no statistically significant difference
29
30 ($p = 0.370$) between Group 1 and Group 2 in success in solving the tasks on *CK*. It can be
31
32 concluded from the post hoc analysis using Tamhane that there is a statistically significant
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34 difference ($p \leq 0.000$) between the mean scores regarding success in solving problems with
35
36 drawing *SMRs* for Group 1 ($M = 9.07$, $SD = 4.02$) and Group 3 ($M = 13.51$, $SD = 4.38$) and
37
38 also for Group 2 ($M = 10.11$, $SD = 3.34$) and Group 3 ($p \leq 0.000$). There is no statistically
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40 significant difference ($p = 0.149$) between Group 1 and Group 2 in success in solving the tasks
41
42 of drawing *SMRs*.
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49 Students' intrinsic motivation for learning chemistry at the symbolic level of the *ITLS*
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51 model is statistically significantly correlated ($r = 0.28$; $p \leq 0.000$) to the students'
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53 achievements in *CK* (*i.e.* reading *SMRs* $r = 0.20$; $p = 0.000$, and drawing *SMRs* $r = 0.31$; $p \leq$
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55 0.000). The correlation coefficients show higher correlation for drawing than for reading
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57 *SMRs*. It can be summarised that only 4 % of variance on reading *SMRs* scores can be
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Independent variables and submicrorepresentations

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3 accounted for by students' interest in learning symbolic chemical concepts and 9.6 % of
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5 variance on drawing *SMRs*, respectively.
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10 Table 6. ANOVA between the three groups of students of different intrinsic motivation for the
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12 symbolic level of chemical concepts and their success on *CK*.
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17 The ANOVA showed (*Table 6*) that the differences between the three groups of students
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19 of different intrinsic motivation for symbolic level of chemical concepts and their success in
20
21 *CK* is statistically significant ($p \leq 0.000$). Post hoc comparisons using the Tukey HSD showed
22
23 that there is a statistically significant difference ($p \leq 0.000$) between the mean total scores on
24
25 *CK* for Group 1 (poor intrinsic motivation) ($M = 19.80$, $SD = 7.00$) and Group 3 (superior
26
27 intrinsic motivation) ($M = 25.59$, $SD = 6.58$) and also for Group 2 (average intrinsic
28
29 motivation) ($M = 20.60$, $SD = 5.86$) and Group 3 ($p \leq 0.000$). There is no statistically
30
31 significant difference ($p = 0.597$) between Group 1 and Group 2 in success on *CK*. The one-
32
33 way analysis of variance showed that the differences between the three groups of students of
34
35 different intrinsic motivation for the symbolic level of chemical concepts and their ability in
36
37 reading *SMRs* is also statistically significant ($p \leq 0.000$). Post hoc comparisons using Tukey
38
39 HSD showed that there is a statistically significant difference ($p \leq 0.000$) between the mean
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41 scores for Group 1 ($M = 10.35$, $SD = 3.49$) and Group 3 ($M = 12.53$, $SD = 2.96$) and also for
42
43 Group 2 ($M = 10.45$, $SD = 3.13$) and Group 3 ($p \leq 0.000$). There is no statistically significant
44
45 difference ($p = 0.970$) between students with low level of intrinsic motivation and those with
46
47 average motivation in success in reading *SMRs*. The Welch test showed that the differences
48
49 between the three groups of students of different intrinsic motivation for learning the symbolic
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51 level of chemical concepts and their success in problems that include drawing ($p = 0.000$) are
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53 statistically significant. The post hoc analysis using Tamhane (for equal variances not
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3 assumed) shows that there is a statistically significant difference ($p \leq 0.000$) between the mean
4 scores for Group 1 ($M = 9,45$, $SD = 4.07$) and Group 3 ($M = 13.07$, $SD = 4.27$) and also for
5
6 Group 2 ($M = 10.15$, $SD = 3.46$) and Group 3 ($p \leq 0.000$). There is no statistically significant
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8 difference ($p = 0.458$) between Group 1 and Group 2 in success in drawing *SMRs*.
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15 **Discussion and implications for education**

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20 The first hypothesis relates to the difference in students' achievements between
21 chemistry problems that include reading *SMRs* and those that include drawing them, and can
22 be confirmed. It can be concluded that the average points scored by the students on items that
23 require reading submicrorepresentations are higher (by 14.1%) compared to the average points
24 for items that include drawing the *SMRs*. These results are consistent with some other research
25 (Kelly & Jones, 2008; Margel, Eylon, & Scherz, 2008) which indicate that students have
26 specific problems with drawing the correct submicrorepresentations of the natural phenomena.
27
28 The results indicate that teachers should devote more of their time in the classroom to
29 introducing to the students the purpose and the meaning of correct drawing of the *SMRs*.
30
31 These activities should be incorporated in all of the parts of the lessons, from introduction to
32 the new topic to students' evaluating their knowledge at the end. Teachers would collect useful
33 data by analysing students' drawing of *SMRs*, and on the basis of the conclusions could
34 modify future classroom activities to correct the discovered students' misinterpretations of
35 chemical concepts at submicro level. Teachers' view of the instructions and their pedagogical
36 knowledge - especially if they see the teaching as transfer of knowledge or as a process of
37 building the students' knowledge - influence teachers' realization of the chemistry lessons
38 (Valenčič Zuljan, 2007). Students' incomplete comprehension and/or misunderstandings of
39 chemical concepts play an important role in the teaching process. Teachers should carefully
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Independent variables and submicrorepresentations

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3 analyse such concepts, and their corrected forms should be integrated into the students'
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5 learning process.
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8 The difference is statistically significant, and further analysis shows a more detailed
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10 picture of some independent variables (i.e. gender, formal reasoning abilities, visualization
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12 abilities and intrinsic motivation for learning chemistry) and their influence on students'
13
14 achievements in solving problems comprising *SMRs*.
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17 The second hypothesis refers to the difference between males and females in solving
18
19 problems involving reading and drawing *SMRs*, and can not be confirmed. It can be
20
21 summarised that female students score significantly lower than male students in drawing or
22
23 reading submicrorepresentations while solving particulate problems. Bunce and Gabel (2002)
24
25 reported similar findings. They said that females score lower than males on the pre-test, but
26
27 after implementing the educational strategies that connect all three levels of chemical concepts
28
29 the significant gender score difference would diminish. The results reported by Barke and
30
31 Engida (2001) can explain the results found in this research. They anticipated that girls have
32
33 lower developed visualization abilities than boys, and they propose that students should use
34
35 different models and visualization material very early in the science education process to
36
37 stimulate development of visualization abilities. It can be speculated that visualization abilities
38
39 can influence motivation, and then hence the science problem solving achievements by both
40
41 males and females. During the educational process teachers should, therefore, pay more
42
43 attention to female students' progress in developing adequate mental models of chemical
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45 concepts regarding submicroscopic level through motivation for learning chemical concepts
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47 on all levels, thus stimulating the meaning of such learning for their professional career and
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49 everyday life.
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57 The third hypothesis is connected to students' formal reasoning abilities, and it can be
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59 confirmed. Results show that students with higher formal reasoning abilities are slightly more
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Independent variables and submicrorepresentations

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3 successful in problems that require reading than drawing *SMRs*. Drawing *SMRs* seems to be
4
5 more intellectually demanding than reading them, but results of the present study do not
6
7 confirm this assumption. It is also evident that students with developed formal reasoning
8
9 abilities are equally successful in reading or drawing submicrorepresentations as are those
10
11 students that reach transitional level, but there is a statistically significant difference between
12
13 concrete and formal reasoners. The difference between concrete and transitional reasoners in
14
15 reading or drawing *SMRs* is not significant. However, it is important to stress, that even
16
17 students on the concrete level of reasoning abilities are sufficiently capable of solving some
18
19 problems on submicro level. It is also evident that those students that fall into the group of
20
21 concrete or transitional reasoners had more difficulties with solving problems that involve
22
23 reading or drawing *SMRs* than those that fall into the group of formal reasoners. The lower
24
25 percent of explained variance was obtained by Gabel, Samuel, & Humm (1987) and Haidar
26
27 and Abraham (1991), that was attributed to the results on chemical concepts test 22.8 % and
28
29 17.5 % respectively of the variance by the students' reasoning abilities. The findings of the
30
31 present study are consistent with the findings of the study by Williamson and Abraham (1995),
32
33 who reported that 27 % of variance can be explained by formal reasoning abilities, and
34
35 Valanides (1998) reported similar results.

36
37 The fourth hypothesis is: "Students with higher visualization abilities score statistically
38
39 significantly higher on the items regarding drawing *SMRs*", but it can not be confirmed.
40
41 Results shows that, in the contrast with formal reasoning ability and its influence on students'
42
43 achievements in solving problems on particulate level, it can be concluded that visualization
44
45 abilities are not so strongly correlated with chemistry knowledge that refers to 2-D
46
47 submicrorepresentations. This is shown by the results, and only a small portion of variance on
48
49 the *CK* score can be explained by students' visualization abilities. Further analysis of variance
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51 shows, that differences between students with low and average, and average and superior
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Independent variables and submicrorepresentations

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3 visualization abilities are not statistically significant in most cases. It can, for that reason, be
4
5 emphasised that students can solve particulate problems even if their visualization abilities are
6
7 not so highly developed. However it is important to emphasise that there is no statistically
8
9 significant difference between students with different speeds of perception abilities in solving
10
11 problems regarding reading or drawing *SMRs*. On the other hand, somewhat bigger
12
13 differences can be determined regarding the use of 2-D submicrorepresentations between
14
15 students with different levels of spatial relations. The difference is not statistically significant
16
17 between students with average and superior spatial relations abilities. The difference between
18
19 students with poor and average spatial relations abilities is statistically significant in the total
20
21 *CK* score and reading *SMRs* score. However the difference is also significant on all three
22
23 levels of *CK* tasks, between students with poor and those with superior spatial relations
24
25 abilities. It can be concluded that chemical problems which include just 2-D
26
27 submicrorepresentations do not pose great difficulties in solving them, even for those students
28
29 with lower visualization abilities. These conclusions ought to encourage teachers to use
30
31 submicrorepresentations in classrooms, not just for laboratory work explanations, but also for
32
33 evaluating students' knowledge, without apprehension that students with lower abilities would
34
35 be discriminated. These results confirmed the predictions of Wu and Shah (2003) and Keig
36
37 and Rubba (1993) that secondary school students' chemical concepts test scores variance
38
39 would not be in a very large percentage accounted for by students' visualization abilities, but
40
41 by more general reasoning abilities. Gabel et al. (1987) also reported no significant correlation
42
43 between students' visualization abilities and achievements on the chemistry test that
44
45 comprises items on submicroscopic level. Higher correlations between visualization abilities
46
47 of secondary school students in Slovenia ($r = 0.472$; $p < 0.01$) were registered by Ferik
48
49 Vrtačnik, Blejec, & Gril (2003). Similar results were obtained also by Yang et al. (2003).
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Independent variables and submicrorepresentations

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3 These results may have their cause in different chemistry conceptual problems (3D model
4 manipulations, computer animations ...) that were used for evaluating students' knowledge.
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8 The last hypothesis relates to the students' intrinsic motivation for learning chemistry on
9
10 different levels of chemical concepts regarding the *ITLS* model, and it can be confirmed. It can
11
12 be summarised from the results that the correlations between *CK* scores, either in reading,
13
14 drawing or overall scores and intrinsic motivation for learning chemistry, are the highest
15
16 regarding motivation for the submicro level of chemical concepts, and the lowest regarding
17
18 macro level. From the ANOVA results it can be summarised that the differences between the
19
20 groups of students with different levels of intrinsic motivation is significant almost in all
21
22 cases, except for reading *SMRs* and intrinsic motivation for the experimental level of chemical
23
24 education. However it is important to emphasise that on all levels of *ITLS* intrinsic motivation
25
26 for learning chemistry, the difference between poor and average intrinsically motivated
27
28 students is not significant. According to these results, students with higher general or specific
29
30 chemical intrinsic motivation achieve higher scores on the chemistry test comprising reading
31
32 or drawing submicrorepresentations. Most students on all levels of education do like chemistry
33
34 at the macro level, so teachers should take advantage of this and extrinsically motivate
35
36 students through laboratory work. After this activity most students would have the chance to
37
38 develop intrinsic motivation for the macro level of chemical concepts, and after that the
39
40 intrinsic motivation for other two more abstract levels of *ITLS* model would evolve. To
41
42 achieve this goal, teachers encounter a difficult task in achieving a sufficient level of external
43
44 stimulation for students to become interested in chemistry, because students, at all levels of the
45
46 educational system, often do not realize the meaning of submicroscopic explanations of the
47
48 phenomena and their symbolic representations. It can be summarised that the most successful
49
50 in solving chemistry problems on different levels of the *ITLS* model would be those students
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52 that are highly intrinsically motivated for learning chemistry on the particulate level. Similar
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Independent variables and submicrorepresentations

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3 results of several studies were reported by Tuan et al. (2005), but their research shows a
4
5 slightly higher correlation between school science achievement and motivation ($r = 0.40$; $p <$
6
7 0.01). Previous research (Napier & Riley, 1985) also indicated that motivation has a moderate
8
9 but significant correlation with students' science achievement. The results obtained in this
10
11 study can confirm Keigs' and Rubbas' (1993) predictions, i.e. that motivation can be a
12
13 potential source of variance regarding students' success on the chemical concepts test. On the
14
15 other hand, Nieswandt (2007) reports the result of her study, that affective variables (students'
16
17 interest and attitudes for chemistry and their chemistry-specific self-concepts) do not have a
18
19 statistically significantly effect on conceptual understanding, but the results do reveal the
20
21 importance of strong and positive self-concept for developing a meaningful understanding of
22
23 science concepts.
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30 The main implication for teaching chemistry or chemical concepts in science education
31
32 is that teachers should encourage students and especially females in activities where they are
33
34 engaged in drawing submicrorepresentations. It is important that teachers at the beginning of
35
36 using *SMRs* in chemistry teaching use simple *SMRs*, especially when students have to draw
37
38 them. Teachers should in the process of chemistry teaching emphasise the meaning of correct
39
40 and accurate reading of the chemistry problem text. They should also stress the meaning of
41
42 the legends of particles and their names before students start to draw the *SMRs*. Students are
43
44 going to develop the abilities of drawing *SMRs* also when their formal reasoning abilities or
45
46 visualization abilities are not highly developed in relation to their age. It is also important to
47
48 stress, that students show an interest in understanding chemical concepts on a particulate level
49
50 and that they try to comprehend the bases of chemical phenomena on the level where
51
52 chemical reactions happen. On the other hand, students who enjoy learning chemistry only on
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54 the bases of symbols (chemical symbols of elements, formulae, equations) or observations of
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56 the experiments, without deeper understanding of the phenomena on particulate level, could
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3 not be very successful in achieving sufficient chemical knowledge. These findings indicate
4
5 that teachers ought to, nevertheless, encourage students to learn chemistry at the particulate
6
7 level. These attempts are going to be only external, and for students mostly unnecessary or
8
9 even discouraging and highly difficult to understand at the beginning of the educational
10
11 process. But with progress in understanding of the basic chemical concepts (e.g. atom
12
13 structure, chemical bond, etc), students' interest in understanding chemistry on submicro level
14
15 will increase and will bring them more success in getting better feedback from the teacher.
16
17 This type of chemistry teaching ought to result in the increase of intrinsic motivation for
18
19 deeper learning of chemical concepts on all levels of *ITLS* model. Teachers with adequate
20
21 chemical and didactical knowledge are able to conduct quality chemistry lessons by
22
23 transferring scientific knowledge into the classroom. It is important to direct pre-service
24
25 teacher students into the reflective way of teaching and into developing the constant need for
26
27 researching their own pedagogical practice (Vogrinc & Valenčič Zuljan, 2009). In-service
28
29 mentoring of beginning chemistry teachers (Author; Valenčič Zuljan, 2007; Valenčič Zuljan
30
31 & Vogrinc, 2007) and the provision of quality permanent in-service teacher education (Kalin
32
33 & Zuljan, 2007) are, beside the pre-graduate study, an important aspect in developing the
34
35 future teacher as a reflective practitioner. Permanent in-service teacher education ought to take
36
37 into account teachers' expectations and needs so that it can offer them the chance to develop
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39 competences to implement quality, also in the student oriented instructions model.
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Independent variables and submicrorepresentations

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Independent variables and submicrorepresentations

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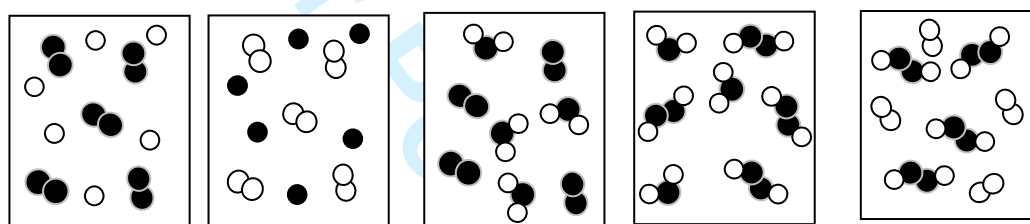
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3 **Appendix 1: Sample items from diagnostic instrument for determining *Chemical***
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5 ***Knowledge (CK).***
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10 Reading *SMRs*

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12 *Pure substances and mixtures*

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



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B

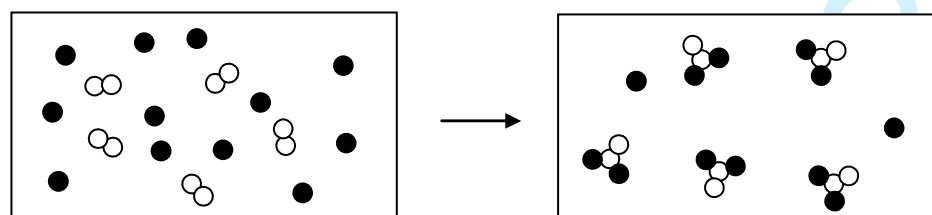
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35 *Chemical reactions*

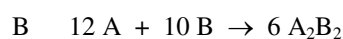
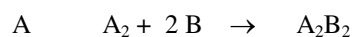
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37 The scheme represents the reaction between substance A and B. Which equation correctly represents this
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60 reaction?

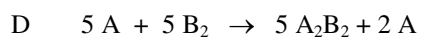
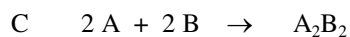


Mixture before the reaction

Mixture after the reaction

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



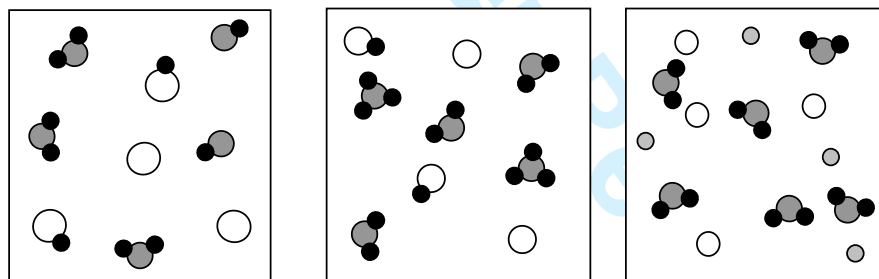


Which substance was completely used during the reaction? _____

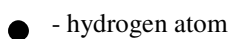
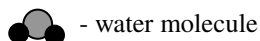
Elaborate the answer: _____

Electrolyte chemistry

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



Legend:



Answer the following questions.

Which scheme represents an aqueous solution of acid? _____

Which scheme represents an aqueous solution of base? _____

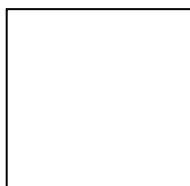
Which scheme represents an aqueous solution of soluble salt? _____

Independent variables and submicrorepresentations

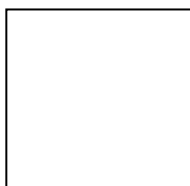
Drawing SMRs

Pure substances and mixtures

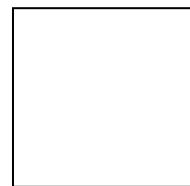
Water can be found in three states of matter in nature. Draw schemes to show different states of water. Draw ten water molecules in each box represented by ● and on the line write the correct state of matter represented in the box above.



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

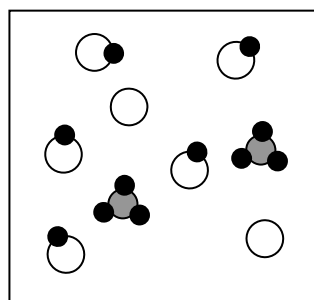
Draw a scheme to show the dissolved potassium bromide with optional concentration in water. Use the legend to illustrate the particles which you have used in the scheme. You need not draw water molecules.



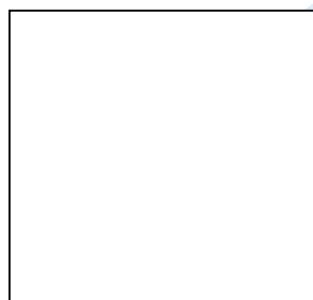
Legend: _____

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.

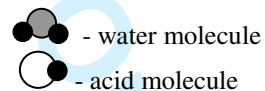


Scheme 1



Scheme 2

Legend:



Elaborate the answer: _____

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2
3 **Appendix 2: Sample items from the questionnaire Intrinsic Motivation for Learning**
4
5 **Science (IMLS)**
6
7

8
9
10 1. Emotional component of interest:
11

12
13
14
15 *I enjoy learning.*
16

17
18
19 *I am often bored during:*
20

21
22 ...chemistry course.
23

24 ... biology course.
25

26 ...physics course.
27

28 ... foreign language course.
29

30 ... mathematics course.
31
32
33

34
35
36 *I enjoy the chemistry course when:*
37

38 ...we observe chemical changes in experiments.
39

40 ...we learn about particles (atoms, ions, molecules).
41

42 ...we learn and write chemical symbols, formulae and equations.
43
44
45

46
47
48 2. Cognitive component of interest:
49

50
51
52
53 *I often look for additional information about school science topics in books, magazines, in the*
54
55 *internet, CDs ...*
56

57
58
59
60 *The media attract my attention when reporting on:*

1
2
3 ...chemistry topics.

4
5 ...biology topics.

6
7 ...physics topics.

8
9 ...foreign language topics.

10
11 ...mathematics topics.

12
13
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15
16
17
18 *I often think about:*

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

20
21 ... particles (atoms, ions, molecules), *also out of school.*

22
23 ...learning and writing chemical symbols, formulae and equations, *also out of school.*

24
25
26
27
28
29 3. Challenge component of internal motivation:

30
31
32
33
34 *I persevere with learning.*

35
36
37
38 *New problems in:*

39 ... chemistry, *challenge me.*

40
41 ...biology, *challenge me.*

42
43 ...physics, *challenge me.*

44
45 ...foreign language, *challenge me.*

46
47 ...mathematics, *challenge me.*

48
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54
55 *If I do not understand something, connected with:*

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

57
58 ...learning about particles (atoms, ions, molecules), *I give up.*

Independent variables and submicrorepresentations

1
2
3 ...learning and writing chemical symbols, formulae and equations, *I give up*.
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For Peer Review Only

Table 1. Descriptive statistics for *CK*.

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

Independent variables and submicrorepresentations

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

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

Independent variables and submicrorepresentations

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 <i>CK</i> score *	2, 107.07	17.05	≤ 0.000
Reading of <i>SMRs CK</i> score	2, 383	9.99	≤ 0.000
Drawing of <i>SMRs CK</i> 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

Independent variables and submicrorepresentations

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 <i>CS</i> score	2, 383	5.28	0.005
Reading of <i>SMRs CS</i> score	2, 383	1.90	0.151
Drawing of <i>SMRs CS</i> 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

Independent variables and submicrorepresentations

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 <i>CS</i> score *	2, 107.40	19.92	0.000
Reading of <i>SMRs CS</i> score	2, 383	12.92	0.000
Drawing of <i>SMRs CS</i> 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.

Independent variables and submicrorepresentations

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 <i>CK</i> score	2, 383	17.85	0.000
Reading of <i>SMRs CK</i> score	2, 383	10.94	0.000
Drawing of <i>SMRs CK</i> 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.