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Supplementary material

SUPPLEMENTARY MATERIAL TO

The influence of active learning and submicrorepresentations on 14-year-old students' understanding of the alkaline earth metal concepts

KATARINA SENTA WISSIAK GRM* and IZTOK DEVETAK

University of Ljubljana, Faculty of Education, Kardeljeva pl. 16, 1000 Ljubljana, Slovenia

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DETAILED DESCRIPTION OF THE INSTRUMENTS

Pre-tests (TOLT and KPT)

The level of students' formal reasoning abilities was obtained with the Test of Logical Thinking (TOLT).[40] 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, which are considered to be 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 ten items, two for each of the five modes of reasoning to be measured (*i.e.* controlling variables, proportional, correlational, probabilistic, and combinatorial reasoning). The test scores from 0-1 point (concrete reasoners), 2-3 points (transitional reasoners) and 4-10 points (formal reasoners) were used as a basis for classifying the students. Students spent 38 minutes solving the test.

TOLT – sample items

Sample question No. 1: Vegetable seeds

The gardener has bought a bag of three pumpkin seeds and three bean seeds. If the gardener takes only one seed from the bag, what is the probability that this seed is a bean?

A. 1/2 B. 1/3 C. ¼ D. 1/6 E. 4/6

1. four trials are required because three pumpkin seeds can be selected in a row.
2. one bean seed must be selected from the six seeds.
3. one bean seed must be selected from a total of three seeds.
4. half of the seeds are beans.

* Corresponding author. E-mail: katarina.wissiak@pef.uni-lj.si

5. in addition to one bean seed, three pumpkin seeds can be selected from all six seeds.

Sample question No. 2: Shopping mall

On the ground floor of the shopping mall, there are four spaces for new stores. TRADE IN COSMETICS (K), TRADE ALL 3 EUR (E), TRADE IN FOOD (H) and TRADE IN ANIMALS (Ž) want to move into these four rooms. Each shop can choose one of the four rooms. One way the shops could occupy the rooms is KEHŽ. List all the other possible ways the shops could be arranged in the rooms.

Write all possible answers on the lines below; more lines are drawn than there are possible answers. Possible combinations of shops KEHŽ ______ ______

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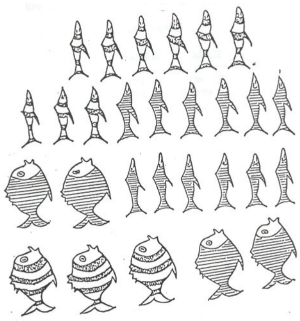
Sample question No. 3: Fish



Do fat fish have broad stripes rather than slender fish have broad stripes?

A. yes

B. no

Reason:

1. some fat fish have wide stripes and some have narrow stripes.
2. 3/7 of a fat fish has broad stripes.
3. 12/28 fish have broad stripes and 16/28 have narrow stripes.

4. 3/7 thick fish have broad stripes and 9/21 slender fish have broad stripes.
5. some fish with wide stripes are slim and some are fat.

The Knowledge Pre-Test (KPT) is a seven-item group paper-pencil test, composed of open-ended and multiple-choice items. All concepts tested in this pre-test were taught later on during lessons or students had to understand specific concepts before the application of the specific educational strategy. The KPT showed satisfactory measuring characteristics (*i.e.*, internal consistency reliability/Cronbach's alpha was 0.81; discriminate indexes for every item between 0.34 and 0.68 were all statistically significant). Kurtosis (0.67) and Skewness (0.96) coefficients show normally distributed data. KPT was designed specifically for this study and was administered by two university chemistry and chemical education professors.

Their responses provided content validation for the instrument. Students could achieve 12 points on KPT; they spent 10 minutes on average to solve the test.

KPT - sample items

Sample question No. 1

What do we call the group of elements in the periodic table in which the magnesium and calcium are classified? ____________________ .

Sample question No. 2

Calcium reacts with water. Name the particles that will result in the chemical reaction?

a hydrogen molecules
b hydrogen atoms
c calcium ion
d calcium atom
e calcium hydroxide molecules

Write the correct answers ____________________

Sample question No. 3

Adding a few drops of phenolphthalein into the beaker after the reaction between calcium and water will turn the colour of the solution into violet. Explain why?

Achievement Tests (AT-1 and AT-2)

Both achievement tests were structured according to the concept analysis of the topic introduced in the classroom (*i.e.* alkali earth metals) not depending on the educational strategy used. The Achievement Tests 1 (AT-1) was a six-item group paper-pencil test, composed of open-ended and multiple-choice questions. The AT-1 comprises similar chemical concepts as KPT. The AT-1 showed satisfactory measuring characteristics (*i.e.* internal consistency reliability/Cronbach's alpha was 0.73; discriminate indexes for every item between 0.29 and 0.85 were all statistically significant). Kurtosis (0.83) and Skewness (-0.32) coefficients show normally distributed data. AT-1 was designed specifically for this study, and its content validity was determined by two university chemistry and chemical education professors. As a comprehensive achievement test, the use of the AT-1 achievement test was immediately administered after students had been exposed to the specific educational strategy. Students could achieve eleven points on AT-1. Students spent 10 minutes on average on solving the test. They did not receive any feedback about their success in solving the AT-1.

Achievement Tests 1 (AT-1) - sample items

Sample question No. 1

Which particles are formed when calcium reacts with water?

a hydrogen molecules
b hydrogen atoms
c calcium ions
d calcium atoms
e calcium hydroxide molecules

Select the correct answers: ______________

Sample question No. 2

You have learned about calcium and magnesium reactivity; can you anticipate the reactivity of the second group of elements in the periodic table? With an arrow indicate the increasing reactivity of the second group elements.

beryllium magnesium calcium strontium barium

Sample question No. 3

Write the chemical equation between an element that was selected in the sample question 2 with the cold water.

____

The Achievement Tests 2 (AT-2) was also a six-item group paper-pencil test, composed of open-ended and multiple-choice questions. Understandably, the questions asked were similar to those in the previous tests (KPT and AT-1), since the same chemical concepts were to be assessed. The AT-2 showed satisfactory measuring characteristics. Its internal consistency reliability - Cronbach's alpha was 0.81; discriminate indexes for every item between 0.34 and 0.68 were all statistically significant. Kurtosis (-0.39) and Skewness (0.14) coefficients show normally distributed data. AT-2 was designed specifically for this study and was administered by two university chemistry and chemical education professors. Their responses provided content validation for the instrument. As a delayed achievement test, the AT-2 test was administered two weeks after the specific educational strategy was applied in the classroom. Students could achieve twelve points on AT-2. They spent 10 minutes on average to solve the test.

Achievement Tests 2 (AT-2) - sample items

Sample question No. 1

The cleaned surfaces of calcium and magnesium have a metallic shine. If we leave them for a longer time in the air, they lose this shine. Explain why this happens.

Sample question No. 2

Which chemical equation represents the reaction of an element that reacts with cold water?

A $Ca(s) + 2\ H_2O(l) \rightarrow 2\ Ca(OH)_2(aq,s)$
B $Ca(s) + 2\ H_2O(l) \rightarrow Ca(OH)_2(aq,s) + H_2(g)$
C $Mg(s) + 2\ H_2O(l) \rightarrow Mg(OH)_2(aq)$
D $Mg(s) + 2\ H_2O(l) \rightarrow MgO(aq) + H_2(g)$

Sample question No. 3

Adding a few drops of phenolphthalein into the beaker where calcium reacts with water will turn the solution from colourless to violet. What can you conclude from this observation?

A The solution has become acidic.
B The solution has become basic.
C The solution has become neutral.
D The acidity or basicity of the solution has not changed.

The concept structure of both achievement tests (AT-1 and AT-2) was similar in order to compare results and obtain data for drawing adequate conclusions. Neither test comprised any items that required specific knowledge about reading or drawing submicrorepresentations for solving the items. Statistically significant correlations between the knowledge tests ($r = 0.37$) show that the tests used in the research do measure similar chemical knowledge.

Detailed description of the teaching approaches in specific group

After the teachers applied the innovative teaching approach, they reported in detail to the researchers how they had followed the researchers' instructions. It was found that all the teachers followed the instructions appropriately, which means that the validity of the teaching strategy used was ensured.

To carry out the active learning method, special material for supporting guided active learning demonstrations (EXP1 and EXP2) was developed, in which every stage of the experimental work is quoted to enable students to follow (observe and explain) the experiment. In the material developed for a guided active learning demonstration, there are target questions, given to help teachers point out the specific phases of the experiment and help students observe and understand them. Students were given the form for a guided active learning demonstration in which all the crucial stages of the experimental work with matching questions were fulfilled. Students had to complete the columns for observations and conclusions, which were blank, during the chemical demonstration performed by the teacher.

Teachers' guide instruction form for an active learning demonstration: (students had to fill in only the white part of the table)

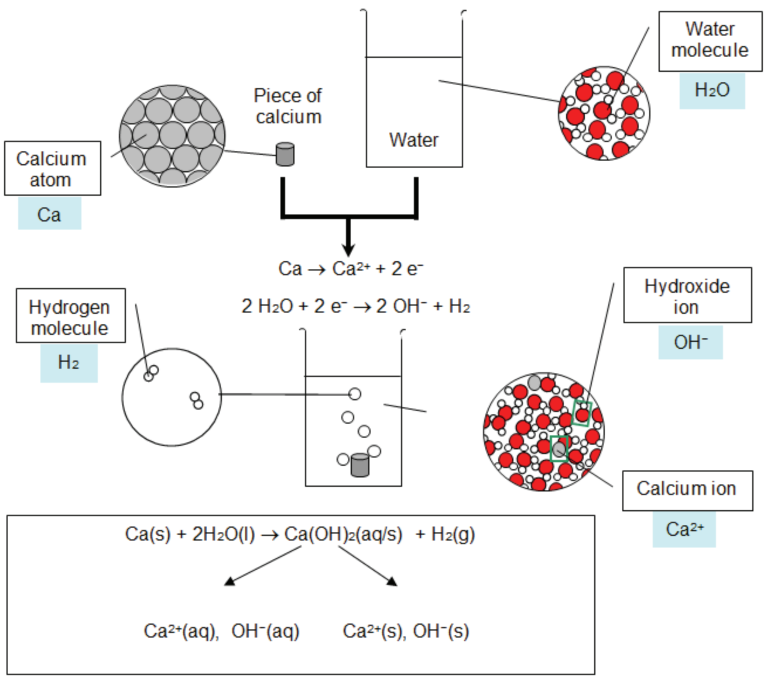
Stages of experimental work	Questions	Observations	Conclusions
1. Observe the appearance of the magnesium.	Can you notice the metallic shine? Do you think magnesium reacts with oxygen from the air?	Yes, magnesium has a metallic shine.	Magnesium reacts with oxygen from the air very slowly, so it keeps on shining.
2. Observe the appearance of calcium.	Can you notice the metallic shine? Do you think calcium reacts with oxygen from the air?	No, calcium does not have a metallic shine.	Yes, calcium reacts with oxygen from the air.
3. Drop a small piece of magnesium into the beaker with cold water.	Do you notice any changes?	No, there are no changes.	
4. Add a few drops of phenolphthalein into the beaker with magnesium and cold water.	Does the indicator change its colour? Do you think magnesium reacts with water?	No, phenolphthalein does not change its colour.	No, magnesium does not react with water during the time needed for the experiment. If we had more time, some changes might be observed.
5. Drop some granules of the calcium into the beaker with cold water.	Do you notice any changes?	Yes, we can observe bubbles of gas going out of the solution. The solution has turned muddy.	Calcium reacts with water. The reaction products are gas and some poorly soluble substance.

6. Add a few drops of phenolphthalein into the beaker with calcium and cold water.	Does the indicator change its colour? Do you think calcium reacts with water?	Yes, phenolphthalein does change its colour, since it turns from colourless into violet. White precipitate is formed.	The reaction product has basic properties.The product is poorly soluble in water; it might be calcium hydroxide.

Experimental demonstrations of the AEMP were performed by the teachers, because alkaline earth metals are very reactive, and dangerous for the 14-year--olds to handle. Slovene legislation also advises against students' individual or group experimentations with potentially dangerous substances in the classroom; therefore, the potentially more dangerous experiments are demonstrated by teachers. After the joint final discussion, students verified the correctness of their answers with the teachers. After that, this material was no longer used and could not be used while taking the achievement tests.

In addition to the form for guided active learning demonstrations, it was required that a PowerPoint presentation be developed to explain the reaction at the submicroscopic level for carrying out the EXP2. The presentation was developed in such a way that separate parts of the final picture were presented to the students. The last slide completed the whole picture.

The final PowerPoint slide of schemata of particles (*i.e.*, submicrorepresentations (SMRs) used in EXP2:



This explanation took a teacher about 10 min. The 10-min period was used only for explaining one experiment (reaction of calcium with water at three levels of chemical concepts) and also because students are used to teachers' explanations of experiments by schemata of particles (*i.e.*, submicrorepresentations (SMRs)). The time used in the EXP2 for explaining SMRs (10 minutes) was used in the CONT and EXP1 group for the activities that were not connected with the research situation (checking homework from previous lessons).

The control group was taught using the symbolic representation of the selected chemical concepts and was supported by chemical equations and teachers' explanation but was carried out without a chemical experiment and its explanation at the submicroscopic level. Teachers used photographs of the final stages of the experiments while explaining AEMP to the students in the control group. Students could observe the color of the solution (violet), and the formation of bubbles of the gas on the photo.

Students were exposed to the symbolic level (chemical symbols and equations) in the CONT and EXP1 group in such a way that teachers attempted to explain the observations from the final photo of the experiment (CONT) or from the chemical demonstrations (EXP1). Students were guided in writing chemical equations by the teacher, following the teachers' explanations of the observations. In the EXP2 treatment group, the symbolic level was introduced after the sub-microlevel of the particle interaction in the discussed reactions of alkaline earth metals had been explained. The static submicro-models of different particles interactions presented with the PowerPoint slide were translated into the chemical symbols and formulae and connected into the chemical equations. Students were familiar with SMRs for explaining experimental observations.

Students who participated in the EXP2 were exposed to such a teaching approach approximately for 1.5 years (chemistry in Grade 8 and half of Grade 9). All three groups of students participating in this study were familiar with the approach of presenting chemical concepts on three levels, because they had learned different topics by using SMRs (*e.g.*, chemical reaction, chemical bonds, acids, and bases are among the topics of Elements of the Periodic Table, which is part of the national curriculum in Slovenia for chemistry). From the topic Elements of the Periodic Table, only reactivity of the second group of elements (according to the curriculum teachers spend approx. one school hour on this subtopic) was presented in this paper.