Chemical education research paper

The Influence of Different Models on 15-years-old Students' Understanding of the Solid State of Matter

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Abstract

Different models are an indispensable part of teaching and learning chemistry for students to develop adequate mental models of solid states of matter. The aim of this study was to establish the importance of using physical models (teachers' demonstrations and students' modelling) and virtual models of solid states in the educational process for students' to acquire a better understanding of the crystal structures of substances. First year grammar school students (average age 15.4 years) participated in the study. All students were divided into three groups, depending on what sort of activity involving models was used in the chemistry teaching and learning process. The solid state of matter was taught in the first group by students' constructing physical models. In the second group virtual models were used, while the third group was taught by teachers' demonstration of physical models. Students' understanding of the solid state structures was assessed with a knowledge test after the educational strategy, whereas the knowledge retention was evaluated one month following the applications of the teaching strategies with the delayed test. The students who modelled physical models scored better on the test than did the students who used virtual models and also those who were taught the solid state of matter by the teachers' demonstration of physical models. Those students who used virtual models or modelling during chemistry learning achieved statistically the same results on the delayed test, whereas the students who were exposed to the teachers' model demonstration achieved the lowest test score. It can be concluded that students who are engaged in active learning strategies that include modelling or computer interaction using virtual models develop more adequate mental models of solid state substance structures.

Keywords: Structure of solids, physical models, virtual models, modelling

1. Introduction

Models are created on the basis of the matter structure research and its mathematical characteristics. The deeper the science delves into the world of particulate matter, the more defined these notions are, and the more reliable becomes the reflection of the real state in the models; thus, models are being constantly changed in line with scientific achievements.[1] Models as a didactic aid have been used in teaching science for a long time.[2] As early as in 1813 Frideric Accum supported the text he wrote with models representing crystal structures. The first physical models were used for demonstrations.[3,4] In textbooks almost never is the text on crystal structures to be found without the description or a picture of the model of the ionic crystal of the sodium chloride structure.[5,6,7,8]

In order to show the layers of constituent parts in crystal structures, commercially accessible balls of polystyrene have been used since 1958,[9] usually connected with wooden rods. In 1957 Westbrook and Devries wrote about the model to illustrate the crystal structure, in which the positions of the constituent parts in the structure were additionally marked with lights.[10] Bodner et al. mentions the tool which is intended for illustration of the different unit cells models.[11] The models illustrating the arrangement of constituent parts in unit cells are described by Kildahl et al. They presented the framework from plexiglass with shelves containing the ball grooves.[3] A similar framework with instructions for its making was also described by Mattson.[12]

The models demonstrating the solid state structure are also accessible on web sites; besides, many workbooks include CDs with animations and movies with interactive models of crystal structures.[13,14,15,16,17,18] Interactive models of 3D crystal structures are also found on home pages (e.g. Keminfo)[19].

It has been established that if teachers often use models in teaching the structure of the matter, the perceptions of pupils and students – within their cognitive abilities – are more developed than if they are taught without application of the models.[20,21] In teaching, one should carefully select and apply models and draw attention to their integration into the education process.[22] Unprofessional application of models can do more harm than good.[23,24] It was established that many students were not able to connect the formula of the compound with the model of its molecule.[22] Students also have difficulties when transferring from 2D to 3D chemical structure presentations.[25] Much research has been conducted on the information value of different types of models, such as: physical models (models of molecules or crystalline structures for manual handling, such as sticks, spacefill, wireframe or ball & stick models) and virtual models (the same physical models of molecules or crystalline structures presented in the computer environment). In the last decade of the previous century was the impact of the application of different types models on the understanding of science concepts studied in parallel to the development of dynamic computer simulations. It has been also established that the application of physical models contributes to the understanding of molecular structures.[26] It was concluded by Ferk Savec that pupils, secondary school students and university students performed better at visualization tasks in a chemistry test, in which molecules were presented by a photo of a three-dimensional ball & stick physical model and the virtual model, respectively, than at tasks including abstract schematic and symbolic molecular recording.[27]

The results of the research in which the students were using the eChem visualization tool for constructing molecular models showed that the students achieved a higher cognitive level of understanding chemical structures than when dealing with the same content without this tool. The students who could construct models of balls, sticks, wire and calotte preferred those made of balls and sticks. By applying these models they were also more successful at defining functional groups in organic molecules and at establishing the differences among chemical structures. The students found the wire models too abstract. In analysing the interviews of this research, the students wished to apply different model types, since in this way individual characteristics of molecular structures can be more or less clearly presented.[22]

Computer models are important for mental perceptions of a molecular structure. The application of computer dynamic 3D animation models enables visualisation of interactions among molecules, contributing to developing submicroscopic perceptions and symbolic records of chemical processes.[22] It is important to emphasize that computer models are not real 3D models; nevertheless, their application contributes to visualizing chemical structures, especially with those students whose spatial perceptions are not so well developed.[28]

Gabel and Sherwood showed that the application of physical models had a positive impact on memorizing (a long-term cumulative effect on students' understanding).[29] Copolo and Hounshell compared the impacts of the application of physical and 3D computer models on the understanding of organic structures.[26] The students who applied both types of models scored better at memory tests than the students who only applied physical models. This is a proof that more visualization aids enhance the ability to memorize and understand crystal structures. Several researchers have established that it is possible to eliminate misunderstanding of the particulate nature of matter by applying computer animations including the models representing the structure of matter; however, one cannot always guarantee success.[30,31,32,33]

On the other hand research shows that a teaching sequence based on the "Model of Modelling" is a valuable basis on which to lead students to a sound understanding of the complex ideas of chemistry and to the demonstration of metavisual capability.[34] Modelling, defined as the dynamic process of producing, testing, and revising a model, is a core skill in scientific enquiry. Authentic science education, based as closely as possible on scientific practice as educational circumstances will allow, must therefore include the development of the skills of modelling.[35]

1. 1. The Purpose of the Research, Research Question and Hypotheses

The aim of the research was to establish the contribution of applying three different models of teaching the structure of solids (i.e. demonstration of physical models, independent constructing of physical models and the application of virtual models) to the understanding and memorizing of the structure of solids by students.

The basic research question is: Which teaching approach using different activities with models to teach solid states of matter contributes to more effective students' knowledge? According to the research question four hypotheses were formulated:

H1: Students who are exposed to modelling physical models or using virtual models score significantly higher on the knowledge test than students who are taught by the teachers' demonstration of models.

H2: Students who construct physical models score significantly higher on the knowledge test than students who are exposed to virtual models.

H3: Students who construct physical models or use virtual models will perform significantly better at the delayed test than students who are taught by the teachers' demonstration of models.

H4: Students who model physical models will perform significantly better on the delayed test than students who are taught by the virtual models.

2. Method

2. 1. Participants

Overall 170 first year secondary school students (80 males and 90 females) participated in the study in the school year 2008/2009. Students were from two general secondary schools (high school). The chemistry curriculum of the Gymnasium is common to all students. The students attended the third year of chemical education in the period that testing occurred (two years in higher primary school – age 13 and 14 and first year in secondary school – age 15). Both schools were located in smaller towns (between 35,000 and 100,000 residents). The sample represented a predominantly urban population with mixed socioeconomic status. All students were divided into three groups: group A 59 students, group B 56 students and group C 55 students. On average, the students were 15.4 years old (M = 195.4 months; SD = 4.8 months). There were no significant differences between the students' pre-knowledge before participating in the specific group (for more details see the Results section).

2. 2. Instruments

2. 2. 1. Pre-test

The Chemical bonds pre-test comprises fifteen items, out of which there are thirteen multiple choice items. Two items are open-ended. The maximum score to be achieved on the pre-test is 15 points. The pre-test showed satisfactory measuring characteristics. Internal consistency reliability using Cronbach's alpha was 0.56. The evidence of construct validity of scales was calculated with "item-total score" correlation using Pearson's correlation coefficient (all items were described as appropriate; $r < 0.20$). The pre-tests' content validity was confirmed by three chemistry teachers and two chemistry education researchers. Students had 30 minutes to solve the pre-test. Pre-test sample items are presented in the Appendix.

2. 2. 2. The Test and the Delayed Test

The items, both in test as well as in the delayed test, were the same. They comprise nineteen items summarized from the chemistry Matura exam (general upper secondary school-leaving external examination). Fourteen items are multiple choice questions with one correct and one incorrect answer, respectively, whereas five items are open-ended. Twelve items comprised pictures of the crystal models and unit cells. The maximum score on the test was 30 points. The test and the delayed test showed satisfactory measuring characteristics. Internal consistency reliability using Cronbach's alpha was 0.60. The evidence of construct validity of scales was calculated with "item-total score" correlation using Pearson's correlation coefficient (all items were described as appropriate; $r < 0.20$). The content validity of the test and the delayed test was confirmed by three chemistry teachers and two chemistry education researchers. Students had 40 minutes to solve the test and the delayed test. Sample items from both tests are presented in the Appendix.

2. 3. Research Design

The design of the research was experimental and quantitative in nature. All students were divided into three groups. In group A students were taught the solid state structure by the teachers' demonstration of physical models (i.e. demonstrations), in group B by students' modelling of physical models (i.e. modelling), and in group C by students' using virtual models displayed on the computer screen (i.e. virtual).

Prior to applying the teaching approach in a specific group of students (from A to C) a pre-test was applied, comprising items testing chemical bond concepts, in order to assess their pre-knowledge important for understanding solid state structures at the particulate level. Students were divided into three groups by the pre-test score. There were no statistically significant differences regarding the average pre-test scores among the students of all three groups (F = 1.45; df = 2; df = 165; p = 0.237), which means that the students presented similar pre-knowledge that can influence their understanding of the concepts of solid state structure during students' learning process in a specific educational strategy.

The group A students were demonstrated models of sodium chloride and cesium chloride, models of the diamond and graphite, models of the simple unit cell and of the body centred cell, as well as a model of the hexagonal and cubic most dense array.

The group B students constructed these models from polystyrene balls, toothpicks and glue. Balls made of polystyrene served to demonstrate atoms and ions, respectively, whereas toothpicks were used to demonstrate bonds. The size of the polystyrene balls was proportionate to the size of the atoms and ions of elements, respectively. For a clearer presentation the polystyrene balls were coloured differently for each specific element. Students received worksheets with a task to construct a model. They could search for pictures of models from books or the Internet and discuss them with their teacher to make a plan for designing their own model.

The group C students learned the concepts by using the computer to display virtual models. The CD, used by the students, contained instructions on how to view virtual models. The CD was developed by one of the researchers. It contained 13 interactive models of crystalline structures. The students could rotate virtual models automatically with a command or a mouse; they could choose the type of models, ranging from sticks to spacefill, wireframe to ball & stick. The view and manipulation of the models was enabled by the Raswin software. Each student could use one computer and manipulate models to learn about the crystalline structure. Students attended seven 45 min lessons taught by an experienced teacher who is also a member of the research group. All three groups were taught by the same teacher who applied specific educational strategy, i.e. the sequence of presenting concepts about crystalline structure was identical, supported by PowerPoint presentation (two sample slides are presented in the Appendix 2). The difference in teaching between the three groups was in the way the models were presented to illustrate different structures (group A – teachers' demonstrations of physical models, group B – modelling physical models, and group C – visual model manipulations).

The understanding of the structure of solid matter was assessed by a test after the topic had been dealt with using different models, while the retention of the adequate knowledge about the structure of solid matter, respectively, was examined by the same test, which was used as a delayed test, one month after teaching the selected concepts.

Descriptive statistics were obtained for illustrating students' scores on the pre-test, knowledge test and delayed knowledge test. The one-way between-groups analysis of variance (*ANOVA*) was conducted to explore the influence of different educational strategies using different models and modelling while teaching and learning about solid states of matter structures on students' test scores. The *ANOVA* was also used to determine the significance of pre-knowledge in all three groups of students prior to applying the educational strategy.

3. Results

The students of all three groups took the pre-test on chemical bonds (pre-knowledge). The *ANOVA* showed no significant differences between the students' pre-knowledge about crystalline structures in groups A (demonstration), B (modelling) and C (virtual) in the average knowledge test scores ($F = 1.45$; $df = 2$; $df = 165$; $p = 0.237$). Immediately after the applied teaching strategy students took the test on crystal structures and after one month students took – according to content – the same test, the delayed test on crystal structures.

3. 1. Students' Achievements After the Application of Educational Strategies

The students exposed to the modelling teaching strategy in constructing their own physical models performed better on the knowledge test (average score 67.5%) than did the students who learned the same topic by using virtual models (average score 65.5%) or by the teachers' demonstration of the models while learning about solid state structure. The students who were taught by the demonstration of the models did not even score half of the total points (average score was only 48.0%) on the knowledge test immediately after the teaching strategies were applied.

The potential statistically significant differences between the A, B and C group students in the averages of their performance on the crystal structures knowledge test were established by a one-way variance analysis (*ANOVA*). The ANOVA showed significant differences between the students in groups A (demonstration), B (modelling) and C (virtual) in the average knowledge test scores ($F = 14.88$; $df = 2$; $df = 165$; $p \leq 0.000$).

Post hoc analysis using Tukey HSD showed that there is a statistically significant difference ($p \leq 0.000$) in the students' average knowledge test score between those who constructed physical models ($M = 20.36$, $SD = 5.05$) and those who were taught by the teachers' model demonstration ($M = 15.81$, $SD = 4.99$), and between the group of students who used virtual models ($M = 19.77$, $SD = 4.10$) and the group of students who were taught by the demonstration of the physical models by the teacher ($p \leq 0.000$).

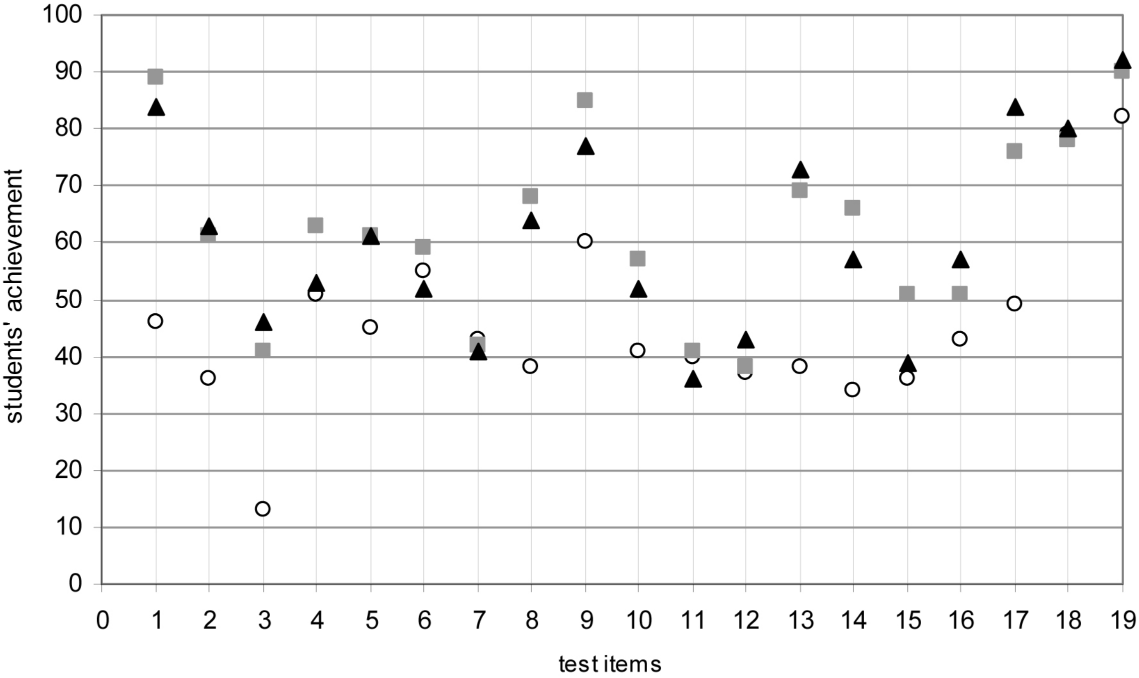
There were no statistically significant differences in average knowledge test scores between the students who constructed physical models and the students who used virtual models during chemistry learning about solid matter structure ($p = 0.784$). The students to whom the models application was demonstrated lagged behind the students who constructed physical models and also the students who were taught by virtual models for understanding the solid ionic, molecular, covalent and metallic matter structures.

More detailed analysis of students' achievement for specific test items are presented in Graph 1 below.

As can be seen from Graph 1, students who were modelling physical models were performing better in eight tasks compared to those who were only manipulating virtual models using computers. The differences in the results for five items in which properties of crystals were tested (out of 7 items) and did not require a presentation of structures, are not noticeable. In nine tasks (out of 12 items) the students, who were making physical models and those who were manipulating virtual models were performing better than those to whom physical models were only demonstrated by the teacher. With these tasks we tested the comprehension of crystal structure using pictures.

3. 2. Students' Achievements One Month After the Application of Educational Strategies

Students' integration of chemical concepts regarding the structure of ionic, molecular, covalent and metallic structures into their long-term memory, and the impact of the specific interventional approach on this process, was determined by the analysis of students' achievements on



Graph 1. Students' test achievements.

Legend: ○ - demonstrations; ▲ - virtual; ■ - modeling

the delayed test. Results show that students who were, during the chemistry teaching, exposed to teachers' demonstrations achieved the lowest score on the delayed test. On average they scored 54%. Students who used modelling and virtual models in their learning process about solid states of matter scored 62.3% and 63.9% on average, respectively.

According to the results of the one-way analysis of variance (*ANOVA*) there are statistically significant differences between the students who participated in the different educational strategies (teachers' physical model demonstrations, students' modelling and students' visual models manipulations) on the delayed test (F = 6.05; df = 2; df = 153; p = 0.003).

Post hoc analysis using Tukey HSD showed that there is a significant difference (p = 0.027), between the students who constructed physical models (M = 18.58; SD = 4.07) and the students who were taught by the demonstration of the physical models by the teacher (M = 16.19; SD = 5.00). The difference in knowledge obtained about the solid state of matter after one month was also significantly different (p = 0.004) between the students who used virtual models (M = 19.17; SD = 4.83) and those who were taught by the teachers' demonstration of the physical models of different solid state structures at the particulate level.

The best performance on the delayed test was expected with the students who constructed physical models, because they were actively engaged in the modelling process and did not just view the models presented by the teacher or on the computer screen. However, the students using virtual models achieved somewhat better results on the delayed test than those who constructed their own physical models, although the difference between these two groups is not statistically significant (p = 0.797).

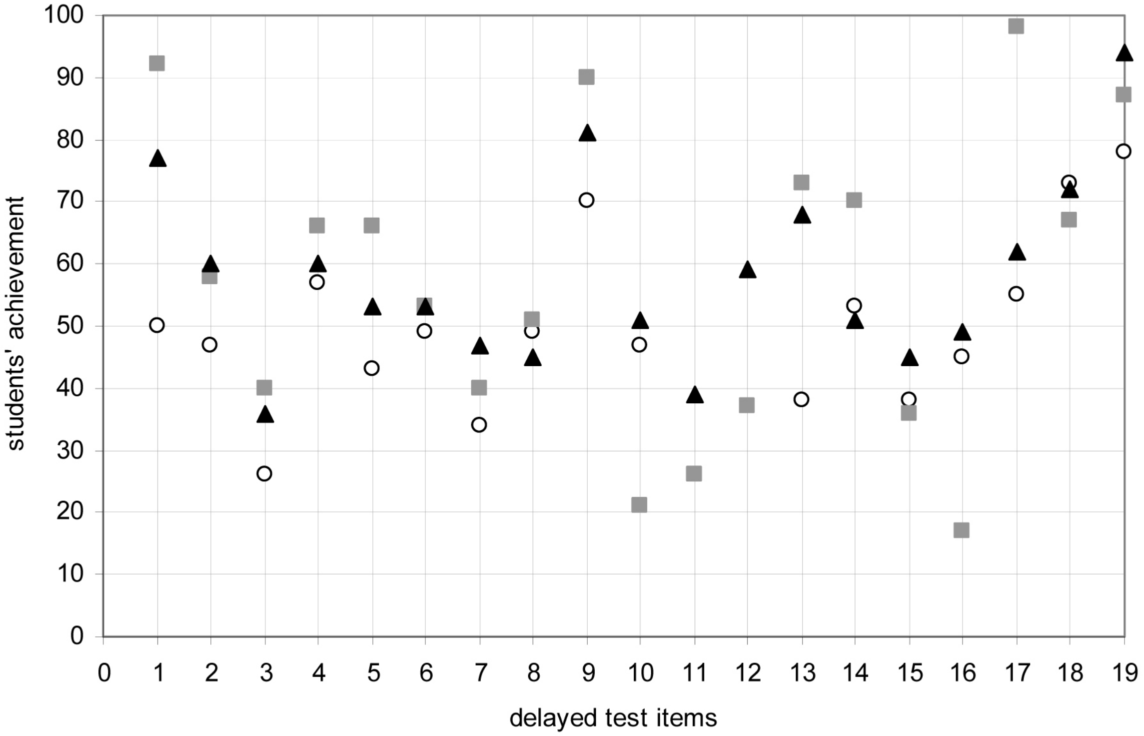
More detailed analysis of students' achievement in specific delayed test items are presented in Graph 2.

The results from Graph 2 show that students achieved similar results in the delayed test, which indicates that previous knowledge has been retained. Those students who had to model physical models were more successful in solving nine tasks compared to the students from the other two groups (demonstration of physical models, virtual models). Similar results were observed also in other tasks (7 items) in the delayed test in which we checked student comprehension of the properties of crystals.

4. Discussion and Implications for Education

According to the research question four hypotheses were formulated.

The first hypothesis stating that: "Students who are exposed to modelling physical models or using virtual models score significantly higher on the knowledge test than students who are taught by the teachers' demonstration of models", is confirmed. It can be summarized that on average 15.4-year-old students who were exposed to the modelling activity and those who used virtual models to learn about ionic, molecular, covalent and metallic structures of solid substances were more successful on items testing understanding of the solid matter structure than students who were taught by demonstration of the



Graph 2. Students' delayed test achievements.

Legend: ○ - demonstrations; ▲ - virtual; ■ - modeling

models by the teacher. These results seem to indicate that students who were actively engaged in the modelling process perform better on the knowledge test. This modelling process refers to active construction of the physical models following instructions, but results show that even limited manipulation of the models on the computer screen can significantly improve students' understanding of solid state crystalline structures. Barke and Engida also concluded that students' modelling contributes to their better cognitive development.[20]

The second hypothesis stating that: "Students who construct physical models score significantly higher on the knowledge test than students who are exposed to virtual models." is not confirmed. If the average students' achievement on the knowledge test, applied immediately after the teaching strategy, is compared between the three groups of students, it can be seen that students who construct their own models score better than those students who handle with virtual models. Statistical analysis, on the other hand, shows that students constructing physical models did not show statistically significant differences in understanding of the solid matter structure than did the students using virtual models. Similar results were obtained also by Coll et al.[21] Ferk Savec also concluded that students exposed to virtual models visualize molecular structures more adequately than those who were exposed only to written structural formulae of compounds.[27]

The third hypothesis predicts, that students who construct physical models or virtual models will perform significantly better on the delayed test than students who are taught by the teachers' model demonstration. This hypothesis is confirmed. It can be concluded from the results that students who construct physical models or observe and manipulate virtual models on the computer screen were more successful at achieving better delayed test scores on items testing the structure of solid matter than those students who were taught the structure of solid substances by the teachers' demonstration of models. These results are consistent with findings by Wu et al. They concluded that using the eChem visualization tool for constructing molecular models showed that the students achieved a higher cognitive level of understanding chemical structures.[22]

The last hypothesis says that students who model physical models will perform significantly better on the delayed test than students who are taught by the virtual models. This hypothesis is not confirmed. It can be summarised that students exposed to virtual models of solid state structures do not performed significantly better on the delayed knowledge test than those who were taught by modelling activities. This means that students obtain similar knowledge of solid state structures also by using virtual models, and not only by modelling activities with physical models. These results are consistent with results obtained by Wu et al. They concluded that computer models are important for developing mental perceptions of a molecular structure. The application of computer dynamic 3D animation models enables visualisation of interactions among molecules.[22] Barnea and Dori also summarised that the application visualization models contributes to visualizing chemical structures, especially with those students whose spatial perceptions are not so well developed.[28]

The overall conclusions indicate that teachers should place more emphasis on students' modelling or using adequate computer programs to demonstrate structures of different substances, so that students can actively visualise the structures. When given only teachers' demonstrations of structures of matter with models, students do not receive enough adequate information. Therefore, students are not able to process this information properly and are not able to integrate it into the mental structures already formed in their long-term memory. We also identified some misconceptions, which are the following: (1) students could not distinguish between crystal systems and unit cells; (2) from the model they were unable to decide which particles in the unit cell belong to the adjacent cells; (3) by calculating the number of particles in the unit cell from the picture they drew a formula Zn_6S_{14} for ionic compound; (4) using a picture of an ionic crystal they could not deduce the coordinate number; (5) they did not understand the concept of isostructurality; (6) they could not distinguish between models of different allotropic carbon modifications; (7) they could not distinguish between two close-packed structures of metal crystals, and (8) they could not distinguish between ionic and molecular crystals. These misconceptions and incomplete conceptions were mainly observed in the group of students who were exposed to teachers' physical model demonstrations. This consequently leads students to new misconceptions or incomplete conceptions related to other chemical concepts, such as solution chemistry, electrolyte chemistry, etc. According to this analysis, teachers should put more effort in explaining these concepts in more detail using different active learning methods, such as GALC approach for example.[36]

In the future, virtual models will most likely prevail and develop even further, because of the informational communicational technology (*ICT*) development; however, virtual models will not fully replace physical models in the chemistry classroom at all levels of education, because students are able actively to build or construct the physical models, which also have a high information value.

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Povzetek

Različni modeli povezani s trdnim agregatnim stanjem snovi so pri poučevanju in učenju kemije nepogrešljivi, saj na njihovi osnovi učenci oblikujejo ustrezne mentalne modele. Namen študije je ugotoviti pomen fizičnih modelov (učiteljeva demonstracija modela in učenčevo modeliranje) in virtualnih modelov trdnega agregatnega stanja snovi na učenčevo ustrezno razumevanje kristalne zgradbe trdnih snovi. V raziskavi so sodelovali dijaki prvega letnika splošne gimnazije (povprečno stari 15,4 let). Dijaki so bili razdeljeni v tri skupine, odvisno od aktivnosti povezane z modeli trdnih snovi, ki so ji bili izpostavljeni med procesom poučevanja in učenja kemije. V prvi skupini so dijaki konstruirali oz. modelirali svoje lastne fizične modele na osnovi slik. V drugi skupini so dijaki uporabili virtualne modele, medtem ko je v tretji skupini učitelj to vsebino poučeval s pomočjo demonstracije že pripravljenih fizičnih modelov. Razumevanje zgradbe trdne snovi je bilo preverjeno s pomočjo preizkusov znanja po aplikaciji izobraževalne strategije, medtem ko se je trajnost znanja preverjala en mesec po končani intervenciji s poznim preizkusom znanja. Dijaki, ki so sami modelirali fizikalne modele so bili na preizkusu znanja uspešnejši kot dijaki, ki so uporabljali virtualne modele ali bili izpostavljeni le demonstraciji fizičnih modelov. Na poznem preizkusu znanja pa so dijaki, ki so uporabljali modeliranje in virtualne modele dosegli podobne rezultate, slabše rezultate pa so dosegli dijaki, ki so bili izpostavljeni le demonstraciji modelov. Zaključiti je mogoče, da dijaki, ki so vključeni v aktivne izobraževalne strategije z vidika dijaka, torej v modeliranje fizičnih modelov oz. manipulacijo virtualnih modelov, oblikujejo ustreznejše mentalne modele o kristalnih strukturah trdnih snovi kot tisti, ki so deležni le učiteljeve demonstracije že izdelanih fizičnih modelov.

Appendix 1

Sample items from the pre-test

1. Which substance does not conduct electricity?

A liquid sulphur
B iron wire
C potassium chloride aqueous solution
D graphite

Answer: A

2. Which formula represents an ionic compound?

A CO_2 B NO_2 C SO_2 D TiO_2

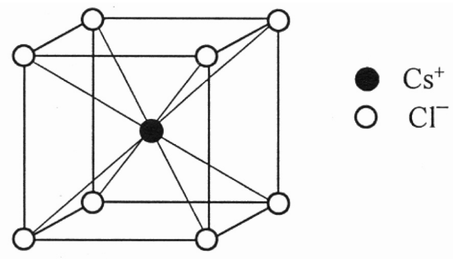
Answer: D

3. What is characteristic for an ionic bond?

a The electron bonding pair is formed between two particles.
b The electrostatic force of attraction between positive and negative charged ions is an ionic bond.
c The electric charge is evenly distributed on ions' surface.
d The ionic bond shows small directionality.

Answer: b, c

15. What does the model in the picture represent[37]?



A There are eight chlorine anions around one cesium cation.
B Cesium cations are organised around chloride anions at the corners of the cube.
C The ionic structure in the cesium chloride crystal is periodically repeated.
D The cesium cation has larger ionic radii than the chloride anion.

Answer: A

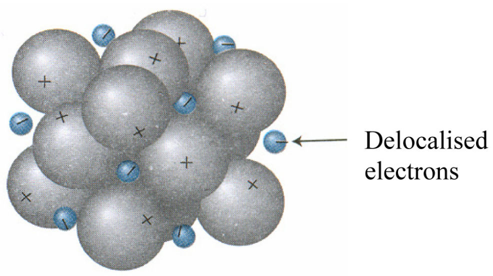
Sample items from the knowledge test and the delayed test

6. What is the characteristic of ionic crystals?

A They conduct electricity in solid state.
B A lot of them are soluble in water.
C They have low melting points because the ionic bonds are relatively weak.
D The number of cations and anions is always the same in the ionic crystal.

Answer: B

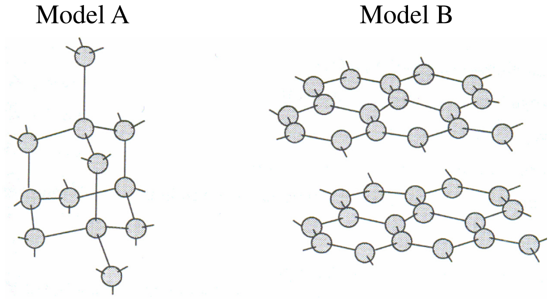
7. Using the picture of the model of cesium chloride[37](ionic crystal) try to figure out which statement is not true.



A A simple model of a metal bond.
B A simple model of an ionic bond.
C A simple model of a molecular bond.
D A simple model of a covalent bond.

Answer: D

9. Models A and B in the picture[37]represent two modifications of the carbon atom. Which statement is correct?



A Model A represents fullerene, and model B graphite.
B Every carbon atom is bonded with another four in the diamond.
C Layers in the graphite are connected with strong bonds.

D It is easy to break C–C bonds in the diamond.

Answer: B

18. Analyse the data presented in the table and answer the questions.

Sub-stance	**Melting point (°C)**	**Electricity conduction**			**Water solubility**
		(s)	**(l)**	**(aq)**	
A	770	no	yes	yes	yes
B	884	no	yes	yes	yes
C	1455	yes	yes	/	no
D	–93	no	no	/	no
E	–210	no	no	/	no

A Which substances could be metals? ______________________

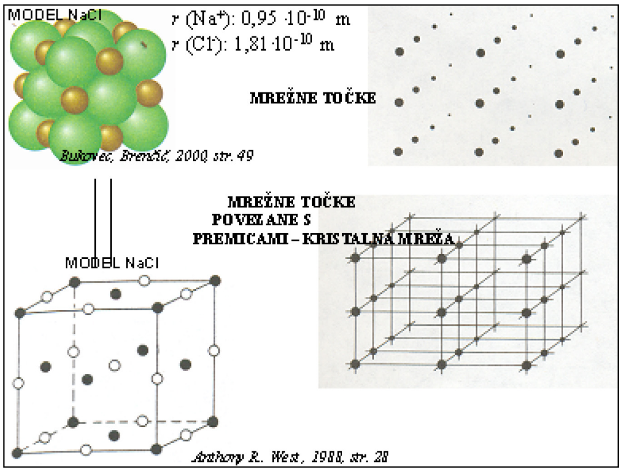
B Which substances could form ionic crystals? ______________________

C Which substances could form molecular crystals? ______________________

Answer: A) C
B) A, B
C) D, E

Appendix 2

Sample slides from PowerPoint presentation



MODEL NaCl

r (Na$^+$): 0,95 ·10^{-10} m

r (Cl$^-$): 1,81·10^{-10} m

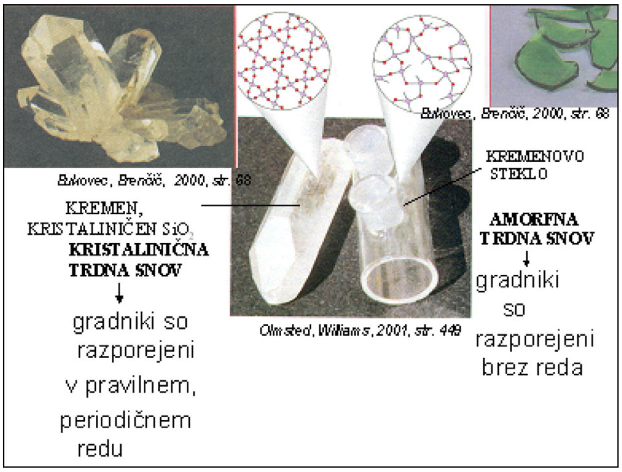
MREŽNE TOČKE

Bukovec, Brenčič, 2000 str. 49

MREŽNE TOČKE POVEZANE S PREMICAMI – KRISTALNA MREŽA

MODEL NaCl

Anthony R. West, 1988, str. 28



Bukovec, Brenčič, 2000, str. 68

Bukovec, Brenčič, 2000, str. 68

KREMENOVO STEKLO

KREMEN, KRISTALINIČEN SiO$_2$

KRISTALINIČNA TRDNA SNOV

↓

gradniki so razporejeni v pravilnem, periodičnem redu

Olmsted, Williams, 2001, str. 449

AMORFNA TRDNA SNOV

↓

gradniki so razporejeni brez reda