Pedagogical Paper

In-Service and Pre-Service Teachers` Optionion on the Use of Models in Teaching Chemistry†

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Abstract

The presented study examined the opinion of in-service and prospective chemistry teachers about the importance of usage of molecular and crystal models in secondary-level school practice, and investigated some of the reasons for their (non-) usage. The majority of participants stated that the use of models plays an important role in chemistry education and that they would use them more often if the circumstances were more favourable. Many teachers claimed that three-dimensional *(3d)* models are still not available in sufficient number at their schools; they also pointed to the lack of available computer facilities during chemistry lessons. The research revealed that, besides the inadequate material circumstances, less than one third of participants are able to use simple (freeware) computer programs for drawing molecular structures and their presentation in virtual space; however both groups of teachers expressed the willingness to improve their knowledge in the subject area. The investigation points to several actions which could be undertaken to improve the current situation.

Key words: chemistry education, molecular models, crystal models, computer literacy

1. Introduction

Most people are familiar with molecular models, having seen those colorful toy-like structures in the pages of school textbooks, science sections of daily newspapers, in popular scientific literature, or even in art-works. Yet, the question arises as to how many people go beyond admiring these magnificent structures.

Since the building blocks of matter - atoms, molecules and ions - can not be naturally perceived by our senses, the desire to reveal 'the world of the invisible' has inspired philosophers and scientists for many centuries. From Plato, or even earlier, to nowadays people have tried to visualize their ideas on the nature of matter by building concrete models. Numerous Nobel Prizes awarded in this field very well manifest the importance and the actuality of this area. In contemporary science new developments related to the application of molecular models and modeling techniques, computational methods, and computer graphics have contributed to resolving the structure of genome, important proteins, fullerens, biologically active molecules (e.g. drugs design), and development of new materials with unusual properties (e.g. self-organizing molecules).

Models did not play an important role only in science research; they had been introduced in chemistry teaching as early as 1811 by Dalton[1]. The 'golden age' of molecular models started with the proliferation of commercial molecular model sets based on Stuart`s space filling models in the 1930s.[2] Today different kinds of molecular models, e.g. traditional *3d* models, stereo-chemical projections, virtual computer models, are widely used in chemistry education and have been proven to be useful in teaching a variety of topics across the curriculum. The usefulness of molecular models as help tools in science education can be explained by the assumption that visualization elements, e.g. structural models, play an important role by supporting students when connecting the different levels of concept representations[3]. According to Johnstone[4], primarily the threefold manner of representation of science concepts (macro, sub-micro and symbolic level) makes science difficult to learn. Students have difficulties with the transfer between different representation levels in chemistry[5,6] compared to the experienced chemists who easily transform data between many kinds of modes of representations in order to solve problems or to reason about the system[7].

On the other hand, research[8, 9, 10] has indicated that students` achievements in chemistry are also related to their spatial ability. Teaching aids such as models, stereo-diagrams, mirrors, shadows and dynamic pictures have been used in remedial instruction programs, and have been proved to be useful in improving spatial intelligence and consequently chemistry achievements[11, 12, 13]. Research indicates that the use of molecular models can compensate for the students` lack of spatial abilities[14]; indeed traditional *3d* models have proven to be equally useful for students as computer pseudo *3d* models[15]. However, some studies[16, 17, 18] suggest the combined use of traditional *3d* models and computer pseudo *3d* models since both types of models have their advantages and disadvantages.

Despite these research indications, many chemistry teachers still take for granted students` skillfulness in dealing with spatial aspects of chemistry and do not devote any attention to developing students` visual literacy. The presented empirical study aims to examine the use of molecular models from the teachers` viewpoint. The attitudes towards and familiarity with prospective and in-service chemistry teachers regarding the use of traditional and computer pseudo *3d* models were examined, and also information was collected on material circumstances relating to molecular and crystal models in Slovenian secondary schools.

2. Methodology

2.1. Sample

54 *chemistry teachers* at general upper level secondary schools[i] from different regions of Slovenia participated in the study. The number of participating teachers represents 57% of all Slovenian chemistry teachers in such educational-programmes. The investigation was conducted in school years 2001/2002 and 2002/2003.

21 *prospective chemistry teachers* from University of Ljubljana (Faculty of Education, Faculty of Chemistry and Chemical Technology) and University of Maribor (Faculty of Education) took part in the investigation. The students involved are pre-graduate students[ii] of chemical education. The population involved represents 70% of the generation of Slovenian pre-graduate students of this type in year 2002/2003, when the investigation was conducted.

2.2. Instruments

'Questionnaire for Teachers'

The 'Questionnaire for Teachers'[14] is composed from thirteen questions; ten of them are multiple-choice type questions and three are open-ended questions. They can be structured into three major areas: (1) General opinion about the importance of students` spatial ability in teaching and learning chemistry, (2) The role of molecular/crystal models in the teaching and learning of specific chemistry content areas, (3) Use of models in school practice. The 'Questionnaire for Teachers' is accessible in full-text in the Appendix.

'Questionnaire for Prospective Teachers'

The 'Questionnaire for Prospective Teachers'[14] comprises fourteen questions, among which nine are multiple-choice type questions and five are open-ended questions. They can be structured into three major areas: (1) General opinion about the importance of students` spatial ability in teaching and learning chemistry, (2) The role of molecular/crystal models in the teaching and learning of specific chemistry content areas, (3) Intention and qualification for the use of models in school practice. The 'Questionnaire for Prospective Teachers' is accessible in full-text in the Appendix.

Some questions in both questionnaires are intentionally similar in order to enable comparison between prospective and in-service teachers.

2.3. Data Analysis

Responses to the 'Questionnaire for Teachers' and 'Questionnaire for Prospective Teachers' were evaluated according to recognized methods for analysis of quantitative and qualitative data.

In both types of questionnaires the 'multiple-choice type' questions, before being entered into the computer files, were coded with numerical marks, and then the frequencies of particular answers were calculated with the use of SPSS.

Coding of the 'open-ended questions' in the 'Questionnaire for Teachers' proceeded in several steps. Firstly 14 questionnaires (25%) were randomly selected and the responses transcribed into the Word document. Afterwards, the answers were structured into natural units of meaning (for example, answers to Question 2.1 were categorised into appropriate chapters of the Slovenian chemistry curriculum for the upper level secondary schools programme[i]). In the next step of analysis a numerical code was ascribed to each of the natural units of meaning. The preliminary coding table, thus derived, was tested and further optimised on the sample of nine additional randomly selected questionnaires (15%). The final coding table was applied on the whole sample – 54 questionnaires – and finally the codes of each questionnaire were entered into the computer files. When it was possible to classify certain answers within more than one natural unit of meaning, the decision as to which group a certain answer would be added was based on the content emphasis in the given answer or the wider context of the answer. Approximately two months after the previous processing, 14 questionnaires (25%) were randomly selected and evaluated again with the use of the final coding table. The reliability of evaluation, acquired as a proportion of equally evaluated answers in the questionnaires, was 99%.

The analysis of the 'open-ended questions' in the 'Questionnaire for Prospective Teachers' was done after the analysis of the 'Questionnaire for Teachers' and is analogous to it in order to enable comparison between the similar tasks. In cases of similar tasks the same coding table was applied. In preparation of the coding tables for questions specific to the 'Questionnaire for Prospective Teachers', equal steps of analysis of open-ended questions, as described previously, were undertaken. Thereby, the small size of the sample was taken into account: initially, 10 questionnaires (48%) were reviewed and transcribed into the Word document, the coding table thus derived was applied to all 21 questionnaires and optimised. The coding table in its final shape was again applied to all 21 questionnaires. Approximately two months after the previous processing, five questionnaires (25%) were randomly selected and evaluated, again with the use of the final coding table. The reliability of evaluation, acquired as a proportion of the equally evaluated answers in the questionnaires, was 98%.

3. Results and discussion

I. In-service chemistry teachers

Results are presented with accordance to the three major areas of questions in the 'Questionnaire for Teachers'.

3.I.1. Teachers` general opinion about the importance of students` spatial ability in teaching and learning chemistry

More than half of the participating teachers (N=28; $f_{\%}\approx52\%$) believed that students` spatial-visualisation ability is important in teaching and learning of *the majority* of chemical contents. The other 26 teachers ($f_{\%}\approx48\%$) thought that students` spatial-visualisation ability is important in teaching and learning of *some* chemical contents. Evidently, teachers are convinced about the importance of students` spatial ability in teaching and learning chemistry. The majority of them (N=39; $f_{\%}\approx72\%$) argumented their statement with one or a combination of the following three ideas: (1) students` spatial-visualisation ability enables the correct perception of molecules` and crystals` three-dimensional structure (N=30; $f_{\%}\approx56\%$), (2) spatial-visualisation ability enables students to gain an understanding of chemical concepts and processes (N=24; $f_{\%}\approx45\%$), and (3) spatial-visualisation ability enables an understanding of the correlation between the molecule's structure and its properties (N=12; $f_{\%}\approx22\%$). Eight teachers ($f_{\%}\approx15\%$) said that spatial-visualisation ability supports concretisation of abstract concepts. Three teachers ($f_{\%}\approx6\%$) noted that what students are able imagine three-dimensionally they could more easily remember. Three teachers ($f_{\%}\approx6\%$) did not explain their decision, and one teacher ($f_{\%}\approx2\%$) thought that spatial-visualisation ability enables faster learning.

Some typical answers were as follows:

'Spatial-visualisation ability is very important because it enables the understanding of the shape of molecules, stereo isomerism, collisions of molecules during chemical reactions on the right spot to result in products. Many students have weak spatial-visualisation ability.'

'Spatial-visualisation ability is very important, because it enables the understanding of processes on the particulate level, e.g. correlation between structure and the molecule's reactivity.'

'The majority of molecules have a three-dimensional structure, but are represented two-dimensionally, therefore it is essential that students have spatial-visualisation ability to understand the reactivity of the molecules and their properties.'

3.I.2. Teachers` opinion on the role of molecular/crystal models in the teaching and learning of specific chemistry content areas

Teachers' responses to this question were categorised according to the Slovenian Chemistry Curriculum for Upper-level General High Schools. From 54 participating teachers, 212 suggestions of chemistry contents, where students` spatial-visualisation ability plays an important role, were registered. This makes on average 4.0 suggestions per teacher.

Table 1 indicates that the majority of in-service teachers` responses (N_A=94; $f_{[\%]A}\approx44\%$) fit in the chapter 'Building blocks' of the curriculum, 70 answers ($f_{[\%]A}\approx33\%$) in the chapter 'Structure of organic molecules', and 23 answers ($f_{[\%]A}\approx11\%$) in the chapter 'Reactivity of Organic molecules'. Consequently, the percentages of answers belonging into other chapters were lower than 6%. From Table 1 it can also be observed that many teachers proposed even more than one suggestion for chapters 'Building blocks' (percentage of answers with regard to the number of participants is $f_{[\%]P}\approx174\%$) and 'Structure of organic molecules' ($f_{[\%]P}\approx130\%$). From these findings we can conclude that teachers believe students` spatial ability to be very important in learning of those chapters, probably due to direct linking of students` spatial-visualisation ability with learning about structure. Beside analysing Table1 from the view-point of distribution-frequency of specific contents (calculating the percentage of

Table 1: Categorised teachers` responses to the question concerning those chemistry contents for which students` spatial ability is most important

Content group according to chemistry curriculum	In-service teachers (N=54)			Prospective teachers (N=21)		
	N_A	$[\%]_A$	$[\%]_P$	N_A	$[\%]_A$	$[\%]_P$
Chapter 1 - Symbolic Notations and the Mole						
1.1 THE MOLE	1	*0.47*	1.85	2	*1.96*	9.52
1.2 CHEMICAL EQUATIONS	3	*1.42*	5.56	3	*2.94*	14.29
Summary of the answers in the framework of Chapter 1	4	*1.89*	7.41	5	*4.90*	23.81
Chapter 2 - Building Blocks						
2.1 ATOMIC STRUCTURE AND THE PERIODIC TABLE	9	*4.25*	16.67	6	*5.88*	28.57
2.2 BUILDING BLOCKS BONDING						
2.2.1 Chemical Bonding	77	*36.32*	142.59	19	*18.63*	90.48
2.2.2 Molecular Bonds	8	*3.77*	14.81	3	*2.94*	14.29
Summary of the answers in the framework of Chapter 2	94	*44.34*	174.07	28	*27.45*	133.33
Chapter 3 - Changes						
3.1 ENERGY CHANGES						
3.1.1 Chemical Reaction as Energy Change	0	*0.00*	0.00	0	*0.00*	0.00
3.1.2 Energy Changes during Dissolving of Ionic Crystal	3	*1.42*	5.56	0	*0.00*	0.00
3.2 CHEMICAL REACTION PROCEEDING						
3.2.1 The Rates of Reactions	1	*0.47*	1.85	1	*0.98*	4.76
3.2.2 Chemical Equilibrium	0	*0.00*	0.00	0	*0.00*	0.00
3.2.3 Equilibrium in aqueous solutions						
3.2.3.1 Acids, bases and salts	1	*0.47*	1.85	3	*2.94*	14.29
3.2.3.2 Redox Reactions	0	*0.00*	0.00	0	*0.00*	0.00
Summary of answers in the framework of Chapter 3	5	*2.36*	9.26	4	*3.92*	19.05
Chapter 4 - Elements in Periodic Table						
4.1 BLOCKS IN PERIODIC TABLE	0	*0.00*	0.00	0	*0.00*	0.00
4.2 CHARACTERISTICS OF ELEMENTS	1	*0.47*	1.85	0	*0.00*	0.00
4.3 NONMETALS	0	*0.00*	0.00	0	*0.00*	0.00
4.4 ELEMENTS OF GROUPS I., II. AND III.	0	*0.00*	0.00	0	*0.00*	0.00
4.5 TRANSITION ELEMENTS	2	*0.94*	3.70	0	*0.00*	0.00
Summary of answers in the framework of Chapter 4	3	*1.42*	5.56	0	*0.00*	0.00
Chapter 5 - Structure of Organic Molecules						
Summary of answers in the framework of Chapter 5	70	*33.02*	129.63	30	*29.41*	142.86
Chapter 6 - Properties of Organic Compounds						
Summary of answers in the framework of Chapter 6	2	*0.94*	3.70	0	*0.00*	0.00
Chapter 7 - Reactivity of Organic Molecules						
7.1. FROM HYDROCARBONS TO ALCOHOLS	0	*0.00*	0.00	2	*1.96*	9.52
7.2. FROM ALCOHOLS TO ORGANIC ACIDS DERIVATIVES	1	*0.47*	1.85	9	*8.82*	42.86
7.3. FROM AMINES TO AMINOACIDS	0	*0.00*	0.00	0	*0.00*	0.00
7.4. FROM MONOMERS TO POLYMERS	3	*1.42*	5.56	7	*6.86*	33.33
GENERAL KEY WORDS TO CHAPTER 7	19	*8.96*	35.19	2	*1.96*	9.52
Summary of answers in the framework of Chapter 7	23	*10.85*	42.59	20	*19.61*	95.24
Chapter 8 - Importance and Role of Organic Compounds						
8.1. HYDROCARBONS AND THEIR DERIVATIVES	1	*0.47*	1.85	2	*1.96*	9.52
8.2. LIPIDS AND SURFACTANTS	0	*0.00*	0.00	4	*3.92*	19.05
8.3. CARBOHYDRATES, PROTEINS AND SYNTHETIC POLYMERS	9	*4.25*	16.67	7	*6.86*	33.33
GENERAL KEY WORDS TO CHAPTER 8	1	*0.47*	1.85	2	*1.96*	9.52
Summary of answers in the framework of Chapter 8	11	*5.19*	20.37	15	*14.71*	71.43
Summary of answers to all chapters together	212	*100*		102	*100*	

N= Number of participants; N_A= Number of answers fitting into specific chapter;
$[\%]_A$= Percentage of answers in specific chapter with regard to all collected answers;
$[\%]_P$= Percentage of participants who mentioned answers fitting into specific chapter. Because participants sometimes suggested more than one answer for a chapter, the percentage in some cases exceeds 100%.

answers with regard to all collected answers), it can also be analysed from the view-point of the proportion of participants who mentioned specific contents. From this, it can be observed that many teachers ($f_{[\%]P}$≈43%) thought that spatial visualisation ability is also important in learning about 'Reactivity of Organic molecules'; 20% of teachers in learning about 'Importance and Role of Organic Compounds'. On the other hand, only 9% of teachers mentioned contents included in the chapter 'Changes', for example learning about chemical reaction, etc. This is a pity, because the percentages of teachers mentioning other contents were even lower.

In our opinion, students` spatial-visualisation ability is involved in learning of the majority of contents throughout the chemistry curriculum.

Further on in the questionnaire all participating in-service teachers ($f_{\%}\approx100\%$) agreed that the use of molecular and crystal models does help students in learning of the mentioned contents. As many as 34 teachers ($f_{\%}\approx63\%$) thought it has to do with supporting students` perception of three-dimensional space. According to the opinion of 11 teachers ($f_{\%}\approx20\%$), molecular models do facilitate students` understanding of chemical concepts. Six teachers ($f_{\%}\approx11\%$) did not explain their opinion and three teachers ($f_{\%}\approx6\%$) claimed to base their opinion on their classroom experiences.

Some typical answers were as follows:

'The space cannot be described; it can only be seen and experienced, consequently the role of molecular models is essential.'

'Many students have problems with spatial ability. To avoid learning chemistry by heart, we use molecular models to facilitate the understanding.'

'Based on my experiences, I know that the use of molecular models is helpful for students.'

The described findings about the usefulnes of molecular and crystal models in the educational process should be a good starting-point for their (more frequent) use across the curriculum.

3.I.3. Use of models in school practice

Practically all teachers involved claim to use molecular and crystal models in their chemistry lessons. Thus, 27 teachers ($f_{\%}\approx50\%$) said that they use models more than once a month and the other 27 teachers ($f_{\%}\approx50\%$) less than once a month. These figures are not consistent with students' statements[14]; namely, students declared that models are used more rarely than teachers admitted. The outcomes indicate that to obtain a more objective overview of the situation, a further study based on independent long-term classroom observations would be necessary.

The study also points to problems with accessibility of concrete molecular and crystal models; surprisingly more than a half of the participating teachers (N=36; $f_{\%}\approx67\%$) thought that they do not have enough models available and claimed that they would use them more often if they were available in sufficient number. The rest of the teachers involved in the investigation (N=18; $f_{\%}\approx33\%$) were satisfied with the availability of models at their school.

Regarding the application of contemporary computer technologies enabling the use of computer models, the study revealed that the majority of participating teachers (N=34; $f_{\%}\approx63\%$) had seen - but never used - virtual computer *3d* molecular or crystal models. Out of the remaining teachers, 15 ($f_{\%}\approx28\%$) estimate that they are skilled in using them, but on the other hand five ($f_{\%}\approx9\%$) had not even seen virtual models. Consequently, the majority of teachers (N=41; $f_{\%}\approx76\%$) claimed not to use pseudo-*3d* molecular models during their chemistry lessons, 11 ($f_{\%}\approx20\%$) said that they use them sometimes - but less than once a month -, and just two ($f_{\%}\approx4\%$) said they use them more often than once a month. Almost all of the participating teachers (N=48; 92% of teachers who do not use such models and those who use them sometimes) claimed that they would use pseudo-*3d* models more often if they were skilled in using them, and if the material circumstances were favourable for their usage. Teachers explained that many of them (N=33; $f_{\%}\approx61\%$) do not have the possibility to access the computer during chemistry lessons; only for 21 teachers ($f_{\%}\approx39\%$) are computers readily available during chemistry lessons. Nevertheless more than about a half of the teachers (N=29, $f_{\%}\approx54\%$) instruct the students to use web pages which include molecular models in the framework of their homework assignments.

II. <u>Prospective Teachers</u>

The results for the population of prospective teachers are also presented in accordance with the three major areas of questions in the 'Questionnaire for Prospective Teachers'.

3.II.1. General opinion of prospective teachers about the importance of students` spatial ability in teaching and learning chemistry

Similarly to in-service teachers, also the participating prospective chemistry teachers thought that students` spatial-visualisation ability is important in the teaching and learning of chemistry: 12 prospective teachers ($f_{\%}\approx57\%$) thought that it is important in *the majority* of chemical contents, and nine prospective teachers ($f_{\%}\approx43\%$) that it is important in *some* chemical contents. The majority of prospective teachers (N=16; $f_{\%}\approx76\%$) explained their opinion by mentioning one or more of the following statements: (1) students` spatial-visualisation ability enables the correct perception of the structure of molecules and crystals (N=10; $f_{\%}\approx48\%$), (2) spatial-visualisation ability enables students to understand chemical concepts and processes (N=12; $f_{\%}\approx57\%$) and (3) spatial-visualisation ability enables the understanding of the correlation between the molecule's structure and its properties (N=2; $f_{\%}\approx10\%$). Five prospective teachers ($f_{\%}\approx24\%$) believed that spatial ability supports concretisation of abstract concepts. The four described major categories of responses that emerged here are the same as those observed with in-service chemistry teachers. The proportions of answers in a certain category vary slightly between both groups of chemistry teachers, and some of the minor categories did not appear with prospective chemistry teachers.

Some typical answers were as follows:

'Spatial-visualisation ability is important because it supports students` perception and understanding of abstract concepts.'

'If students can imagine something, they can more easily remember it; they understand it better and can more swiftly upgrade their knowledge.'

3.II.2. Opinion of prospective teachers on the role of molecular/crystal models in the teaching and learning of specific chemistry content areas

The answers of prospective teachers were categorized according to the Slovenian Chemistry Curriculum for Upper-level General High Schools, as was done previously with responses of in-service teachers. Out of 21 participating prospective teachers, 102 suggestions of chemistry contents were registered, which makes 4.9 suggestions per prospective teacher.

When analysing the distribution-frequency of specific contents, it can be concluded that the majority of answers fit in the following curriculum chapters: 'Structure of Organic Molecules' (N=30; $f_{[\%]A}=29\%$), 'Building Blocks' (N=28; $f_{[\%]A}=28\%$), 'Reactivity of Organic Molecules' (N=20; $f_{[\%]A}=20\%$), and 'Importance and role of organic compounds' (N=15; $f_{[\%]A}=15\%$). The percentages of responses fitting into other chapters were lower than 5% (Table 1). On the other hand, from the view-point of the proportion of participants who mentioned specific contents, it can be concluded that they suggested at least one item for the chapters 'Structure of Organic Molecules' ($f_{[\%]P}=143\%$) and 'Building Blocks' ($f_{[\%]P}=133\%$), which is similar with in-service teachers. Almost all prospective teachers mentioned also the chapter 'Reactivity of Organic Molecules' ($f_{[\%]P}=95\%$). The chapter 'Importance and role of organic compounds' was also given significant attention ($f_{[\%]P}=71\%$) by prospective teachers. Additionally, the chapters 'Symbolic Notations and the Mole' and 'Changes' were mentioned by quite a number of prospective teachers ($f_{[\%]P}=24\%$; $f_{[\%]P}=19\%$), which is significantly more in comparison to in-service teachers ($f_{[\%]P}=7\%$; $f_{[\%]P}=9\%$, Table 1). Anyway, it has to be stated in the favour of in-service teachers that some of them proposed ideas for the chapters 'Elements in Periodic Table' ($f_{[\%]P}=6\%$) and 'Properties of Organic Compounds'($f_{[\%]P}=4\%$), while the prospective teachers didn`t come up with any suggestions.

To synthesize the comparison from answers of the two groups of teachers, it can be concluded that they both believe spatial ability to be most important in the same three chapters: 'Building Blocks', 'Structure of Organic Molecules' and 'Reactivity of Organic Molecules'. The percentages of responses among the chapters of the curriculum vary between prospective and in-service chemistry teachers, being generally more focused on certain topics by in-service teachers and more distributed by prospective teachers. Additional chapters were given significant attention by prospective teachers; e.g. the chapter 'Importance and role of organic compounds'.

Moving forward to estimating the usefulness of molecular and crystal models in helping students when learning chemistry: here all of the enrolled prospective teachers ($f_{\%}\approx100\%$) were convinced of their importance. Five prospective teachers ($f_{\%}\approx24\%$) explained their belief by the explanation that molecular models support students` perception of three-dimensional space. A further four prospective teachers ($f_{\%}\approx19\%$) proposed that molecular models help students in the improvement of their understanding of chemical contents; 12 prospective teachers ($f_{\%}\approx57\%$) listed both of the above reasons.

Some typical answers were as follows:

'Students learn more easily when the content is visually presented to them or they can learn through hands-on activity.'

'Students can more easily understand abstract chemical concepts with the help of models.'

3.II.3. Intention and qualification of prospective teachers for the use of models in school practice

The majority of prospective teachers (N=18; $f_{\%}\approx86\%$) are intending to use *3d* molecular models in their future pedagogical work when dealing with the mentioned contents. The rest of the students (N=3; $f_{\%}\approx14\%$) are intending to use molecular models in some of the mentioned contents.

Prospective teachers were asked to write down some possible students` misunderstandings that could be developed by students when using models without additional teachers` explanations. Altogether 46 answers were registered, which makes 2.2 suggestions per participant.

Most of the answers ($f_{\%}\approx37\%$) mentioned *ascribing colours to certain kinds of atoms in models* as one of the students` possible misunderstandings; another group of responses ($f_{\%}\approx26\%$) was dealing with *bonding*. *The size of the molecules in comparison to the size of models* was also mentioned as a possible source of misunderstanding in 22% of responses. A further 11% of responses pointed to *the shape and consistency of atoms*, 2% of responses were dealing with the misunderstandings concerning *the dynamics of molecules,* and 2% of questionnaires had no response to this question. Although it can be generally concluded that prospective teachers as a group are aware of the major traps relating to the use of molecular models, there is apparently still space for further improvement of individuals` knowledge.

Further on in the questionnaire, it was found that 52% of prospective teachers claim to be able to work with computer programs for drawing structural and stereo-chemical molecular formulas, 29% of students have seen such programs, but have never used them, and 19% of students involved have never seen such programs. 77% of the students who are familiar with such programs have learned to use them during courses at the faculty, 18% have learned from friends or others, and 6% have learned by themselves. It is surprising that quite a lot of the prospective chemistry teachers are not keen on using the simplest contemporary computer chemistry programs when approaching the end of their university education. This is a sign for their educators to think about introducing more contents, which would enable students to develop their basic computer science literacy, into the pre-graduate curriculum.

In total, 13 of the prospective teachers involved ($f_{\%} \approx 62\%$) have seen but not used computer pseudo *3d* molecular models; a further four of them ($f_{\%} \approx 19\%$) have used this technology by themselves. On the other hand, four prospective teachers ($f_{\%} \approx 19\%$) have not even seen pseudo *3d* molecular models. 16 prospective teachers - 94% of those who are familiar with the use of virtual computer *3d* molecular models - were confronted with them during courses at the faculty, and the rest of them (N=1; $f_{\%} \approx 6\%$) have learned to use them with the help of friends. 12 prospective teachers ($f_{\%} \approx 57\%$) are planning to use virtual computer *3d* molecular models during their chemistry lessons, and a further 9 ($f_{\%} \approx 43\%$) would like to use them if they were able.

Fifteen prospective teachers ($f_{\%} \approx 71\%$) estimated that they had received enough profesionnal and methodological knowledge at the university for using molecular and crystal models in chemistry teaching and learning, but six ($f_{\%} \approx 29\%$) were not of that opinion. When students were asked what they would like to learn additionally, eight ($f_{\%} \approx 38\%$) responded that they would like to improve their computer literacy; seven students ($f_{\%} \approx 33\%$) would like to have more practice and examples of molecular models usage. One pre-graduate student ($f_{\%} \approx 5\%$) would appreciate better accessibility of models at the faculty, and another one ($f_{\%} \approx 5\%$) believed that no matter what knowledge they had received, it is up to them to use molecular models. Four prospective teachers ($f_{\%} \approx 19\%$) did not make any additional suggestions.

4. Conclusions

The results of the prospective and in-service teachers participating in our investigation are quite similar in the areas examined by current research, which indicates the crucial role of teachers` education for their future pedagogical work.

The majority of in-service and prospective teachers estimated that students` spatial intelligence plays an important role in chemistry education. Both groups of teachers estimated that students` spatial intelligence and the use of models are important above all in teaching and learning of the following chapters in the chemistry curriculum for secondary schools: 'Building Blocks', 'Structure of Organic Molecules' and 'Reactivity of Organic Molecules'. Additionally, quite a number of prospective teachers estimated the same also for the chapter 'Importance and role of organic compounds'. The percentages of responses among the chapters of the curriculum vary between prospective and in-service chemistry teachers, being generally more focused on certain topics by in-service teachers and more distributed by prospective teachers. The question arises as to why models are apparently more rarely used in teaching and learning of other topics; is this neglect justified by their nature? We doubt it, and speculate that it is probably due to direct linking of students` spatial-visualisation ability with learning about structure. We believe that the use of models could improve the quality of the educational process and students` knowledge in numerous additional contents throughout the curriculum and should therefore be more widely used (e.g. to visualize chemical equations, periodic table, correlation between structure and properties, etc.)

According to the results collected in our investigation, the majority of teachers would use molecular and crystal models more often, if the circumstances were more favourable. Many teachers claimed that *3d* models at their schools are still not available in sufficient quantity, they also pointed to the lack of available computer facilities during chemistry lessons. The research revealed that, besides the unfavourable material circumstances, less then one third of teachers are able to use simple (free-ware) computer programs for drawing molecular structures and their presentation in virtual space (e.g. IsisDraw, Chime, RasWin). This is a further obstacle to over-bridging of the lack of traditional *3d* molecular and crystal models by the use of contemporary technology. The scientific computer literacy of prospective chemistry teachers is unfortunately not much better, but both groups of teachers expressed the willingness to improve their knowledge in the subject area.

Prospective teachers most often mentioned the following students` misunderstandings connected with the use of molecular models: colour of certain kind of atoms, bonding, size of the molecules, shape and consistency of atoms. Only one student thought also about the dynamics of the molecules. Although it can be generally concluded that prospective teachers are aware of the major traps related to the use of molecular models, the need for further improvement of individuals` knowledge in this area has to be admitted.

On the basis of the presented research several actions can be indicated, which could be undertaken to improve the situation:

1. The financer – the Ministry of Education, Science and Sport – should be informed about the situation and encouraged to allocate funds for the improvement of schools` instructional infrastructure.

2. The existing curriculum for the tertiary education of prospective teachers` should be improved by giving more emphasis to topics regarding models of molecules and crystals (introducing contemporary technologies, discussing possible misconceptions, and indicating more practical examples of their use).

3. Special training courses for in-service chemistry teachers, aimed at improving their scientific computer literacy and indicating practical examples of how models can be used in the educational process, should be developed.

4. Educational materials focusing on molecular and crystal models, equipped with methodological suggestions for their use, should be developed to support the educational process. The materials should be preferably in electronic format (e.g. web-based or CD-rom) to enable direct access to pseudo-*3d* models.

5. Possibilities for further cross-curriculum linkages between chemistry and other subjects at the secondary level to stimulate the development of students` spatial intelligence (e.g. in mathematics by using different molecular structure representations as objects when teaching geometry; in biology by using models when teaching genetics, etc.) should be examined and implemented.

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i. General upper secondary education (students` age 15-19) is performed at upper level secondary schools (slo. gimnazija) and lasts 4 years. Two types of upper level secondary schools exist in the Slovenian education system: *general upper level secondary schools* (slo. splošna gimnazija: vključuje splošno in klasično gimanzijo) and *professional upper level secondary schools* (slo. tehniška gimnazija: vključuje tehniško, ekonomsko in umetniško gimanzijo).

ii. Students enrolled in preparation of graduation work at the university are in this article assigned as pre-graduate students (slo. absolventi). Because of their future profession, in this article they are also named prospective teachers.

Povzetek

V raziskavi smo preučevali mnenje aktivnih in bodočih učiteljev kemije v gimnazijah o pomenu uporabe molekulskih in kristalnih modelov ter skušali razkriti nekaj razlogov za (ne) uporabo modelov pri pouku kemije. Večina udeležencev se je strinjala, da imajo modeli pri poučevanju in učenju kemije pomembno vlogo ter so zagotovili, da bi jih želeli pogosteje uporabljati, a mnogi za to nimajo ustreznih pogojev (pomanjkanje *3d* modelov in težka dostopnost do računalnikov v času pouka kemije). Pokazalo se je tudi, da zna le manj kot tretjina udeležencev raziskave samostojno uporabljati preproste (brezplačne) računalniške programe za risanje molekul in njihovo predstavitev v navideznem prostoru, obe skupini učiteljev pa sta pokazali željo po izboljšanju znanja. V zaključku prispevka je predstavljenih nekaj dobronamernih idej, ki nakazujejo možnosti za izboljšanje stanja na tem področju.

APPENDIX

'Questionnaire for Teachers'

1. General opinion about the importance of students` spatial ability in teaching and learning chemistry

1.1 How important is students` spatial-visualisation ability in teaching and learning chemistry in your opinion?
a) It is not important in teaching and learning chemistry.
b) It plays an important role in the teaching and learning of some chemical contents.
c) It plays an important role in the teaching and learning of the majority of chemical contents.

1.2 Please explain briefly why you think that students` spatial-visualisation ability is (not) important in teaching and learning chemistry.

2. Opinion on those chemistry contents for which students` spatial ability is most important, and the role of molecular and crystal models in teaching and learning of those contents

2.1 Please write down in which chemistry contents you think that students` spatial-visualisation ability plays an important role (if there are many such contents, indicate the five most important).

2.2 On the basis of your experience do you believe that molecular and crystal models usage helps students in efficiently dealing with the contents mentioned in Question 2.1?
a) yes b) no

2.3 Please explain your answer to Question 2.2.

3. Use of models in school practice

3.1 Do you use three-dimensional (plastic or wooden) molecular models during chemistry lessons?
a) never b) sometimes (less than once a month) c) often (more than once a month)

3.2 Do you have enough three-dimensional molecular models at your school?
a) yes b) no

3.3 Would you more often use three-dimensional molecular models during chemistry lessons if they were available in sufficient number? (Only teachers who replied 'b' to Question 3.2 should answer this question.)
a) yes b) no

3.4 Are you familiar with virtual computer three-dimensional molecular models (e.g. programs Chime, RasMol, etc.)?
a) I have never seen them b) I have seen, but not used them c) I am able to use them myself

3.5 Do you use virtual computer three-dimensional molecular models during chemistry lessons?
a) never b) sometimes (less than once a month) c) often (more than once a month)

3.6 Would you (more often) use computer molecular models in virtual space during chemistry lessons if you were able to use them and if the material circumstances were favorable for their usage? (Only the teachers who replied 'a' or 'b' to Question 3.5 should answer this question.)
a) yes b) no

3.7 Do you have readily available a computer during your chemistry lessons at your school?
a) yes b) no

3.8 Do you instruct your students, in the framework of their homework activities, to use web pages which incorporate virtual molecular models?
a) yes b) no

'Questionnaire for Prospective Teachers'

1. General opinion about the importance of students` spatial ability in teaching and learning chemistry

1.1 How important is students` spatial-visualisation ability in teaching and learning chemistry in your opinion?
a) It is not important in teaching and learning chemistry.
b) It plays an important role in the teaching and learning of some chemical contents.
c) It plays an important role in teaching and learning of the majority of chemical contents.

1.2 Please briefly explain why you think that students` spatial-visualisation ability is (not) important in teaching and learning chemistry.

2. Opinion on those chemistry contents for which students` spatial ability is most important, and the role of molecular and crystal models in teaching and learning of those contents

2.1 Write down those chemistry contents in which you think that students` spatial-visualisation ability plays an important role (if there are many such contents, indicate the five most important).

2.2 Do you believe that the use of molecular and crystal models can help students in learning the contents mentioned in replying to Question 2.1?
a) yes b) no

2.3 Please explain your answer to Question 2.2.

3. Intention and qualification for the use of models in school practice

3.1 Are you planning to use three-dimensional molecular models in your future pedagogical work when dealing with the contents mentioned in Question 2.2?
a) yes b) in some of them c) no

3.2 Write down some possible students` misunderstandings that could be drawn upon when using molecular models without additional teachers` explanations.

3.3 Are you familiar with spatial computer programs for drawing structural and stereo-chemical molecular formulas (e.g. programs IsisDraw, ChemDraw, etc.)?
a) I have never seen them b) I have seen, but not used them c) I am able to use them

3.4 Explain where you learnt to use the special computer programs for drawing structural and stereo-chemical molecular formulas. (Only students who replied 'b' or 'c' to the Question 3.3 should answer this question.)
a) I learned by myself b) I learned during courses at the faculty c) others

3.5 Are you familiar with virtual computer three-dimensional molecular models (e.g. programs Chime, RasMol, etc.)?
a) I have never seen them b) I have seen, but not used them c) I am able to use them

3.6 Please explain where you learned to use virtual computer three-dimensional molecular models. (Only the students who replied 'b' or 'c' to Question 3.5 should answer this question.)
a) I learned by myself b) I learned during courses at the faculty c) others

3.7 Are you planning to use computer three-dimensional molecular models in virtual space in your future pedagogical work when dealing with the contents mentioned in Question 2.2?
a) yes b) I would, if I were be able to use them c) no

3.8 Do you think that you have received enough professional and methodological knowledge at the university for using molecular models in chemistry teaching and learning?
a) yes b) no

3.9 Please briefly explain your answer to Question 3.8 or write down what specifically you would like to learn.