# PROMOTING STUDENT LEARNING ACHIEVEMENTS IN CHEMISTRY BY USING THE TETRAHEDRAL SPATIAL MIND MODEL

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## Abstract

*Students' knowledge is the main resource for stimulating the development of each country. The results of international and national comparative studies in science show a tendency of a decrease of the level of students' knowledge. The problem draws attention to the need to promote organization in teaching and learning and the use of progressive methodological approaches. The developed method, called the TETRA-method, is directed to the formation of connections among various phenomena, it was tested to ensure that students (grade 8-10) achieve stable knowledge, improve understanding and promote the students' learning achievements if the method is used in learning chemistry. The students' achievements were compared on different topics during the learning process. Obtained results of the research allow us to conclude that the use of the TETRA-method gives an option to raise the students' knowledge level more frequently one level above the previous. The knowledge stability test showed that students' knowledge becomes stable. Students' learning achievements have a tendency to enhance by using the developed method.*
**Key words:** *chemistry, knowledge, teaching and learning method.*

## Introduction

The main resource in Latvia is the knowledge and the wisdom of people as well as skilful and purposeful use of these qualities. Knowledge determines the quality of labor, promotes the use of capital, and stimulates the development of technologies. Discussions about the quality of education and its developmental tendencies have taken place since Latvia regained its independence. The results of international and national comparative studies show a tendency of a decrease of the level of students' knowledge although science education has retained its position as one of the country's priorities (Mozeika, Cedere & Gedrovics, 2008). Therefore, the problems mentioned before draw attention to the need to promote organization in the teaching and learning process by using progressive methodological approaches, so that the understanding about the nature of science forms in students. For the activation of students' thinking and an increase in the efficiency of learning it is recommended that graphical information organizers be used by taking into account that the tendency of knowledge formation is more oriented towards the selection and connection of information, addressing the students' different approaches to comprehend the world (Zohar & Schwartzer, 2005; Hakkarainen & Ahtee, 2005; Siemens, 2006; Coll, Lay & Taylor, 2008).

The large proportion of students perceives the everyday flow of information fragmented; hence majority of them have a problem to connect this information to further cognition process. This causes difficulties for students to find united conception about the surrounding world. Students learn biology, chemistry, physics that basically study the same phenomenon – nature, the processes in nature, though in lessons the explanation of the processes in every subject is different. The specificity of the chemistry is the fact that major part of „the real chemistry" is to be explained in the level of atoms, ions and molecules, so using abstract concepts (Erduran, 2009). Exactly this is the uniqueness of the chemistry and simultaneously also a problem for a student, because the incomprehension of the nature of chemistry deflects the chemistry to the list of unwelcome subjects and the students' learning achievements in chemistry decreases (Mozeika, Cedere, 2008).

The formation of the connections is suggested for linking together incoming information, fragmentary knowledge and for developing connected knowledge (Siemens, 2008; Downes, 2010). In general, spatial mind models as visual models give an opportunity to students to visualize in their mind both abstract and specific connections (Held, Knauff & Vosgerau, 2006; Barke, Hazari &Yitbarek, 2009).

Using the basic principle of connectivism – to establish connections - there is a chance to use the tetrahedral spatial mind model. The name of the developed teaching and learning method, named as *TETRA*-method, was derived from of the selected form for the spatial mind model – *tetrahedron* as a simplest polyhedron. The tetrahedron is the main tool for setting up the connections. It is also used as visualization instrument according to the proposed activities in the *TETRA*-method. The *TETRA*-method was developed for the increasing students` knowledge level in scientific literacy context based on the results of pedagogical research which was done in previous years. The action of the spatial mind model develops students' skills in forming the connections among several phenomena, stimulates learning activity, links knowledge and as a result promotes students' scientific literacy (Mozeika & Bleive, 2009; Mozeika, Cedere & Gedrovics, 2010a; 2010b). The *TETRA*-method is intentionally oriented to achieve connected knowledge which is based on the understanding. This means that students would understand the regularity of the nature, they are able to use their knowledge for making the decisions and in practical action by expressing critical and responsible attitude to environment.

This research is focussed to the ascertainment that the use of the tetrahedral spatial mind models affects students` learning achievements positively and it is possible to acquire more stabile students' knowledge if the verification of statement places more emphasis on the connected knowledge. The developed method will be tested at comprehensive school as an alternative teaching and learning method to ensure that after using the *TETRA*-method students' knowledge becomes stable, understanding about substances and their changes improves and the students' learning achievements in chemistry increase.

Research questions:

1. Does the use of the tetrahedral spatial mind model promote the students' learning achievements in chemistry?

2. What is the stability of the students' knowledge if the tetrahedral spatial mind model is used in learning chemistry?

## Research Methodology

### *General Characteristics of Research*

The method was approved at three comprehensive schools in 2009 and 2010. The method was integrated in the common teaching and learning process of chemistry. The experimental group and control groups were formed. The data were obtained from the students' learning achievements in the experimental group which used the spatial mind model for the learning and were compared with the students' achievements of the control group who did not use the model during the learning of chemistry.

The chemistry teacher evaluated students' learning achievements mainly by using examination works at the end of the learnable topic. Students' learning achievements were analyzed for both groups about various topics of the chemistry in order to show that the use of the tetrahedral spatial mind model positively affects the learning process of chemistry. Additionally the test *Stability of students' knowledge* was organized to ensure that the forming of connections promotes the stability of students' knowledge and it becomes more long-lasting. Also some science teachers apart from the approbation from different schools in Latvia were invited to express their opinion on the *TETRA*-method. A discussion was carried out.

### *Respondents*

The total number of respondents: 246 students including 71 students from grade 8, 84 students from grade 9 and 91 students from grade 10.

Three comprehensive schools (coded as school C, school L and school R) from various areas of Latvia took part in the research. Each school had at least two parallel grades (for example, grade 8A, and grade 8B), which one of them were accepted as an experimental group but other as a control group without any special criteria. There were 39 students in experimental group and 32 students in control group from grade 8. There were 46 students in experimental group and 38 students in control group from grade 9. In grade 10 there were 43 students involved in experimental group and 48 students in control group.

Totally 6 teachers; three chemistry and two biology teachers, one teacher of physics took part in the discussion about the method.

### *Procedure*

1. The *TETRA*-method was used for the experimental group in the common learning of chemistry. The following topics *Water*, *Chemistry language, Substances, Substance changes* were used for students in grade 8. The topics *Structure of substances, Oxides, Hydroxides, Salts* were used for students in grade 9. Topics *Substances and their properties, Structure of substances, Groups of inorganic substances (Oxides, Hydroxides, Salts, Acids, Structure of substance)* were used in grade 10. The learning materials were upgraded Microsoft PowerPoint presentations about various topics mentioned above to make lessons more varied, exciting for students and to ease the teachers' work.

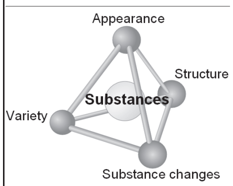
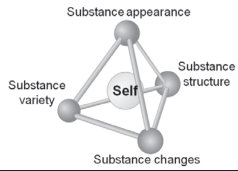
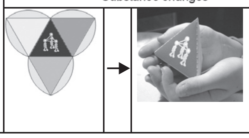
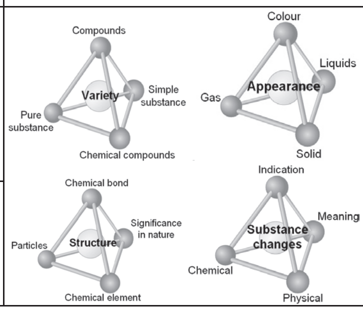
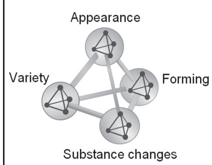
2. The example for the use of the *TETRA*-method for a learning topic *Substances*
The basis of the *TETRA*-method is a four step system (Table 1),
Step 1 ***Thematic system***,
Step 2 ***„Self-perception" phenomenon*** (base of theory from Bem, 1972)**,**
Step 3 ***Systemic components,***
Step 4 ***Interconnections of systemic components***.

The spatial mind model is used in all steps, in each of them different methodological activity is carried out (Mozeika, Cedere & Gedrovics, 2010a). The role of the model is to show the connections among various topics and phenomena.

The teachable topic is written in the middle of the mind model (Step 1). This should be imagined that all the tetrahedron is the particular topic. Teacher together with students discuss, agree and moot four subtopics connected to the main topic. Subtopics are written on each peak of the tetrahedron. It should to be mentioned that all connected topics that are placed of the nodes of the model are also similarly important. Numbers on the nodes show the order of the subtopics.

The model has an inner fractal structure (Step 1 and 4) which gives the possibility to understand the world around as an united system more completely. The fractal technique allows entering into the learning topic from the upper level to the level below, from the main topic to a subtopic, to enter in the learning topic in details.

**Table 1. The example of the using of the tetrahedral spatial mind model for the learning the topic Substances.**

| Step 1 | Step 2 | Step 3 | Step 4 |
|---|---|---|---|
| Actualization of the main topic and subtopics (1,2,3,4) | Activation of student's learning | Characterization of connected subtopics | Summarizing of the main topic |
|   |    |   |   |

During the lesson each student makes for himself a small tetrahedron model out of paper kit (Step 2), which is going to be used in Steps 3 and 4 as a visualisation for learning supplementary aid. In Step 3 the subtopics are characterized and explained. **Each of four components in thematic system can be further expanded with internal fractal structure.** Step 4 provides the characterization, explanation and summarizing of the interconnections of components of the main topic. The previously mentioned Step system is equal for all topics.

3. The teacher of chemistry tested students' learning achievements after their familiarization with each topic by using examination works. The evaluation of the students' achievements in learning chemistry was organized according to the evaluation criteria – knowledge level, quality and acquired skills (section *Measures)*.

4. The test *Stability of students' knowledge* shows the persistency of students' knowledge in grade 9. The knowledge stability test consists of two parts: test and re-test. The test was

used to check the students' learning achievements after 6 weeks of learning chemistry using the *TETRA*-method to learn the topic *Water*, where the sub topics about water in nature, inorganic and organic substances in the environment from the previous school year (spring time) were included. The test was done to approve the stability of students' knowledge. Students' knowledge level was retested after the summer holidays (3.5 months). Similar questions about the topic Water were used in the re-test, though they were not identical to those in the previous test. The common evaluation of students' learning achievements was used in the knowledge stability test.

*Measures*

The learning achievements of students from experimental and control groups (evaluation by chemistry teacher) were compared during the learning process. To make sure that the student has acquired basic skills, tasks revealing students' knowledge, understanding and practical skills are included in the examination.

Evaluation is a resolution of the acquirement level of the learning contents established in learning; the result of an evaluation is expressed with a rating - the *effective learning index.* Mainly it is the total number of points in the examination which is divided by the maximum number of points possible. The index of effective learning was used to evaluate students' achievements. Examinations were used to obtain qualitative data about students' achievements.

In this study students' achievements in learning chemistry were evaluated by using the effective learning index (further in text $I_{EL}$) scale according to the evaluation criteria – knowledge level, quality and acquired skills which are divided into four positions:

- Very high level ($0.85 \leq I_{EL} \leq 1.0$), a student has acquired knowledge and skills at a level where he understands, comprehends the learning contents, and is able to use them independently to acquire new knowledge and to solve creative tasks; is able to see and explain regularities in practice; is able to express his opinion independently.
- High level ($0.65 \leq I_{EL} \leq 0.84$), a student is able to reproduce learning contents completely, sees regularities, distinguishes the important from the unimportant; is able to use knowledge and skills following everyday examples, in analogy or familiar situations, performs standard and combined learning tasks; expresses his/her personal opinion at a level of fixing basic questions regarding the contents of the subject.
- Optimal level ($0.45 \leq I_{EL} \leq 0.64$), a student has become acquainted with the subject contents, distinguishes the important from the unimportant, knows and is able to define the concepts, the main laws, is able to formulate recognition rules, solves standard tasks.
- Low level ($I_{EL} \leq 0.44$), a student is only able to perceive and recognize the subject contents, he/she reproduces an insufficient amount of acquirable contents, performs only primitive tasks by following an example in a well known situation.

The system of evaluating examination works was formed to more completely display students' achievements in learning chemistry. In the examinations students were able to confirm their acquired knowledge, analytical and creative skills, and the use of scientific verities which are evaluated by taking into account the aggregation principle of positive achievements, by registering the positive achievements at all evaluation levels of the learning achievements – the level of understanding, use and independent, productive action of knowledge; the principle of assessment compliance, by enabling a student to confirm his/her knowledge and skills at the evaluation levels of the learning achievements in adequate tasks, examples and situations; and the diversity principle of assessment methodological technique, by using the organization of examinations in writing, in words and combining the two; the evaluation of individual and group achievements in ordinary examinations, practical works and tests.

*Methods of Analysis*

The data for quantitative processing was obtained by using the methods of statistical analysis (t-test, Kolmogorov-Smirnov test) of the SPSS program.

## Results of Research

*Students' Learning Achievements*

Grade 8. Obtained results of students' learning achievements in grade 8 show that by using the *TETRA*-method in chemistry classes the level of students' knowledge increases in experimental classes if compared with control groups. Tendencies were observed in both schools that took part in the approbation of the method. The students' learning achievements in experimental group ($I_{EL}$=.69) at school R and ($I_{EL}$=.71) school L reached almost similar results showing no statistically significant differences (t=1.31, df=70, p>.05).

Statistically significant differences were observed in the experimental group of School L between topics *Chemistry language* (t=1.78, df=69, p<.05) and *Substance Changes* (t = 2.40, df=69, p<.05) if compared with the control group. The experimental group of school L showed statistically significant results ($I_{EL}$=.69) compared with students knowledge level of the control group ($I_{EL}$=.62) of school R in the topic *Chemistry language* (t=2.66, df=69, p<.05). A similar situation was observed in control groups at both schools, where the control group of school L showed higher results (t=2.73, df=68, p<.05) compared to school R in the topic *Changes of the substances* (Figure 1).

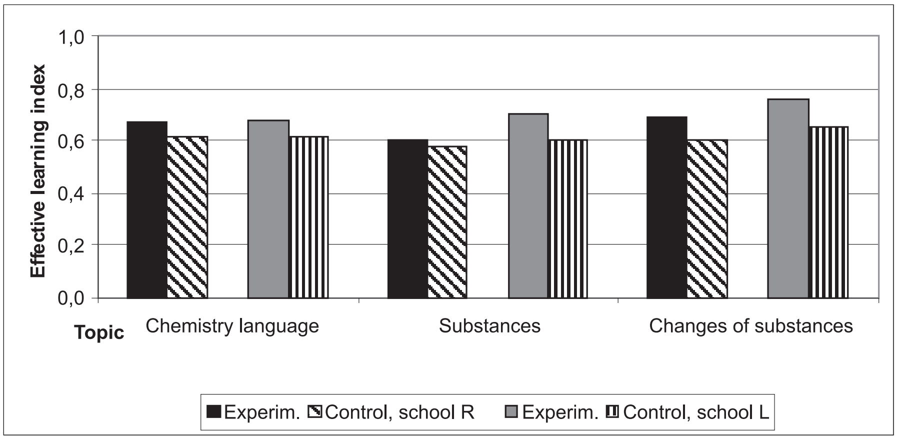



**Figure 1. Comparison of students' learning achievements in acquiring the topics used in grade 8.**

There were also positive changes in the topic *Substances* at school L if compared to the experimental group ($I_{EL}$=.70) and control group ($I_{EL}$=.60*)* by showing a lower result. Analysis of the learning achievements on the topic *Changes of the substances,* as a subtopic of the main topic Substances, showed that the students of experimental group ($I_{EL}$=.76) at school L showed higher results than students of control group ($I_{EL}$=.65). Significant changes of the level of students' knowledge between experimental group ($I_{EL}$ =.68) and control group ($I_{EL}$=.60; t=1.17, df=69, p<.05) in topic *Substances* were observed at school R. In general, the experimental classes from both schools showed relatively higher results of students' learning achievements if the *TETRA*-method was used, which proves the suitability of the method for acquiring chemistry in the group of grade 8.

Grade 9. The results of students' learning achievements in grade 9 show that the variety of different methods which are used in learning chemistry promotes students' successes and enhance their learning achievements (Figure 2).

The level of students' knowledge increased at both schools if the *TETRA*-method was used. Finally, students' achievements and the level of knowledge in the first semester of the school year at school L ($I_{EL}$=0.73) was different from students' achievements at school R ($I_{EL}$=.65).

In the gender context, girls ($I_{EL}$=.66) showed relatively higher results when acquiring the topic *Structure of substance* compared to boys ($I_{EL}$=.52; t=2.56, df=81, p<.05) at school R. The obtained results show that the topic *Hydroxides* was acquired differently at both schools involved in the approval of the method.

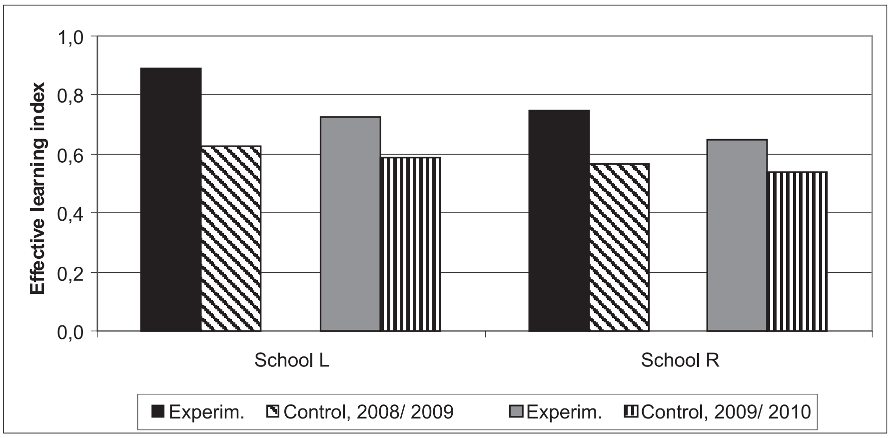



**Figure 2. The comparison of the students' learning achievement in grade 9.**

At school L girls showed a relatively higher effective learning index ($I_{EL}$=.84) on the topic *Hydroxides* than boys ($I_{EL}$=.70; t= 2.08, df=82, p>.05). The exception was boys ($I_{EL}$=.81) from school L who showed relatively higher results in the topic *Hydroxides* than girls ($I_{EL}$=.77), although there is no statistical significance (p>.05).

Grade 10. Obtained results of students' learning achievement in grade 10 showed that students have a higher knowledge level if the *TETRA*-method is used in learning chemistry. Students of the experimental group reached higher results ($I_{EL}$=.86) than students of the control group ($I_{EL}$=.50; t = 2.69, df=90, p<.001) at school C. Achievements ($I_{EL}$=.71) of the experimental group at school L also show a statistically significant increase (t = -2.37, df=89, p<.001) in the first semester when compared with students who did not learn chemistry with the *TETRA*-method ($I_{EL}$=*.55*). It proves that it is possible to improve the level of knowledge if the spatial mind model is used in learning.

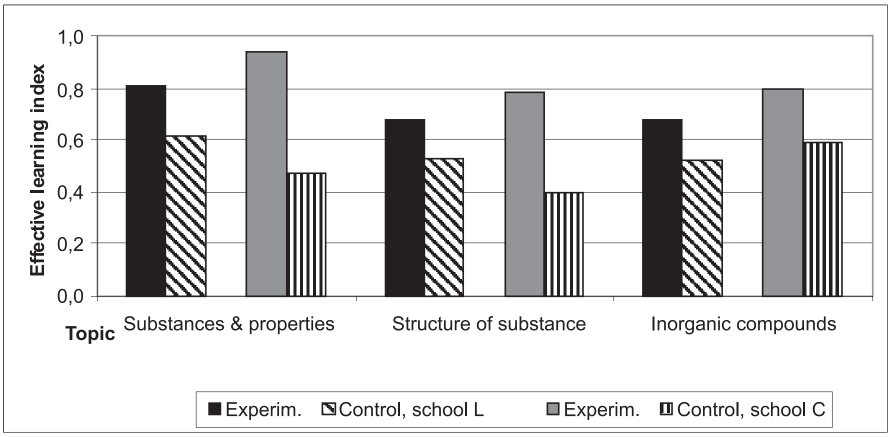



**Figure 3. The changes of the students' learning achievements of different topics in grade 10.**

Students of experimental group show relatively higher results of acquirement in topic *Substances and their properties* then students of the control groups ($t=2.69$, $df=88$, $p<.05$) at school L and school C. Students of experimental group ($I_{EL}=.68$) at school L and experimental group ($I_{EL}=.78$) at school C achieved relatively higher results in the topic *Structure of substance* then control groups respectively from school L ($I_{EL}=.54$) and school C ($I_{EL}=.40$). Subtopic *Structure of atom* was extendedly acquired (2 lessons) within the topic *Structure of substance*, this was necessary for students to study in grade 10 according to the learning program. In experimental class at school L the students' acquirement ($I_{EL}=.68$) of the topic *Groups of inorganic substances* showed statistically significant lower result ($t=2.29$, $df=89$, $p<.001$) if compare with the topic *Substances and their changes* ($I_{EL}=.81$). Students' results of the experimental group at school C prove that method promotes the raising of the level of students' knowledge for both students with relatively lower results and students with relatively higher results of achievements (Figure 3).

The significant differences were not observed in the gender context, this proves that method is adaptable for both girls and boys to acquire chemistry. In general, the girls' mean acquired level of knowledge is 6.0% higher in comparing to boys. Obtained results allow conclude that in general the using of the *TETRA*-method gives an option to raise the knowledge level for students in grade 10. Learning materials which are used in the *TETRA*-method promote the developing of the connections for students among separate topics and unite fragmental knowledge by forming knowledge based on comprehension.

*Stability of Students' Knowledge*

Results of the knowledge stability test prove that the level of students knowledge in the re-test decreased by 20.2% when comparing the instant level of knowledge ($I_{EL}=.71$) with the level of knowledge 3.5 months ago ($I_{EL}=.89$; $t= 2.69$, $df=79$, $p<.05$). Students showed relatively lower results ($t=2.35$, $df=78$, $p<.001$) in the re-test (Figure 4).

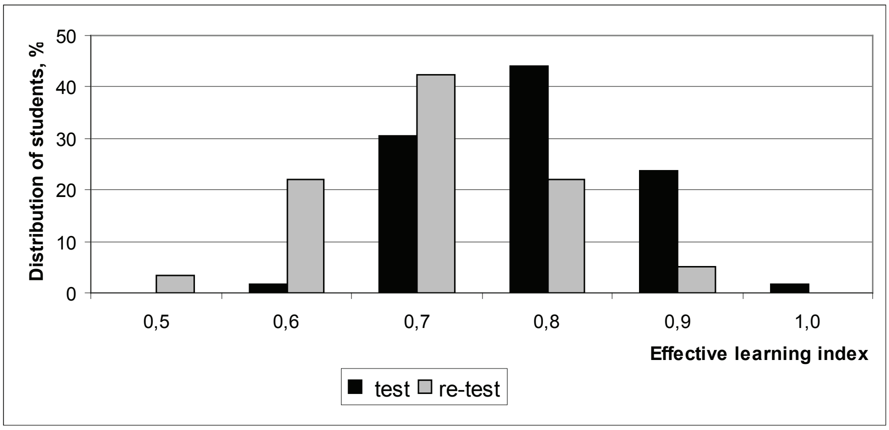



**Figure 4. The comparison of students' learning achievement in the test and re-test, grade 9.**

There are observable differences both in the test and re-test in the gender context. Girls show higher results compared to boys in both tests. The mean result for girls ($I_{EL}$=.91) is 6.6% higher compared to boys ($I_{EL}$=.85; t=2.24, df=79, p<.05) in the test. Girls also show 4.3% higher learning achievements ($I_{EL}$=.72) in the re-test on the topic *Water* compared to boys ($I_{EL}$=.69; t=1.14, df=78, p>.05), though the data do not show statistically significant differences (Table 2).

**Table 2. Comparison of the changes in the knowledge stability test in the gender context, grade 9.**

| Pair | Item | Paired Differences | | | t | df | p |
|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | | | |
| 1 | **Test,** girls/ boys | .80 | 1.105 | .247 | 2.238 | 79 | .004 |
| 2 | **Re-test,** girls/ boys | .32 | 1.204 | .276 | 1.143 | 78 | .268 |

The data show a tendency that boys have a comparatively lower decrease of learning achievements than girls. Results prove that the spatial mind model can be used for all students irrespective of gender. It should be mentioned that during the re-test the spatial mind model was not used as a visual supplementary aid. This could be an explanation for the decrease of the level of knowledge.

The knowledge stability test showed that students' knowledge is stable. After three months it decreased on average by 25%, while teachers' experience shows that changes like these are usually larger.

## Discussion

The observations of chemistry teachers prove that during the lessons students do not concentrate only to memorize the chemical facts, but start to comprehend the chemistry as a component of a nature. Student forms a connected view about chemistry as the united science subject by connecting acquirable topics in the subject. If these topics are connected with every day use, it gives an opportunity for students to become acquainted with chemistry from practical aspect. Model is visually exciting, pays students' attention, and stimulates cognitive interest. However learning became creative, exciting, informal, simultaneously profound and well-thought-out when the spatial mind model is used in the learning chemistry.

Students would willingly use team as one of the organization forms of the learning work in chemistry classes. Majority of the teachers avoid using teams when acquiring basic topics, due to students' behavioural problems, which reduce efficacy of the learning process. Using *TETRA*-method this problem is avoided if team consists of four participants. On the basis that the spatial mind model has 4 peaks, every student researches and explores one of the connected topics. Comprehensive, creative, active action in lesson and topical connection with the practical life promotes meaningful learning.

Those teachers of chemistry who were involved in the approval of the *TETRA*-method see its prospect not only as a connection builder between separate acquirable topics in chemistry, but also in science subjects biology and physics. Therefore independent science teachers were invited and asked for their opinion on prospect of the *TETRA*-method in chemistry and in other science subjects (Table 3).

**Table 3. Overview of teachers' opinion on the using of the TETRA-method.**

| | | |
|---|---|---|
| Chemistry teachers | + | *The method can develop the students` interest, activity, creativity and promote formation of topical connection. Model systemizes incoming information and forms connected knowledge. Model is nice, sympathetic and congenial. „Self-perception" phenomenon enhances students appraisal, stimulates to think about the role of human in nature.* |
| | | *It is not possible to use in all topics of curriculum.* |
| Biology teachers | + | *It really could promote the students interest of acquirable topics. Use of the method could more easily explain conformity to natural laws. Transitions from main topic to subtopics are clear and understandable. Model is colourful; it is visually attractive and could catch the student's attention.* |
| | | *The making of small paper mind model takes at least 10 minutes. Virtual spatial mind model is not identical with the paper mind model.* |
| Physics teacher | + | *Method is interesting, it is easy to understand it, connected with everyday.* |
| | | *Great investment of mine should be done for making the materials in physics.* |

At the beginning of the discussion science teachers were informed about the success of students` learning achievements in chemistry learning; and also about our aim to find out the science teachers' opinions about the using potentialities of the spatial mind model in learning. At the first moment of the discussion teachers' thoughts were more different about the placement and the formation of connections if the *TETRA*-method is used in the learning. This should be noticed, that teachers previously were not familiar with the method, and in the addition every teacher at first analyzed the method from his /her subjects' point of view. Teachers agree that the method could rouse students' cognitive interest, which is important precondition for the acquirement of chemistry, so that students knowledge would be acquired more effectively, steady and would form skills to use the knowledge, as a result the stability of students knowledge would increase. All teachers were sure that"Self-perception" phenomenon promotes student interest in teaching-learning process.

The teachers of chemistry and other science subjects draw attention that the use of the spatial mind model is successful solution to form scientific literacy for students and they think that method is suitable to use it in both biology, and physics. The period of the learning method efficacy probation gave an opportunity to ascertain the using potentialities of the *TETRA*-method in the process of chemistry learning.

## Conclusion

The tetrahedral spatial mind model which represents the *TETRA*-method gives an opportunity for students to form the connections concerning various phenomena. The application of this model improves the activation of students' thinking, and as the result the connected and knowledge-based understanding about the nature in the context of chemistry forms which increase the efficiency of the learning.

The using of the spatial mind model also increases students' cognitive interest, which is important precondition for the acquirement of chemistry, so that learning material of chemistry would be acquired more effectively, students would have steady knowledge and would form skills to apply the knowledge, as a result the stability of students` knowledge would be improved. The results of the research prove that by using the developed *TETRA*-method in learning chemistry students reach a relatively stable level of knowledge based on understanding.

Students' knowledge level has a tendency to enhance more frequently one level above the previous (mainly from optimal to high level); followed by improved students' learning achievements. In the context of gender there is no statistically significant differences, it means that the application of the spatial mind model in the chemistry learning influences positively both girls and boys. The level of students' knowledge increases on average by 20% independent of gender, grade and school. The influence of the teacher factor was not observed.

There is a visible connection between the application of the *TETRA*-method and the formation of students' scientific literacy: the use of the spatial mind model improves students' activity in chemistry classes, understanding about chemical substances used every day as the components of nature and - in connection with practical life - promotes the useful learning.

The *TETRA*-method has good prospects for use in learning chemistry in lower secondary school and in secondary school as an alternative and innovative teaching and learning method.

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