Calculations exercises in applied chemistry
Ejercicios de cálculos en química aplicada

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Abstract

Research shows that during the last 10 – 13 years the number of students who claim to enjoy solving chemistry exercises has decreased by almost one fifth. One way to make chemistry exercises more interesting for students is to relate the content to real life situations. This article presents a conceptual approach to include practical elements in chemistry exercises. Based on this concept, we have devised an educational model for effectively relating real life to the content of chemistry exercises. The didactic objective of the model is to ensure a link between the student's real life experiences and the chemistry exercise – to include this practical aspect in the exercise and, in turn increase the chances that the student will apply what is learned in the exercise later on in life. Trialling of the model shows that student interest increases if they perceive the exercise as useful, but students still find it difficult to relate their personal experience to chemistry exercises and chemistry in general.

Key words: *chemistry education, calculations exercise in chemistry, practical life.*

Resumen

La investigación muestra que durante los últimos 10-13 años el número de estudiantes que afirman disfrutar de ejercicios prácticos de química se ha reducido en casi una quinta parte. Una manera de hacer con la química ejercicios más interesantes para los estudiantes, es relacionar el contenido con las situaciones de la vida real. Este artículo, presenta un enfoque conceptual, para incluir elementos prácticos en los ejercicios de química. Basado en el concepto, hemos ideado un modelo de educación para la vida real de manera eficaz, en relación con el contenido de los ejercicios de química. El objetivo didáctico de este modelo es garantizar el vínculo entre las experiencias de la vida real del estudiante y el ejercicio de química – para incluir este aspecto práctico en el ejercicio y, a su vez, garantizar que el alumno aplicará lo aprendido en el ejercicio más tarde en la vida. La aprobación del modelo, muestra que aumenta el interés del estudiante, si perciben que el ejercicio es útil, pero a los estudiantes aún les resulta difícil relacionar su experiencia personal con los ejercicios de química y la química en general.

Palabras clave*: enseñanza de la química, cálculos en la química, la vida práctica.*

INTRODUCTION

Historically we have seen that along with changes in social and economic conditions, education paradigms change as well. During the transition to a humanitarian pedagogic paradigm, a teacher's way of thinking changes in favor of the development of each student's individuality and away from the purely academic and stereotypical. In chemistry too, the emphasis is being placed on student activities, increasing the student's desire to know and developing experimental and problem solving skills (Bartusevica, 2004). In the natural sciences the explanatory-illustrative learning model is being replaced by the student activity-oriented model (Orlik, 2002; p. 11). As a result the chemistry curriculum content and chemistry exercises are more related to real life. Thus, the goal of doing chemistry exercises also changes. The goal is not only to learn how to solve certain types of problems, but also to understand the significance of the problem and to help answer the student's own questions: why am I doing this? How will I be able to apply this in my life? Essential to a chemistry education paradigm centered on the development of a scientifically literate personality (Toldsepp & Toots, 2003), (specifically a chemically literate personality), is the desire on behalf of the student to learn with interest and understanding (Brown & Reveles & Kelly, 2005), customizing the curriculum to suit his or her needs (Chernobelskaya, 2000). Much research has been done on the changes in the chemistry learning process form offering knowledge to acquiring learning skills, from scientific knowledge and algorithms to the student's own discoveries (Abd-El-Khalich & Lederman, 2000; Coll & Taylor, 2003; Jong, 2005). This research has uncovered numerous problems, inconsistencies and trends and has led to continued study (Namsone, 2002; Jong, 2006; Waters-Adams, & Lederman, 2006). It is only by making a connection with the curriculum and real life that it is possible to actualize the student's personal experiences (Tronson & Ross, 2004; Lamanauskas & Gedrovics, 2005; Rannikmae, Rannikmae & Holbrook, 2006), thus making what is learned relevant to many and varied situations. The ISEC and ESF project *Curriculum development and in-service training of teachers in science, mathematics and technology* (2005-2008) played a considerable role in raising the importance of the applied aspect of chemistry (lit. 11). The aim of our study was to determine how and if increasing the applied aspect of chemistry helps the student understand what is going on around him and helps him better understand the theoretical aspects chemistry.

METHODOLOGY

Background. Not only have various international studies pointed out the need to develop the student's ability to use what he has learned at school in real life situations. Our research results also show that during the last 10-13 years in Latvia the number of students who claim they like doing chemistry exercises has fallen by one fifth (Tomina & Krumina, 2008).

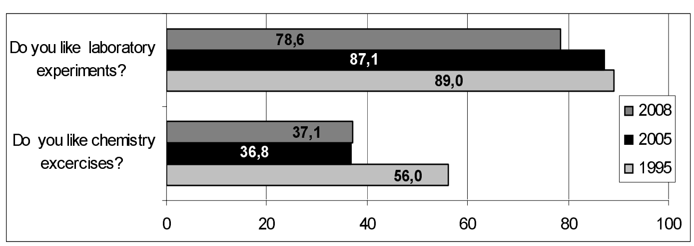

Figure 1. Changes in Latvian student attitudes toward chemistry exercises and laboratory experiments from 1995 to 2008, (confirming answers, percentage).

If in 1995 56% (N=282) claimed to like doing chemistry exercises, then in 2005 (N=389) and 2008 (N=364) the number has fallen to about 37%. It must be noted that the number of students who like to do laboratory experiments has fallen as well. In general, however, twice as many students would rather do laboratory experiments than chemistry exercises. One way to make learning chemistry more interesting and exciting is to relate laboratory experiments and chemistry exercises to real life situations along with experimental visualization of the essence of the exercise in class (Tomina & Bartusevica, 2006). In chemistry, as in mathematics, a single exercise can be used in various ways either restructuring it or using it as a research topic in progress. A research type exercise involves a certain problem which helps the student learn how to make assumptions and how to resolve the given problem. This type of exercise helps develop the student's subjective experience which is important in the discovery and understanding of new concepts. One of the significant aspects of our study, which was conducted between 1995 and 2008, was to analyze the students' interest in and understanding of the significance of the applied aspect in chemistry exercises.

RESULTS AND DISCUSSION

Elaboration and approbation of the methodology

In devising methodology for studying applied exercises in chemistry, we relied on didactic models in use in Latvia today. They are the Society-Nature-Technologies model (Bartusevica & Cedere D., 2004) and the curriculum conceptual model for the natural sciences Society-Technologies-Environment (10). During this process we separated out those chemistry exercises that created student interest and encouraged them to think and work independently. Interest, as we know, is the phase in the educational process involving student initiative and motivation, will and cognitive activity. In order to make the chemistry exercises interesting to the students, the exercises have to make the student understand the importance of chemistry in various professions, they have to create an interest in the students to pursue chemistry as part of their future plans, they should provide the students with the knowledge, skills and abilities that will serve them well at university and they should be useful in their everyday life.

The philosophical and conceptual basis of our ***Model for the effective connection of real life and chemistry*** exercises is presented in Figure 2. It is important that students do not solve problems and exercises simply for the sake of solving them, but rather learn the methods that will help them understand other exercises of this type (step 1). The cognitive aspect, of course, exists; the students like the exercise, they have learned something new and their personal experience was necessary for them to solve it. Step 2 involves the student understanding how the exercise relates to specific theoretical issues in chemistry. It is evident that the student has gained not only knowledge of the process itself, but also the skills to apply what he has learned. The ability to use the knowledge, skills and experiences gained in chemistry in other subjects, especially mathematics and the natural sciences, is step 3.

This process of solving problems based in everyday experience helps the student to develop his ability to think – *cognition* is followed by *consideration* which in turn is followed by *understanding/behavior* which leads to ***literacy***. In our case, this refers not only to scientific literacy and specifically, chemical literacy but also to ***literacy for life.*** Of course, the amount of information in exercises and current life experience is not sufficient for this growth to occur. If the *knowledge, skills, and experience* (Figure 2) concept is developed further to include the conscious and purposeful use of knowledge, skills and experience in everyday situations, chemistry studies reflect *the science education for life* (Broks, 2007) concept espoused by the nature sciences and helps perceive science as part of ***life experience for life***.

To continue, we will look specifically at the content of applied chemistry exercises. In devising the appropriate methodology, certain concepts were noted (**Figure 3**). In pedagogic practice, these concepts are expressed in concrete didactic methods: *from simple to more complex* and *from the known to the unknown*.

Even prior to doing a specific exercise, the student already has basic skills that prepare him to solve the problem in one way or another, to record the acquired information in a certain order and to find the necessary formulae. If the subject of the exercise is not interesting, then the process truly becomes an exercise in futility. But anything unexpected or new makes the student study and ponder the problem in greater depth. This can act as a stimulus for the student to seek additional related information and to use the information not only in chemistry, but in other subjects as well (Figure 3).

Similarly, reading through the text of the exercise, if the student sees something familiar he tends to feel that the solution will not be that difficult to find. Visualizing the desired results also is easier if there is

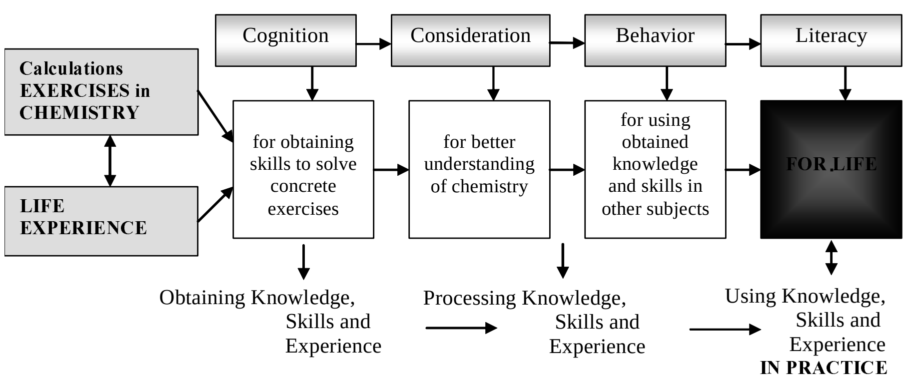

Figure 2. A model for the effective connection of real life and chemistry.

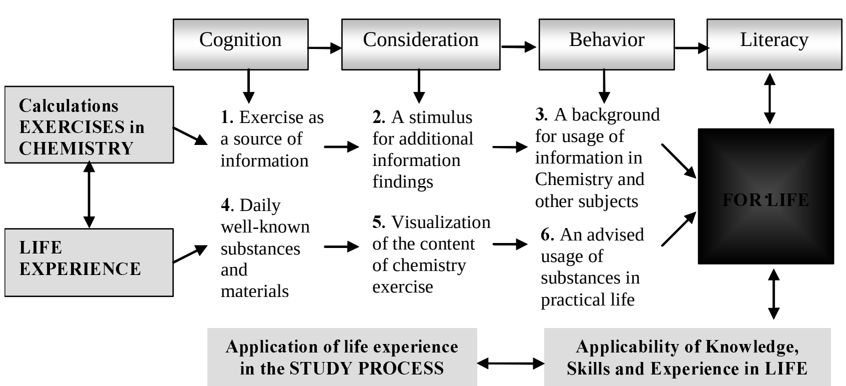

Figure 3. A model for the effective connection of real life and chemistry – didactical solution and results.

this aspect of subject familiarity. It follows that chemical substances will be applied and used in real life. What might the result of such a method be? The efficacy of the model was projected by comparing student and expert opinions on the following questions:

- Can the student use the skills gained by using this method to use his existing and newly acquired experience in chemistry and in other subjects?
- Can the student relate the knowledge, skills and experience gained during work on the exercises with practical usefulness?

The final evaluation of the efficacy of the model was performed at the end of approbation (see result analysis).

The chemistry exercise as a source of information

One way to introduce theoretical concepts in chemistry in a way that is interesting to students is to include interesting and informative information in the description of the exercise (Bunder & Parchmann, 2004). In practice, exercises prepared in such a way motivate the student to quickly and precisely find the correct answer to the problem posed by the exercise. For example, when doing the exercise on the Cullinan diamond, questions always come up about the cost of this diamond, about its location etc. When following the recipe for postal stamp glue, there are always students who want to try and prepare this type of glue. The didactic objective of the activity has been reached – the student solves the problem with great interest and the results have practical value in the eyes of the student.

Examples of exercises:

- *One of the largest diamonds in the world is the Cullinan. Its mass is 3106 carats (1 carat = 0.2 grams). Calculate the number of carbon atoms in this diamond!*
- *The isotonic solution used for intravenous injections in medicine actually is 0.9% sodium chloride solution in water. Calculate the mass of water and sodium chloride needed to prepare 2 kg of such a solution! Can tap water be used to prepare this solution? Justify the answer!*
- *The recipe for non-toxic postal stamp glue is the following: dissolve 400 g dextrine in 600 ml water, add 20 g glucose and 5 g anhydrous aluminum sulfate. How will the amount of salt and water change if* $Al_2(SO_4)_3 \cdot 18H_2O$*? is used?*
- *Glass has a complex structure. It is common to write the chemical formula for glass by showing the ratio of oxide amounts. The melting of glass can be represented by the equation:* $6SiO_2 + Na_2CO_3 + CaCO_3 \rightarrow Na_2O.\ CaO.\ 6SiO_2 + 2CO_2$ *Calculate the amount of sand (kg) needed to produce 100 kg of glass!*

The chemistry exercise as stimulus for seeking additional information

In today's changing world with its ever growing amount of information it is becoming more and more difficult for a student to make sense of all the information, to remember it and use it. It has been shown that a student retains only 10% of what he reads, 20% of what he hears, 50% of what he both sees and hears, 80% of what he needs to express his opinion on and up to 90% is retained as a result of independent activity by a student (Barke, 2006). It is precisely for this reason that it is important for the student to find the necessary information himself by going to text books, chemistry handbooks, the internet and other sources. In order to solve the following exercises the student must know how to find the chemical composition of dolomite, he must know how to calculate the number of carats in a piece of jewelry, and he must be able to find the chemical formulae for red iron ore and magnetic iron ore.

Examples of exercises:

- *A gold medallion weighs 18.00 grams. How much pure gold is in the medallion whose hallmark number is 583?*
- *Calculate the calcium and carbon percentage by mass in dolomite.*
- *Show by calculation which of the iron ores is richer in iron – red iron ore or magnetic iron ore.*

The chemistry exercise as a basis for the use of information in Chemistry and other subjects

Knowledge and skills in chemistry are necessary for anyone to avoid mistakes in everyday life. For more than half a century students in many countries start to learn about chemistry by learning about what they see and encounter every day. This method has been accepted as the most apt conceptual approach (Barke, 2006). The curriculum is directly linked to that which the student is familiar with. Therefore, it is vital that the teacher knows and uses methods that make problem solving in chemistry more useful and meaningful for the student. In teaching practical application of information in the exercise, it is important that the student also understands that he can use it not only in chemistry, but in other subjects as well – biology, physics, mathematics, geography, medicine and others.

Examples of exercises:

- *An ampoule containing 10ml liquid chlorine (density 1.6g/ml) broke in the laboratory. The volume of the laboratory is 873 cubic meters. Is it necessary to vacate the premises if work safety regulations allow a chlorine concentration of 0.003 mg/l in the air? Calculate the volume of chlorine that leaked out in the laboratory.*
- *Defoliants are substances that cause the loss of leaves. A particular defoliant contains 21.6% sodium, 33.3% chlorine and 45.1% oxygen. Determine the chemical formula.*
- *The human skeleton contains about 80% calcium orthophosphate and 13% calcium carbonate. Calculate the mass of these salts in 1 kg bone.*
- *What is the mass of 1 mole of iron on the surface of the moon?*

The chemistry exercise as a connection with substances and materials the student is familiar with

The objective is to develop the skills necessary to include substances that students have contact with when writing the exercises, to include information meaningful to students in the exercises, to provide students the opportunity to search for additional data and facts needed. The result is a more creative and interested student.

Examples of exercises:

- When learning how to calculate molecular mass, 8th grade students were asked to name seven substances that can be found in their kitchen and calculate the molecular mass for three of them. In the next lesson the students (first in groups of 4, then all together) discussed the following questions:

a) *what substances were selected* (salt, sugar, aluminum, water, vinegar, sand, potassium permanganate, carbon dioxide etc.)?

b) *how were the chemical formulae for the selected substances found*?

(students had asked their parents, brothers and sisters, they found them on labels, chemistry books and the internet).

The significance of the exercise was not only reinforcing information and the ability to calculate molecular mass but also emphasizing the connection between chemistry and substances found in the home, the fact that parents and other family members participated and the fact that various sources were searched for chemical formulae.

Visualization of the content of the chemistry exercise

The literature abounds with various methods of content visualization (Herman, 1999; Davidowitz & Rollnick, 2001). These include schematic drawings by the student or the teacher on the blackboard or in a notebook; the exercise can be represented graphically in tables or graphs; appropriate laboratory experiments prior to the exercise itself etc. Often a seemingly insignificant nuance is all it takes to help make the exercise more understandable and interesting. The following are two examples of the same exercise:

- *Class A: the teacher dictates the text of the exercise, students solve the problem.*

  How many moles of aluminum are there in 20 g aluminum?

- *Class B: the teacher shows the class an aluminum spoon and then reads the exercise.*

This teaspoon is made of aluminum. Calculate how many moles of aluminum this spoon contains.

The students wanted to know the weight of the spoon. They take turns guessing before the spoon is weighed on an electronic scale (the scale is described, rules for its use are discussed). The class determines which student's guess was closest to the actual weight of the spoon and then the problem is solved. Needless to say, the experience of Class B solving this simple exercise was one of interest and fun.

Purposeful use of substances in daily life

The teacher is neither the only nor the main source of knowledge for the student, but rather the person who helps the student learn how to study at the appropriate level (Bailey & Garratt, 2002). According to this model, the student structures his own learning; no one can do this for him. Knowledge and skills develop concretely; they are based on specific processes. The resulting skills and knowledge are developed further as the student connects them with previous knowledge and skills and uses them in other subjects.

Examples of exercises:

- *In order to protect greenhouse tomatoes from fitoftora, it is suggested to add a 1.5% copper sulfate solution to the soil. How much $CuSO_4\ 5H_2O$ is needed to make 100 l of this solution?*
- *The recipe for cream pie calls for 500g cream, ½ glass sugar, 3 glasses milk and ¼ baking soda. Write down the reaction that occurs with the drinking soda as the pie bakes. What is the purpose of adding the drinking soda? How many moles of drinking soda are necessary to bake 100 pies?*

Success of the teaching process is a two-way process. Both the teacher and the student need to evaluate the results of the work. Our method was tested in practice for this very reason. At the end of the experiment the efficacy of the method was evaluated by experts (the chemistry teacher in this case) and the students as a self-evaluation and comparing the two evaluations.

ANALYSIS OF RESULTS

Upon conclusion of the study, the methodology was evaluated. The questionnaire contained both closed and open type questions: closed questions in order to perform data processing using the data processing packet SPSS (Statistical Package of the Social Sciences) and open questions in order to qualitatively (subjectively) substantiate the quantitative results. The experimental group consisted of 11th and 12th grade students, two grades (N=50). The questionnaire was administered at the end of the school year, when the students had been working with this method for 2 and 3 years, respectively. During the structured interview students were asked to rate their experience in chemistry lessons and their opinion of the applied chemistry exercises on a scale of 1 to 5 (1 – never; 2 – very seldom; 3 – yes, sometimes; 4 – yes, often; 5 – very often). The instructor (expert) evaluated each student individually, resulting in two sets of independent opinions (student self-evaluation and the instructor's evaluation) to be used for comparing the data.

Analysis of the student self-evaluation

The descriptive data analysis shows whether or not the questions in the study are reliable. The Kronbach-Alpha test was administered in order to determine how effectively a specific questionnaire helps answer the questions therein: student interest in and understanding of an increased emphasis on the applied aspect of chemistry in chemistry exercises. The overall reliability of the questionnaire its cultural and social propriety was rated with the Kronbach-Alpha coefficient – "a"; the propriety of each question was rated with the selectivity coefficient – "s". Since the value of "a" in our case is 0.57, it can be concluded that the questions are appropriate for a student audience. In answer to the question *Do you find the questions related to real life more interesting*? (s=0.433), the frequency analysis shows that 82% (N=41) of the students (Code 4+Code 5) considered these questions interesting or very interesting. Only 18% (N=9) said they found these questions to be interesting sometimes.

Interest in a question is directly linked to understanding the question. Of note is the students' ability to glean information from chemistry exercises that is useful in their everyday life. In answer to the question *Can you gain useful information by solving chemistry exercises*? (s=0.300), 90% (N=45) responded *yes, often* and *yes, sometimes* (Code 3+Code 4). Only one student said that he seldom found useful information in chemistry exercises.

The positive effect of our didactic approach is demonstrated by student responses to the question *Do exercises using substances that are used every day help you understand chemistry better*? (s = 0.397). Almost one half or 40% (N=20) agree that this happens sometimes, but 60% (N=30) of the respondents feel that this type of exercise helps them understand chemistry better *often* and *very often* (Code 4 + Code 5). Use of personal experience to aid in the solution of chemistry exercises presented considerably greater problems. In response to the question *Does practical experience help you better understand how to solve a specific chemistry exercise?* (s = 0.385), 32% (N=16) admit that this happens very seldom (Code 2). 44% (N=22) said that it helps sometimes (Code 3) while less than one fourth of the students responded often and very often (Code 4 + Code 5).

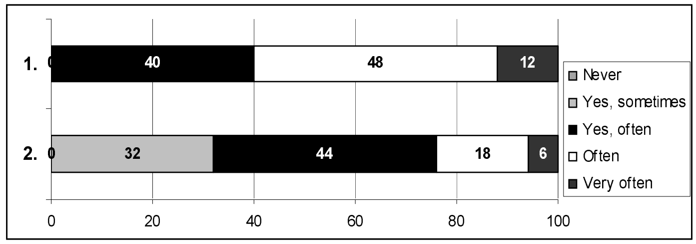

Figure 4. Respondents' answers to questions: 1. *Do exercises using substances that are used every day help you understand chemistry better*? and 2. *Does practical experience help you better understand how to solve chemistry exercises?* (Confirming answers, percentage).

These responses seem to indicate that at this particular age (15-17) the ability to think has not yet reached the point where thinking (processing information) as a process grows into understanding (application of processed information).

Correlation analysis confirms the inadequate relationship between thinking and understanding in the student responses. Correlation coefficient "r" is used to rate this relationship between various choices offered the student. There is a very weak correlation between the two groups of responses analyzed above ("r" = 0.174).

Comparison of student self-evaluations and expert evaluations

In comparing the opinions of two independent groupings, in this case students and experts (chemistry teachers) (Mann-Whitney test), data comparison took place using the Mean Rank and significance indicator "p", which rates the significance of the responses of the two groups. If indicator "p" is less than 0.05, statistically significant differences exist between the opinions of the two groups. The responses to the question *Do you solve exercises that include substances that are used every day?* show that there is no significant difference in the opinions of the two groups (p=0.0667). A summary of the comparison of student and expert opinions is shown in Table 1.

Table 1
Comparison of student self-evaluations and expert evaluations (S - student; E - expert)

Question	Significance	Student self-evaluations/ Expert evaluations			
		Mode		Mean Rank	
Do you solve exercises that include substances that are used every day?	0.067	M_{-S}	3	M_{R-S}	45.76
		M_{-E}	4	M_{R-E}	55.24
Do you find the questions related to real life more interesting?	0.672	M_{-S}	4	M_{R-S}	49.39
		M_{-E}	4	M_{R-E}	51.61
Do you solving chemistry exercises it is possible to gain practically useful information?	0.427	M_{-S}	4	M_{R-S}	47.39
		M_{-E}	4	M_{R-E}	53.61
*Do solving applied chemistry exercises help you understand chemistry in general?**	0.360	M_{-S}	4	M_{R-S}	**52.96 ***
		M_{-E}	3	M_{R-E}	48.04
Does practical experience help you better understand how to solve a specific chemistry exercise?	0.491	M_{-S}	3	M_{R-S}	48.62
		M_{-E}	3	M_{R-E}	52.38

Table 1 show that the student self-evaluation is quite close to the expert evaluation. In almost all cases the teacher/expert rated his students slightly higher than the students rated themselves. Only in response to the question *Does solving applied chemistry exercises help you understand chemistry in general:* was the student self-evaluation slightly higher (M_{aver}=52.96) than that of the expert.

If we compare the mean value of the responses (Mode), we see that both students and experts most often selected the responses *yes, sometimes – code 3 and yes, often – code 4*. Slight differences were noted between expert and student evaluations of how often chemistry exercises worked in class actually use substances encountered every day. Teachers seem to see this connection a bit more (M_E=4) than do the students (M_E=3). When evaluating how much exercise skills help the student understand theoretical concepts in chemistry, the teachers were a bit more critical (M_E=3) than were the students (M_E=4). The responses to the remaining questions differed even less and the mean values of the responses correlate nicely.

The propriety and suitability of our methodological approach is reflected by the positive evaluation at the close of the didactic experiment. The method promotes student interest and creates an understanding of the processes going on in the world around us, motivating them to seriously study chemistry. The complex approach advocated by our model has proven to be quite effective because it allows the student to view the chemistry exercise from various aspects – using everyday substances, visualizing through experimentation etc. The skills required for solving chemistry exercises are acquired gradually, step by step. The steps involved are: gathering information, pondering the information, understanding the information and applying the information, not only in chemistry but in other subjects as well.

CONCLUSIONS

1. Based on the decrease in student interest in solving chemistry problems and exercises over the last 10-13 years, a method incorporating the practical and everyday in chemistry exercises has been devised. During the process of development and testing of the methodology, a selection of those chemistry exercises that students found to be interesting and stimulating was made.
2. The conceptual approach to including applied aspects in as part of the content of chemistry exercises is part of our model: *A model for the effective connection of real life and chemistry exercises*. One of the didactic functions of the model is to establish the connection between the student's experience of learning to solve chemistry exercises and the guarantee that his knowledge, skills and experience will prove useful.
3. As a result of our experiment, it was seen that 82% of the students in the experimental sample group (p=0.672) found the applied exercises more interesting. Slightly more than one half of the student self-evaluations said that chemistry exercises presented information that they would consider useful (p=0.427).
4. The results of our study also point to the fact that as we continue to amend and develop the model further, more attention must be paid to the issue of helping the student effectively put his own experience to use in solving chemistry exercises.

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