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Application of Systemic Approach in Initial Teaching of Chemistry: Learning the Mole Concept

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Abstract

Many studies carried out on the mole concept emphasize that students show significant difficulties in learning this concept. The aim of our research was to analyze those difficulties that students, who have their first contact with chemistry in school, encounter, and also to examine the usefulness of systemics as a graphical way of knowledge representation. The sample of the study included seventh grade students from a primary school in Novi Sad, Serbia. Based on the results of the pre-test, students were divided into three main groups: "excellent", "good" and "acceptable", which all consisted of two subgroups: experimental and control. Students in the experimental subgroup were learning by applying systemics, while the students in the control subgroup were taught by traditional method. The final results show that systemics is convenient in overcoming the difficulties in the case of "excellent" and "acceptable" groups of students, while the same cannot be concluded for the students characterized as "good". Systemics has not proved to be adequate for them. The following question remains a topic for the future research: Is there any way that the group of students characterized as "good" still benefits from learning with systemics? In addition, new research on a larger number of students should be conducted, in order to statistically confirm these results, or to discuss new ones.

Key words: *concept map; difficulties in learning mole concept; ontology; systemics.*

Introduction

That chemistry is a very complex subject is shown by the research on problem solving and misconceptions (Gabel, 1999). Many of the concepts studied in chemistry are abstract, even those presented to the students who are encountered with chemistry in school classes for the first time. These include concepts such as: atom structure (Park & Light, 2009), chemical and physical changes (Hesse & Anderson, 1992), chemical bonds (Nicoll, 2001), chemical laws (Özmen & Ayas, 2003), chemical calculations (stoichiometry) (de Astudillo & Niaz, 1996). Many students at this level of learning chemistry are often unsuccessful since, generally, these topics are too difficult for students to understand.

Many researchers and educators have tried to find the reasons or sources of these difficulties. They have pointed out several sources such as: the abstract nature of concepts, curriculum demands, the overload of students' working memory capacity, language and communication (Oloruntegbe, Ikpe & Kukuru, 2010) and suggested some instructional designs or teaching methods for overcoming the learning difficulties. A good method of teaching is the one that creates a rich and stable knowledge-based system. In chemistry this system comprises scientific chemical theories, chemical laws, scientific chemical concepts and facts. When there is a stable knowledge-based system, we can continue with the expansion of knowledge by learning new information relevant to the already understood information and this is referred to as the quality of education.

Relying on the constructivist theory of learning (Glasersfeld, 1989) and the learning outcomes defined by Gagné (1984), we decided to test if Systemic Approach to Teaching and Learning Chemistry, SATLC (Fahmy & Lagowski, 2002) might be used to teach primary school students the mole concept.

Ontological Knowledge Representation

Constructing ontologies in educational design is not really new (Breuker, Muntjewerff & Bredewey, 1999). It can be concluded that ontology is constructed in education because it is not possible to present a certain area (field, discipline) with all its details. In order to present a certain domain (part of the particular field), it is necessary to restrict attention to a small number of concepts which are meaningful and sufficient to interpret that domain and provide a representation adequate for a certain goal (Breuker et al., 1999). But, if we want to make a complete "picture" of a given domain, and to facilitate understanding in this domain, we need to link the chosen concepts. As a result, a central part of representation of knowledge consists of elaboration of a conceptualization: a set of abstract entities which are assumed to exist in a certain domain and relations set among them (Genesereth & Nilsson, 1987). So, in the context of knowledge sharing, according to Gruber (1993), ontology is an explicit specification of a conceptualization, while a conceptualization is an abstract, simplified view of the world that we wish to present for some purpose (Gruber & Olsen, 1994).

Ontology graphs, such as knowledge maps, Petri nets, concept maps and semantic networks (Kim, Suh & Hwang, 2003), became a broad graphical way of ontological knowledge representation that is already getting new sub-specifications. As one of them, we apply systemics - graphical tools for representing knowledge in SATL method, in scientific (educational) content. The key point that connects ontology and systemic approach is a method of selecting concepts and their organization in a system which provides a clear interpretation of concepts and their relationships.

Systemic Approach to Teaching and Learning (SATL)

Systemic Approach to Teaching and Learning Chemistry (SATLC) has been designed, implemented and evaluated by Fahmy and Lagowski in 1997, with the aim of transforming mechanical (rote) learning to deep (meaningful) learning by students (Fahmy & Lagowski, 2002). It verifies the major goals of educational system and continuous growth of knowledge that is referred to as the quality of education.

During that time (more than ten years), and with the previously mentioned goals, SATL technique has been applied and evaluated in many different knowledge domains at all levels of education (pre-college, college, adult education), but the major teaching applications have been reported on chemistry topics in secondary and tertiary education (Vachliotis, Salta, Vasiliou, & Tzougraki, 2011). Fahmy and Lagowski (2002) set up this approach after the sudden expansion of globalization in a wide range of human activities, so, this approach has been applied in: basic sciences (chemistry, biology, physics, mathematics), applied sciences (environmental sciences, agricultural sciences, pharmaceutical sciences, engineering sciences), law, medicine, linguistics and commercial sciences (http://www.satlcentral.com). They came to the conclusion that by using the systemic approach people can learn in all areas of human activities, in order to obtain a more global view of important relations in sciences. SATL is supported with constructivist theory and current ideas of how the brain functions (Cardellini, 2010). The closest connection between SATL and constructivist theory can be found in the idea of concept mapping (Lagowski, 2009).

Concept maps are graphical teaching and learning tools that are convenient for representing and organizing knowledge, with strong psychological and epistemological background. This background is based on Ausubel (2000) and Novak's (2002) theories. Using Ausubel's ideas of how learners construct meaning, and relying on the main distinction between the meaningful and rote learning, Novak has developed a concept map as a tool to represent concept/propositional framework for domain-specific knowledge (Lagowski, 2009). In practice, it is highly improbable that any student could learn any chemistry topic in a completely rote manner, and hence Ausubel stresses that rote/meaningful distinction is not a dichotomy but a continuum (Novak, 1984).

It is well known that our brain organizes knowledge in a hierarchical structure, and thereby further facilitates the learning process. In the concept map, the given set of concepts is arranged in a hierarchical order, connected by linking verbs. To organize a concept map hierarchically, a student must make an effort to choose a key concept (the most inclusive and the most general) for the given topic. Furthermore, the concepts should be sorted from the more general to the more specific ones. According to the constructivist theory, it is important how students build their own concept map during the acquisition of a new concept. In this way they assimilate new knowledge in the existing structure of knowledge, with the understanding of the basic knowledge structure. Figure 1 presents a simple concept map constructed by the authors of this paper.

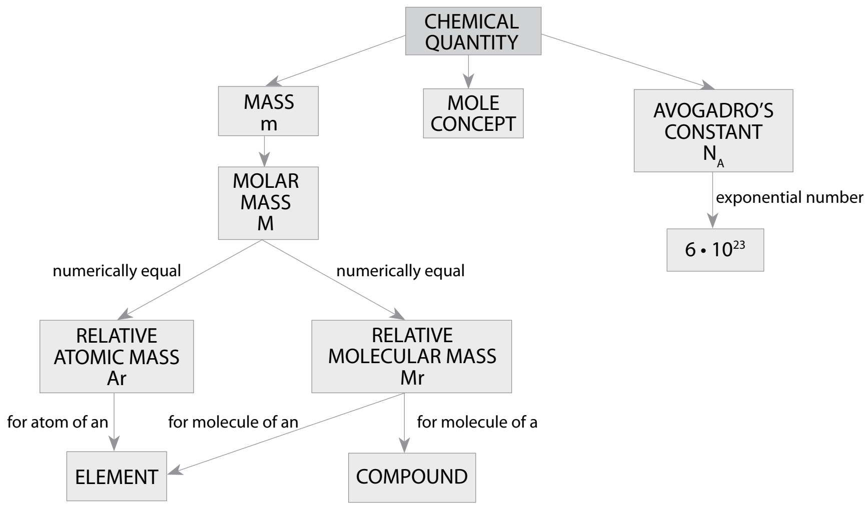

Figure 1. A simple concept map for the chemical quantity

This organization is hierarchical because the concept of chemical quantity is the key concept of a given group and it is placed the highest in the hierarchy, above other concepts, as "molar mass" or "compound". But, a different person (a teacher or a student) might produce a different concept map by choosing a different key concept. In our example "molar mass" might be a key concept as well. So, it is possible to create several concept maps with the same set of concepts and that is why we can pose an important question: *Is a concept map a suitable assessment tool?* Johnston and Otis (2006) investigated the possibility of using concept maps created by students as an assessment tool. Their findings showed that there was no significant relationship between the quality of a concept map and the student's assessment score (Adamov, Segedinac, Cvjetićanin, & Bakoš, 2009). They noticed that "poor" maps (those with few concepts) were created both by students who did not have good maps (for example ill-connected), and also by the students who did not need a complex map for the activation of a large body of knowledge and understanding. These results lead to the conclusion that the map is a very personal thing, idiosyncratically construed by an outsider, by anyone trying to assess what appears on paper (Johnston & Otis, 2006).

Relying on the crucial characteristics of concept maps as teaching and learning tools, but following Fahmy and Lagowski's claim that systemic approach still provides a more global view of collection of concepts by defining all relations between them (Fahmy & Lagowski, 2002), we applied "*systemic*" (or "systemic diagram") in our research as a way of knowledge representation, in the lessons in which mole was taught and learned.

Students' Difficulties in Learning the Mole Concept

The mole, a fundamental concept in quantitative chemistry (Dori & Hameiri, 1998), has been presented in various papers. A vast body of research carried out into the mole concept emphasizes that students have great difficulties in learning this concept. Students' ideas about the mole have been well documented (Case & Fraser, 1999). These studies mainly refer to learning difficulties and students' errors in learning mole concept, as well as students' comprehension of the mole.

Yalçinalp, Geban and Özkan (1995) consider that the abstractness of knowledge has an influence on learning difficulty. Specifically, in problems involving chemical formulas and the mole concept students have to deal with very small and very large numbers. The Avogadro constant unavoidably additionally complicates the problem.

Gabel and Sherwood (1984) stressed that some students did not understand the basic mathematical principles, which could be mathematical manipulations, such as proportional reasoning, changing orders of magnitude and converting units (Dori & Hameiri, 1998). That is a real impediment to solving mole problems correctly using the reasoning methods. In addition to mathematical difficulties, Gabel and Sherwood (1984) cited the following difficulties:

(1) One-step test items were easier to solve than two-step items, even when the student was very familiar with the content. Gabel and Sherwood (1984) associated this problem with students' difficulties with division. Students found division more difficult than multiplication, and as two-steps tasks always require both division and multiplication, students find them more difficult to solve.
(2) Students showed significant difficulties in tasks that involve decimal numbers rather than the whole unit.
(3) When scientific notation was used in the problems, students found them more difficult to solve.
(4) Very simple changes in problems made them more difficult to solve. More precisely, if the task, which was done during the lesson (as a teaching example), contained changed data, generally students were not able to solve it.

The analysis of the interview responses in the research conducted in Israel by Novich and Menis (1976) revealed some misconceptions such as: *"the mole is a certain mass and not a certain number"* (the mole is seen as a mass and not as amount) or *"the mole is a property of a molecule"*. They concluded that most 15-year-old pupils in Israel achieve neither a coherent understanding of the mole concept and its significance in the interpretation of chemical phenomena, nor the ability to use it effectively in solving problems (Novich & Menis, 1976).

In Italy, Cervellati, Montuschi, Perugini, Grimellini-Tomasini and Pecori Balandi (1982), based on the results of their research, concluded that the mole concept was not mastered by most pupils. Students generally were not familiar with the use of the mole concept as a unit of the amount of substance. They chose the wrong answer for the "mole" definition, identifying it with the weight in grams.

These difficulties in learning the "mole" are an important issue, not only because of the repercussions they may have on the teaching and learning of this concept as a unit of one of the seven fundamental physical quantities – "the amount of substance" (Schmidt, 1990), but also because of their influence on the solving of stoichiometry problems (Dori & Hameiri, 1998; Schmidt, 1990; Furió, Azcona, Guisasola, & Ratcliffe, 2000). The mole concept is an important foundation for more complex chemical concepts such as: concentration of solutions, the equilibrium constant and pH (Staver & Lumpe, 1993). Many methodological hints and algorithmic devices that are intended to facilitate the learning and teaching of the mole have been suggested over the years (Strömdahl, Tullberg, & Lybeck, 1994). Yalçinalp et al. (1995) presented computerized instruction, which they called computer-assisted supplementary instruction, with an aim of overcoming difficulties in learning the mole concept. They compared computerized instruction with problem-solving classes and concluded that both approaches have their advantages and disadvantages. Gabel and Sherwood (1984) used analogies in their research, with remark that analogies and related scientific concepts possess similarities that help students to understand science concepts. Novick and Menis (1976) used a structured interview procedure to collect data, using questions which were recorded on cards.

Staver and Lumpe's (1993) goal was to examine the means used by textbook authors to introduce, define, and explain the mole concept in high school and introductory college chemistry textbooks. They stated that if students want to construct frameworks of complex chemical concepts and to solve quantitative problems involving such notations, they must have a clearly defined and well-connected conceptualization of the mole concept. They concluded that students whose learning is best characterized as concrete and intuitive rather than abstract and reflective may have a great difficulty with the mole concept.

The Application of Systemics in Teaching and Learning the Mole Concept

Fahmy and Lagowski suggest the development of an educational process based on the application of "systemics", which they believe can affect both the teaching and the learning process. It is a tool designed to help teachers teach and students learn (Lagowski, 2009). By "*systemic*" they mean an arrangement of concepts or issues through interacting systems in which all relationships among concepts and issues are made clear, up front, to the learner using a concept map as representation (Fahmy & Lagowski, 2002; 2003). In contrast to the usual strategy of concept mapping, which involves establishing a hierarchy of concepts (see once again Figure 1), this approach strives to create a more or less "closed system of concepts" which stresses the interrelationships among concepts (Fahmy et al., 2002). Figure 2 shows a systemic diagram for the mole concept.

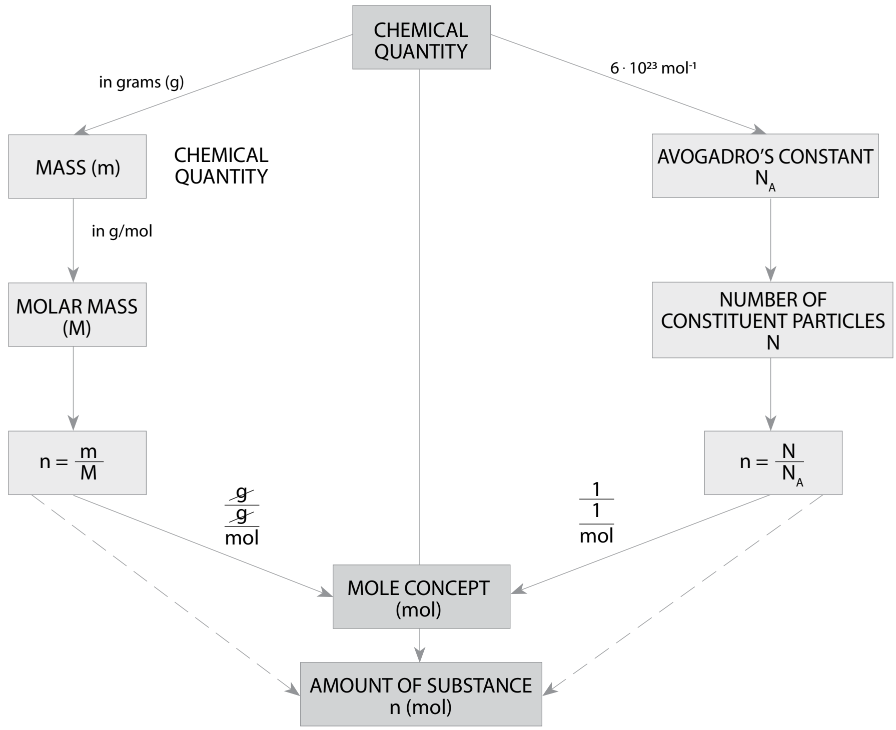

Figure 2. Systemic for the mole concept

We can say that it is more difficult to obtain a global view of a collection of concepts with a concept map or linear representation than with a systemic ("closed-cluster" representation of concepts), which stresses all relationships among the concepts. For example, from the systemic presented in Figure 2 we can observe the relationship between the "amount of substance" and "mass" or "the Avogadro constant" correctly but we do not have that precision using the concept map (Figure 1).

Some research has also been carried out into applying the systemic approach in chemistry education. Fahmy and Lagowski (2003) conducted a study which included students from six secondary schools, from Cairo and Giza (Egypt), who were studying organic chemistry – carboxylic acid and its derivatives. The control group was taught by applying the standard linear approach, while the systemic-oriented module was created for the experimental group. Students who had been taught by instructors using SATL technique were more successful in the final examination in comparison to the students who had been taught linearly. Success was defined as achievement of at least 50% in the final examination. Approximately 80% of the experimental group was successful, but only 10% of the control group reached the level of success. At the university level, Fahmy and Lagowski (2002) studied SATL approach in aliphatic chemistry at pharmacy and science colleges in two Egyptian universities. They conducted research in the first semester of the second year in organic chemistry course at Zagazig University. For teaching in the experimental group, the standard course materials were converted to a systemic approach. Students in the control group were taught in the traditional, linear manner. The success of the learning process was measured by the difference in the pre-test and post-test achievement. Both tests contained linear questions and systemics. The results of the study confirmed that the experimental group, which was taught by using the SATL technique, performed better than the control group taught in the traditional way, in all three categories: linear questions, systemics, as well as in the overall achievement. Al-Bashaireh (2011) examined the effectiveness of teaching using systemic approach, involving the fifth grade students of Tafila (Jordan) province and their achievement in science. In Jordan, the fifth grade students are 11-12 years old. The results of this study confirmed the previous results of Fahmy and Lagowski's research. Considering the achievement in the final test which consisted of 30 multiple choice questions, students from the experimental group (SATL technique) were better than students from the control group (conventional linear method of teaching). All of these studies showed that systemic representation has provided higher pupils' achievement than the traditional way of teaching and learning.

Purpose of the Study

The purpose of conducting this study was to determine the effects of teaching and learning using the systemic approach on the seventh grade students' achievements in single chemical teaching unit – the mole concept. In addition to determining the usefulness of systemics in initial chemistry teaching, the question is whether the application of systemics can overcome the common difficulties that arise in the course of mastering the "mole" by the students. Once again, these difficulties are:

(1) difficulties with the Avogadro constant;
(2) difficulties with the basic mathematical principles;
(3) differences in students' abilities to solve two-step problems versus one-step problems;
(4) difficulties with tasks that are changed by adding some scientific notation;
(5) difficulties with understanding the mole as a unit of the quantity of substance.

Method

Study Participants

The sample of the study included the seventh grade students from a primary school ("Kosta Trifković") in Novi Sad, Serbia. Only one school was chosen in order to avoid the interference factor such as the impact of different teachers on research. In the school year 2011/2012, these seventh grade students encountered chemistry in school for the first time. Students were 13-14 years old, and they attended four independent classes. The total number of students was 96, and after taking the pre-test, 50 pupils, who belonged to two independent classes, were chosen for this research. It was not possible to perform research on the whole sample of 96 students, because we were not able to equalize these four classes by pre-test results. Pre-test results for the two classes which were chosen as the experimental and the control group were most similar, which was statistically confirmed by t-test (Table 1).

Table 1.
Results of the t-test for dividing students into experimental and control group

Group of students	Number of students	Mean	SD	Conf. int.	t	p
Experimental	25	10.68	3.00	[-0.83; 2.43]	0.98	0.33
Control	25	9.88	2.74			

By looking at the results in Table 1, we can conclude that there is no statistically significant difference in the pre-test achievement of the students belonging to the experimental group and those belonging to the control group, at the 95% confidence interval. Since the confidence interval contains value 0.00, p-value is greater than 0.05, and our t-value is less than the critical t_c-value (t_c=1.68, for df=48 and α=0.05). In order to determine whether the distribution of the pre-test data satisfies the normality criterion with 95% confidence, the values for standardized skewness and kurtosis were checked, and the Shapiro-Wilk test was performed. We can conclude that our data come from normal distribution as standardized skewness and kurtosis are within the range of -2 to +2, and the result of the Shapiro-Wilk test confirms the conclusion about the normal distribution of the pre-test data.

The pre-test included 10 tasks, and the maximum possible score was 16 points. The pre-test was composed following the requirements of the curriculum for Chemistry for the seventh grade of elementary school education in the Republic of Serbia, and according to the recommended textbook (Curriculum regulations, 2009; Mandić, Korolija, & Danilović, 2009), for the teaching unit *Solutions*. This teaching unit includes the following teaching topics: The concept of solution and dissolving; Quantitative composition of solution – percent composition by mass; Water and its importance for the living world. The teaching unit *Solutions* is taught prior to the teaching unit *Chemical reactions and calculations*, within which the mole concept is taught. The mole concept was studied after conducting the pre-test, in the second semester in May 2012, which was in accordance with the curriculum.

Design and Instruments

This research was conducted in the form of action research. The collected data are used as a feedback for defining the research findings, but also for planning some of the following activities, such as quantitative research with a larger sample.

Based on the results of the pre-test, students were arranged in three main groups characterized as: "*excellent*", "*good*" and "*acceptable*", depending on the quality and quantity of knowledge that they had shown in the pre-test. In each of the three main groups there were two sub-groups: experimental and control, equalized by prior knowledge of chemical concepts related to the teaching unit *Solutions*, which they had learned during previous classes. Thereby, the first five students in the experimental group, who were the most successful ones in the pre-test, were characterized as "excellent", followed by the second group of fifteen students in the experimental group who were characterized as "good" and the last was the group of five students who were characterized as "acceptable". The same procedure was performed for the control group.

Table 2 shows the distribution of students in the groups *"excellent", "good" and "acceptable"*, as well as in the subgroups: experimental and control.

Table 2.
Distribution of students in the groups and subgroups

Group of students	Subgroups	Number of students
"Excellent"	Experimental	5
	Control	3
"Good"	Experimental	15
	Control	16
"Acceptable"	Experimental	5
	Control	6

The study was conducted during a two-week period (four lessons). During that time students were being taught a new chemistry teaching unit – *Quantity of substance, mole and molar mass*. During those two weeks both the pre-test and post-test were conducted. Two approaches were used in this study to reinforce and examine the students' achievement and understanding of the mole concept. The experimental subgroup was learning by using systemics, and the control subgroup was learning by the conventional method. For the experimental group there were specifically designed systemics, in the form of panels. In the first lesson of teaching and learning with systemics, the teacher was explaining new concepts, unfamiliar to students, by displaying the already filled-in systemics, such as systemic shown in Figure 2.

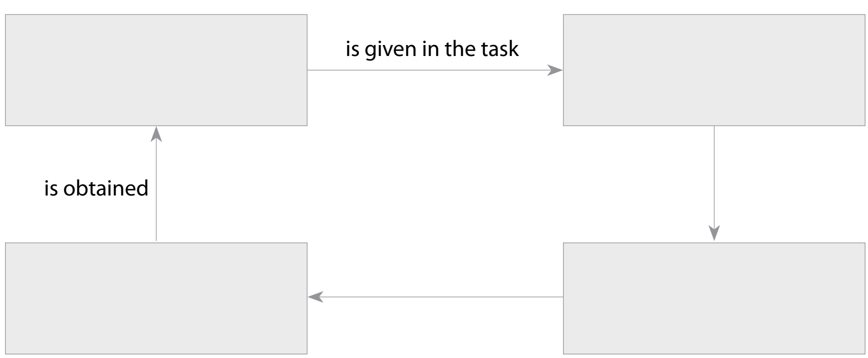

Figure 3. Empty systemic ready to be completed

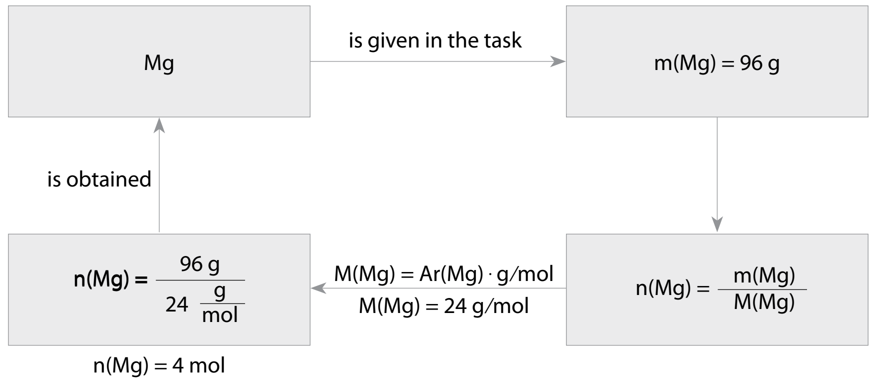

Figure 4. Completed systemic

Using systemics, the teacher carefully explained connections among the given set of concepts, so that students could see all existing relations among the new concepts. During the second class, new systemics were presented to students. They consisted of the associated empty fields, which were then completed (filled-in) by students, guided by the teacher during the lesson. The representations of such systemics are shown in Figures 3 and 4. Figure 3 presents an empty systemic, ready to be filled-in, while Figure 4 shows the already filled-in systemic for the following task: "*The sample of magnesium strip has a mass of 96 g. How many moles of magnesium are there in the sample?*"

The basic data for discussion were collected as a result of the final test, which consisted of 12 tasks, including concepts such as mole, quantity of substance, mass, molar mass, the Avogadro constant. Types of tasks in the test were:

– *write an expression for the required quantity (task 1)*
– *connect the related quantities (task 2)*
– *circle the letter of the correct answer (task 3)*
– *calculate the required quantity (tasks 4,5,6,7,8,11,12)*
– *answer the question after calculation (task 10)*
– *fill in the table (task 9).*

Each task which was done correctly scored one point, with the possibility of scoring partially correct answers. So the maximum possible score was 12 points, or 100%.

Results and Discussion

Before we start our discussion which is focused on students' mistakes and difficulties which occur during the process of solving problems with the mole concept, we will present the summarized t-test results, which confirmed that there was a statistically significant difference in students' post-test achievement between the experimental and the control group (Table 3).

Table 3.
Results of the t-test for students' post-test achievement

Group of students	Number of students	Mean	SD	Conf. int.	t	p
Experimental	25	8.02	3.49	[0.05; 3.94]	2.06	0.04
Control	25	6.02	3.35			

By analyzing the results from Table 3, we can conclude that there is a statistically significant difference in the students' post-test achievement between the experimental and the control group, at the 95% confidence interval; since the confidence interval does not contain value 0.00, p-value is less than 0.05, and the obtained t-value is greater than the critical t-value (t_c=1.68, for df=48 and α=0.05). In order to determine whether the distribution of the post-test data satisfies the normality criterion with 95% confidence, the values for standardized skewness and kurtosis were checked, and the Shapiro-Wilk test was performed. We can conclude that our data come from normal distribution because the standardized skewness and kurtosis fall within the range of -2 to +2, and the result of the Shapiro-Wilk test confirms the normal distribution of the post-test data. So, we can conclude that our students in the experimental group, who were taught by systemic approach, showed higher achievement (66.83%) in the final test than the students in the control group (50.17%), who were taught in a traditional, linear manner.

Further, during the discussion on the final test results we will first turn to the students who were characterized as *"excellent"* after examining the pre-test results, then to the students characterized as *"good"*, and finally to those characterized as *"acceptable"*. We will inspect mistakes and difficulties which occurred in twelve different tasks in the test, and further consider whether such difficulties occurred in both the experimental and control sub-group. All the difficulties that were found in the students' tests will be compared with those difficulties which have already been identified as the results of the previously carried out research.

Students Characterized as "Excellent"

The first major problem that we have encountered while reviewing students' tasks, is a problem with the number of particles N and the Avogadro constant N_A. During drafting these tasks, students in the control group did not write the unit for the Avogadro constant (1/mol) at all. Instead, they wrote only $6 \cdot 10^{23}$. Therefore, at the end of the task, the number of particles N was expressed in moles, as if the "amount of substance n" and "the number of particles N" had the same unit - mole. This problem has, for instance, been reported in *Task 11* and one such drafting appears in the following manner:

$N(Br) = n(Br) \cdot N_A$

$N(Br) = 2\ mol \cdot 6 \cdot 10^{23}$

In this example, specifying the difficulties with the Avogadro constant, we can agree with Yalçinalp et al. (1995), who clearly stated students' difficulties in mastering the

Avogadro constant, naming the notation of abstraction as the key reason. The number of particles N has also been observed, relating to the problem of misunderstanding. While students, as described in a paper by Novich and Menis (1976), see the mole as a mass and not as amount, our students in the control subgroup saw the number of particles as the amount of substance, and not as a number. It is important to note that the problem with N and N_A occurred primarily in the control subgroup, while students characterized as *"excellent"* in the experimental subgroup solved these tasks correctly.

Another difficulty occurred in *Task 10*. This task is specific because students did not do the same task in the class, since some changes were made (i.e. the inclusion of some scientific facts in the text of the task so the text was longer). In order to solve this task the following was needed:

– the proper selection of data,
– the right combination of data.

We want to emphasize that all students characterized as *"excellent"* in the experimental subgroup solved this task correctly. However, the majority of students in the control subgroup did not manage to solve this task correctly. They did not know how to combine or how to select the data given in this task.

Task 10: *"Daily water requirement for the proper functioning of human body is 2 kg. Will a man drink enough water, if he ingests* $150 \cdot 10^{23}$ *molecules of water that day?"*

Gabel and Sherwood (1984) concluded that these kinds of problems occur because when science notation is used in the problems, or very simple changes are made, students find them more difficult to solve.

The third source of difficulty found in the students' tests included mathematical difficulties with division. As the tested students were not allowed to use calculators, this problem occurred in both groups. The question is whether these students rushed through the test in order to complete it quickly, so that mistakes are just the result of a lack of attention, or it is a significant mathematical problem.

Table 4 shows a summarized review of students' difficulties in both subgroups of students who belong to the "*excellent*" group of students.

Table 4.
Summarized review of difficulties of "excellent" students in the experimental and control subgroups

Group of students	"Excellent"	
Subgroup	Experimental group	Control group
Difficulties with N and N_A	-	+
Difficulties in *Task 10*	-	+
Difficulties with division	+	+

"-" without difficulties (the majority of students who belong to this group and subgroup did not have difficulties with the stated concept); "+" with difficulties (the majority of students who belong to this group and subgroup had difficulties with the stated concept)

Students Characterized as "Good"

There has been a significant lack of understanding of molar mass. In both groups it has been noticed that most students have difficulties with some of the basic chemical concepts such as: chemical symbols, chemical formula, atom, molecule, chemical compound. Therefore, students did not know when to apply relation $M=Ar \cdot g/mol$, and when $M=Mr \cdot g/mol$. For example, in *Task 11*:

$M(Br)= Mr(Br) \cdot g/mol$

Or in *Task 4*:

$M(Fe)= Mr(Fe) \cdot g/mol$

They also had difficulties with the unit of molar mass, g/mol. They wrote it as a unit of relative atomic mass, relative molecular mass and molar mass. For example, in *Task 8*:

$Mr(NaCl)=58$ g/mol

And also:

$M(NaCl)=58$ g/mol

These students, characterized as *"good"*, did not understand the mole concept as a unit of amount of substance. They wrote the amount of substance without its unit, mole. For example, in *Task 9*:

$n(MgO)= 18 \cdot 10^{23}/6 \cdot 10^{23}$

$n(MgO)= 3$

As an explanation of these examples of misunderstanding, we refer to Novich's and Menis's (1976) conclusion that 15-year-old students in Israel did not achieve coherent understanding of the mole concept.

In this group of students, there have also been difficulties with tasks which require multi-step procedures for obtaining a solution. For this age of pupils (13-14 years old), two-step items are sufficient to master. In our test, *Tasks 11 and 12* are of this kind. In the control subgroup only five of sixteen students (31%) have correctly solved two-step tasks. In the experimental subgroup the percentage is slightly higher, but difficulties remain. Gabel and Sherwood (1984) associated this problem with students' difficulties with division, but in these tests these two problems are not associated. Students do not know how to link the initial (given) information with the terminal, required quantity, and this is the main reason for unsuccessful solutions of these types of tasks.

Afterwards, we have been faced with a new problem which was not found with the previous group of students, and also it has not been mentioned in the previously cited papers. Difficulties with mathematical symbols have been noticed in the tests of many students, in both the experimental and control subgroups. They do not differentiate between the symbols such as <, >, and they do not know what terms "increase in range" or "decrease in range" mean.

In addition to these, in the group of students characterized as *"good"*, some difficulties that have been listed in the group of students characterized as *"excellent"*, have also been reported, such as: difficulties with N and N_A, as well as the difficulties reported in *Task 10.* But while in this group of students *("good")* such difficulties appear in both the experimental and control subgroups, in the previously analyzed group of students *("excellent")* these difficulties have been noticed only in the control subgroup.

Table 5 shows a summarized review of the difficulties of "good" students belonging to the experimental and control subgroups.

Table 5.
Summarized review of the difficulties of "good" students from the experimental and control subgroups

Group of students	"Good"	"Good"
Subgroup of students	Experimental group	Control group
Difficulties with molar mass	+	+
Difficulties with mole as a unit of amount of substance	+	+
Difficulties with two-step tasks	+	+
Difficulties with some mathematical symbols: <, >	+	+
Difficulties with N and N_A	+	+
Difficulties with Task 10	+	+

"+" with difficulties (the majority of students who belong to this group and subgroup had difficulties with the stated concept)

Students Characterized as "Acceptable"

In the control subgroup, the students characterized as *"acceptable"* had difficulties with tasks that require mass calculation. They did not express mass of a substance in grams but in moles. When we had a look at *Task 8* in students' tests, we noted that these students did not know the unit for molar mass, and hence the mass of substance was assigned a unit of amount of substance (mol).

Task 8:
m(NaCl)=n(NaCl) · M(NaCl)
m(NaCl)= 4 mol · 58

This problem has already been described in the paper by Novich and Menis (1976). Our perception of this problem is identical to their observation, because our students in the control subgroup also associated the mole with mass rather than amount.

We would like to emphasize that such difficulties did not occur in the experimental subgroup with the students who were taught with systemics, but only in the control subgroup with the students who were taught using the conventional methods.

Subsequently, in the group of students characterized as *"acceptable"* we have noticed some difficulties which have already been mentioned in this paper with the students characterized as *"good"* or even *"excellent"*. For example, difficulties with molar mass (previously mentioned in the group of students characterized as *"good"*) were noticed only with the students in the control subgroup, while students in the experimental subgroup showed no significant difficulties with molar mass. Then there were difficulties with N and N_A. We concluded that both subgroups of *"acceptable"* students had these difficulties, already mentioned in the other two groups, but students in the experimental subgroup knew that the value of N_A is $6 \cdot 10^{23}$ 1/mol, while the students in the control subgroup did not know this value. After that we noticed that the students in the *"acceptable"* group exhibited the same difficulties with basic mathematical processes (division, <, >), identical to *"good"* or *"excellent"* group of students. So, we can say that mathematical difficulties are universal difficulties for all three groups of students. Regarding the difficulties with two-step items, students in the control subgroup were not able to solve these tasks, while half of the students in the experimental subgroup solved them completely correctly. It is interesting to point out that the students belonging to the *"good"* group (both the experimental and control subgroups) were not able to solve these tasks, while students in the experimental subgroup characterized as *"acceptable"* managed to solve them. Finally, when we looked at this group of students, it was found that nobody managed to solve *Task 10*. So, *Task 10* has gained the feature as "the most difficult one", because only students from the *"excellent"* group, the experimental subgroup, solved it correctly.

Table 6 shows a summarized review of students' difficulties, including both the experimental and control subgroups of students characterized as *"acceptable"*.

Table 6.
Summarized review of difficulties of "acceptable" students from the experimental and control subgroups

Group of students	"Acceptable"	
Subgroup	Experimental	Control
Difficulties with mass of substance (and its unit)	-	+
Difficulties with molar mass	-	+
Difficulties with N and N_A	+/-	+
Mathematical difficulties (division, <, >)	+	+
Difficulties with two-step items	+/-	+
Difficulties with Task 10	+	+

"+" with difficulties (the majority of students who belong to this group and subgroup had difficulties with the stated concept); "-" without difficulties (the majority of students who belong to this group and subgroup did not have difficulties with the stated concept); +/- "with some difficulties" (the majority of students who belong to this group and subgroup did not completely master the stated concept, but still showed some basic knowledge)

Conclusions and Future Work

Based on the results of our research, we present several conclusions. Firstly, we can conclude that most of the difficulties which were presented in the cited studies appeared in our research as well. These included difficulties with the Avogadro constant, with basic mathematical principles, two-step problems, then tasks in which some changes were made in comparison with the task that students did in the class, and difficulties with understanding the mole as a unit of quantity of substance.

The general conclusion is that systemic approach to teaching and learning (SATL) should be applied in the initial teaching of chemistry in order to facilitate the learning process for students who meet chemistry as science for the first time. We believe that systemic as a graphical form of knowledge representation in which all connections among the given set of concepts are clearly highlighted for students, is especially useful for those students characterized as *"excellent"* and *"acceptable"*. Most students in the experimental subgroup characterized as *"excellent"* solved all 12 tasks correctly. The only difficulties noticed with these students were mathematical difficulties, but once again, it has been a common difficulty for many students who participated in our research. These students were the only ones who did *Task 10* correctly, with no difficulties, as a group. But also, students of the experimental subgroup characterized as *"acceptable"* showed significant improvement and quite a high achievement after our study. For example, they did the task with molar mass correctly, they did not make mistakes with units, and half of them completely mastered two-step tasks. Only students characterized as *"good"* did not make any progress during the research. Students from both the experimental and control subgroups made the same mistakes. So, we cannot conclude about any improvement by using systemics in this group of students. The reason why the students belonging to this group have not adjusted to the new method of teaching could be functional fixedness. Stoyanov (1997), who conducted his research using cognitive maps (mind maps and concept maps) as instructional tools, called this group of students "serialist type of learners" who are concentrated on details and all procedural steps, and who typically combine information in linear manner. They focus on small chunks of information, working step by step, from the bottom up, ignore important connections, and fall into functional fixedness – inability to perceive that one concept can be used for more different purposes. So, they cannot perceive how certain concept can be connected with another one in a systemic way, because they are fixed on traditional, linear presentation and interpretation of concepts and their relationships. On the other hand, students characterized as "excellent" and "acceptable" belong to the "global or holistic type of learners". They are focused on several aspects of the problem, using complex links to relate concepts (Stoyanov, 1997) - this is more common for "excellent" group of students; their attention is not focused on details (Stoyanov, 1997) (this is more common for "acceptable" group of students), so they are more flexible and they relatively easily adapt to a new method.

We would like to mention that this research has several limitations. First, it requires a lot of time for teachers to learn how to construct and apply systemics in the teaching process. Besides, teachers and students who have poor visual skills may have difficulties with this approach. In addition, using panels for presenting systemics is limited with notation that replacing a filled-in systemic with systemic for the next task requires time, and some students can lose their concentration during that period. This limitation could be solved by using computers, but still many schools do not have the required equipment.

As a topic for future research the following question remains: Is there any way that the group of students characterized as "good" still can benefit from learning with systemics? In addition, new research on a larger number of students should be conducted, in order to statistically confirm these results, or to discuss new results. Also, the described method should be applied to some other educational content, as well as to some other educational levels. The main direction of our future research will be to connect the systemic approach with the cognitive load theory, or, precisely, with the students' mental effort caused by learning with systemics, and also to determine how systemics affect knowledge retention.

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Primjena sistemičkog pristupa u početnoj nastavi kemije: usvajanje pojma mola

Sažetak

Mnoga istraživanja koja su se bavila pojmom mola naglašavaju činjenicu da učenici imaju znatne poteškoće u usvajanju toga pojma. Cilj našeg istraživanja bio je analizirati upravo one poteškoće s kojima se učenici susreću kada prvi put počinju učiti kemiju kao školski predmet, kao i ispitati korisnost sistemika kao grafičkog načina prikazivanja znanja. Uzorak u istraživanju obuhvatio je učenike sedmog razreda jedne osnovne škole u Novom Sadu, u Srbiji. Na temelju provedenog testa predznanja učenici su bili podijeljeni u tri glavne skupine: „odličnu", „dobru" i „prihvatljivu", a svaka od njih sastojala se od dvije podskupine: eksperimentalne i kontrolne. Učenici u eksperimentalnoj podskupini učili su primjenom sistemika u nastavi, a učenike u kontrolnoj podskupini podučavalo se primjenom tradicionalnih metoda. Završni rezultati pokazuju da je sistemički pristup pogodan za prevladavanje poteškoća u slučaju „odlične" i „prihvatljive" skupine učenika, ali se isto ne može zaključiti za učenike koji pripadaju „dobroj" skupini. Sistemici se nisu pokazali prikladnim za njih. Sljedeće pitanje može biti temom budućih istraživanja: Postoji li ikakav način da skupina učenika koji su opisani kao „dobri" može imati koristi od učenja po sistemičkom pristupu? K tomu, trebalo bi provesti novo istraživanje na većem uzorku učenika, da bi se navedeni rezultati statistički potvrdili ili da bi se raspravilo o novim rezultatima.

Ključne riječi: *ontologija; pojmovna mapa; poteškoće u usvajanju pojma mola; sistemici.*

Uvod

Činjenicu da je kemija vrlo kompleksan predmet potvrđuje istraživanje o rješavanju problemskih zadataka i zabludama (Gabel, 1999). Mnogi pojmovi koji se u kemiji uče su apstraktni, čak i oni koji se objašnjavaju učenicima koji se prvi put susreću s kemijom kao nastavnim predmetom. Ti pojmovi su: struktura atoma (Park i Light, 2009), kemijske i fizikalne promjene (Hesse i Anderson, 1992), kemijske veze (Nicoll, 2001), kemijski zakoni (Özmen i Ayas, 2003), kemijski računi (stehiometrija) (de Astudillo i Niaz, 1996). Mnogi su učenici na tome stupnju neuspješni jer su, općenito gledajući, te teme preteške da bi ih mogli razumjeti.

Mnogi stručnjaci koji su proveli istraživanja, kao i pedagozi, pokušali su utvrditi razloge ili izvore poteškoća. Istaknuli su nekoliko izvora kao što su: apstraktna priroda pojmova, zahtjevi koje postavlja kurikul, preopterećenost kapaciteta radne memorije učenika, jezik i komunikacija (Oloruntegbe, Ikpe i Kukuru, 2010). Predložili su neke nastavne planove ili nastavne metode koji bi mogli pomoći u prevladavanju poteškoća. Dobra nastavna metoda je ona koja stvara opširan i stabilan sustav utemeljen na znanju. U kemiji takav sustav obuhvaća znanstvene kemijske teorije, kemijske zakone, znanstvene kemijske pojmove i činjenice. Kada postoji stabilan sustav utemeljen na znanju, tada možemo nastaviti sa širenjem znanja učenjem novih informacija važnih za one informacije koje su učenici već razumjeli, što se naziva kvalitetom obrazovanja.

Oslanjajući se na konstruktivističku teoriju učenja (Glasersfeld, 1989) i na obrazovne ishode koje je definirao Gagné (1984), odlučili smo provjeriti može li se sistemički pristup poučavanju i učenju kemije (*engl.* Systemic Approach to Teaching and Learning Chemistry – SATLC) (Fahmy i Lagowski, 2002) koristiti u poučavanju osnovnoškolaca o pojmu mola.

Ontološki prikaz znanja

Izrada ontologije u nastavnim planovima nije ništa novo (Breuker, Muntjewerff i Bredewey, 1999). Može se zaključiti da se ontologija koristi u nastavi zato što nije moguće prezentirati određeno područje (polje, disciplinu) sa svim njegovim detaljima. Da bi se prezentirala određena domena (dio određenog polja), neophodno je ograničiti pažnju na manji broj pojmova koji su značajni i dovoljni da bi se mogla interpretirati ta domena, te dati prikaz koji je primjeren za ostvarivanje određenoga cilja (Breuker i sur. 1999). No, ako želimo dati potpunu „sliku" određene domene i olakšati njezino razumijevanje, moramo nekako povezati odabrane pojmove. Kao rezultat, središnji dio prikaza znanja sastoji se od razrade konceptualizacije: skupa apstraktnih pojmova za koje se smatra da postoje unutar određene domene i veza između njih (Genesereth i Nilsson, 1987). Stoga, u kontekstu razmjene znanja, prema Gruberu (1993), ontologija je eksplicitni detaljni opis konceptualizacije, a konceptualizacija je apstraktni, pojednostavljeni pogled na svijet koji, zbog nekog razloga, želimo prikazati (Gruber i Olsen, 1994).

Grafički prikazi koji se u ontologiji koriste, kao što su mape znanja, Petrijeve mreže, pojmovne mape i semantičke mreže (Kim, Suh i Hwang, 2003) postali su opširan grafički način ontološkog prikazivanja znanja, ali koji već dobiva nove podopise. Kao jedne od njih, mi smo primijenili sistemike – grafičke alate za prikazivanje znanja u metodi SATL-a, u znanstvenom (obrazovnom) kontekstu. Ključna točka koja povezuje ontologiju i sistemički pristup jest metoda odabira pojmova i njihova organizacija u sistem, što pruža jasnu interpretaciju pojmova i veza između njih.

Sistemički pristup poučavanju i učenju

Sistemički pristup poučavanju i učenju kemije (engl. SATLC) osmislili su, proveli i ocijenili Fahmy i Lagowski 1997. godine, s ciljem transformiranja mehaničkog učenja (učenja napamet) u smisleno učenje (Fahmy i Lagowski, 2002). Taj pristup potvrđuje glavne ciljeve obrazovnog sustava i trajnu nadogradnju znanja, što se naziva kvalitetom obrazovanja.

Tijekom toga razdoblja (koje je trajalo više od deset godina), i uz prethodno spomenute ciljeve, primjenjivana je i procjenjivana tehnika sistemičkog pristupa poučavanju i učenju u mnogim različitim domenama znanja, na svim razinama obrazovanja (srednjoškolskoj, fakultetskoj, obrazovanju odraslih), no glavna primjena u nastavi zabilježena je u nastavi kemije u srednjoškolskom i fakultetskom obrazovanju (Vachliotis, Salta, Vasiliou i Tzougraki, 2011). Fahmy i Lagowski (2002) uveli su taj pristup nakon iznenadnog porasta globalizacije u širokom rasponu ljudskih aktivnosti, pa se taj pristup primjenjivao u: osnovnim prirodnim znanostima (kemiji, biologiji, fizici, matematici), primijenjenim znanostima (ekologiji, poljoprivredi, farmaciji, strojarstvu), pravu, medicini, lingvistici i trgovini (http://www.satlcentral.com). Oni su došli do zaključka da koristeći sistemički pristup ljudi mogu učiti u svim područjima svojeg djelovanja, da bi dobili sveobuhvatniji pogled na važne veze u znanosti. Sistemički pristup poučavanju i učenju podržavaju i konstruktivistička teorija i suvremene ideje o tome kako ljudski mozak funkcionira (Cardellini, 2010). Najjača veza između sistemičkog pristupa učenju i poučavanju i konstruktivističke teorije može se pronaći u ideji pojmovnih mreža (Lagowski, 2009).

Pojmovne mreže su grafički alati koji se koriste u nastavi i učenju, pogodne su za prikazivanje i organiziranje znanja, a imaju jako psihološko i epistemološko uporište. To uporište se temelji na teorijama Ausubela (2000) i Novaka (2002). Služeći se Ausubelovim idejama o tome kako učenici konstruiraju značenje, te oslanjajući se na glavnu razliku između smislenog učenja i učenja napamet, Novak je osmislio pojmovnu mrežu kao alat kojim bi se prikazivao pojmovni/propozicijski okvir znanja o određenoj domeni (Lagowski, 2009). U praksi, malo je izgledno da će ijedan učenik naučiti bilo koju temu iz kemije samo učenjem napamet. Stoga Ausubel naglašava da razlika između učenja napamet i smislenog učenja nije dihotomija, nego kontinuitet (Novak, 1984).

Dobro je poznato da naš mozak organizira znanje po hijerarhijskoj strukturi, što čini lakšim daljnji proces učenja. U pojmovnoj mreži prikazani set pojmova organizira se po hijerarhijskom poretku, a povezuje glagolima. Da bi se pojmovna mreža organizirala hijerarhijski, učenik mora uložiti napor da bi odabrao ključni pojam (najopsežniji i najopćenitiji) za danu temu. Nadalje, pojmove je potrebno složiti od najopćenitijih do najkonkretnijih. Prema konstruktivističkoj teoriji, važno je kako učenici izrađuju svoje pojmovne mreže tijekom procesa usvajanja novog pojma. Na taj način oni asimiliraju znanje u postojeću strukturu znanja, s razumijevanjem osnovne strukture znanja. Slika 1 prikazuje jednostavnu pojmovnu mrežu koju su izradili autori ovoga rada.

Slika 1.

Ovakva organizacija znanja je hijerarhijska zbog toga što je pojam kemijske kvantitete ključni pojam dane skupine pojmova i zauzima najviše mjesto u hijerarhiji, iznad ostalih pojmova kao što su „molarna masa" i „spoj". Međutim, neka druga osoba (nastavnik ili učenik) mogao bi izraditi sasvim drugačiju pojmovnu mrežu odabirom drugačijeg ključnog pojma. U našem primjeru „molarna masa“ bi također mogla biti ključni pojam. Dakle, moguće je izraditi nekoliko pojmovnih mreža s istom skupinom pojmova. Zbog toga možemo postaviti važno pitanje: *Je li pojmovna mreža prikladna kao alat za ocjenjivanje znanja*? Johnston i Otis (2006) su istraživali mogućnost korištenja pojmovnih mreža koje su izradili učenici kao alata za procjenjivanje znanja. Rezultati do kojih su došli pokazali su da ne postoji značajna veza između kvalitete pojmovne mreže i ocjene učenikova znanja (Adamov, Segedinac, Cvjetićanin i Bakoš, 2009). Primijetili su da su „loše“ pojmovne mreže (one s manjim brojem pojmova) izradili i oni učenici koji nisu imali dobre mreže (loše povezane mreže), kao i oni učenici koji nisu trebali kompleksnu mrežu da bi aktivirali veliko znanje i razumijevanje. Ti rezultati upućuju na zaključak da je pojmovna mreža vrlo osobna stvar, koju je idiosinkratski izradio autsajder, odnosno bilo koja osoba koja pokušava ocijeniti ono što je napisano na papiru (Johnston i Otis, 2006).

Oslanjajući se na ključne karakteristike pojmovnih mreža kao alata za poučavanje i učenje, no podržavajući tvrdnju Fahmyja i Lagowskog da sistemički pristup pruža globalniji pogled na skup pojmova definiranjem svih veza između njih (Fahmy i Lagowski, 2002), mi smo u našem istraživanju primijenili „sistemike“ (ili „sistemičke dijagrame“) kao način prikaza znanja na nastavnim satima na kojima je obrađivan pojam mola.

Poteškoće učenika u učenju o molu

Mol, temeljni pojam u kvantitativnoj kemiji (Dori i Hameiri, 1998), obrađivan je u raznim radovima. Brojna istraživanja provedena o pojmu mola naglašavaju da učenici imaju velikih poteškoća u učenju toga pojma, a njihove ideje o molu često su i zabilježene (Case i Fraser, 1999). Te studije uglavnom se odnose na poteškoće u učenju i pogreške koje učenici čine prilikom učenja o pojmu mola, kao i na njihovo razumijevanje toga pojma.

Yalçinalp, Geban i Özkan (1995) smatraju da apstraktnost znanja utječe na poteškoće u učenju. Konkretno, u problemskim zadacima koji uključuju kemijske formule i pojam mola učenici izračunavaju vrlo male i vrlo velike brojeve. Avogadrova konstanta zasigurno još dodatno komplicira problem.

Gabel i Sherwood (1984) su naglasili činjenicu da neki učenici ne razumiju osnovne matematičke principe, koji bi mogli uključivati matematičke manipulacije kao što su proporcionalno razmišljanje, promjena redoslijeda veličina i pretvaranje mjernih jedinica (Dori i Hameiri, 1998). To je važna prepreka za točno rješavanje problemskih zadataka koji uključuju mol, korištenjem metoda rasuđivanja. Uz matematičke poteškoće, Gabel i Sherwood (1984) naveli su i sljedeće poteškoće:

(1) Zadatke čije rješavanje podrazumijeva jedan korak bilo je lakše riješiti nego one čije rješavanje zahtijeva dva koraka, čak i kada je učenik bio dobro upoznat sa sadržajem. Gable i Sherwood (1984) povezali su taj problem s poteškoćama koje

su učenici imali s računskom operacijom dijeljenja. Učenicima je dijeljenje bilo daleko teže nego množenje, a kako zadaci koji se rješavaju u dva koraka uvijek zahtijevaju i dijeljenje i množenje, učenicima ih je bilo i teži riješiti.

(2) Učenici su pokazali značajne poteškoće u zadacima u kojima su uključeni decimalni brojevi, a ne cijeli brojevi.

(3) Kada se u problemskim zadacima koristila znanstvena notacija, učenicima ih je bilo teže riješiti.

(4) Vrlo jednostavne promjene u problemskim zadacima učinile su te zadatke teškima. Točnije, ako je zadatak koji je bio riješen na nastavnom satu (kao primjer) sadržavao promijenjene podatke, učenici ga općenito nisu mogli riješiti.

Analiza odgovora dobivenih tijekom intervjua koji su u sklopu istraživanja u Izraelu proveli Novich i Menis (1976) otkrila je neke zablude poput: „mol je određena masa, a ne određeni broj“ (mol se smatra masom, a ne količinom) ili „mol je svojstvo molekule“. Oni su zaključili da većina petnaestogodišnjih učenika u Izraelu ne postiže ni koherentno razumijevanje pojma mola i njegovu važnost u interpretaciji kemijskih pojava, kao ni sposobnost da ga uspješno koristi u rješavanju problemskih zadataka (Novich i Menis, 1976).

U Italiji su, na temelju rezultata svojeg istraživanja, Cervellati, Montuschi, Perugini, Grimellini-Tomasini i Pecori Balandi (1982) zaključili da većina učenika ne uspije savladati pojam mola. Učenici općenito nisu upoznati s korištenjem mola kao jedinice za količinu tvari. Izabrali su netočan odgovor o definiciji mola, poistovjetivši ga s težinom u gramima.

Te poteškoće u učenju pojma mola vrlo su važan problem, ne samo zbog odjeka koji mogu imati na poučavanje i učenje toga pojma kao jedinice jedne od sedam osnovnih fizikalnih veličina – „količine tvari“ (Schmidt, 1990) nego i zbog njihova utjecaja na rješavanje stehiometrijskih zadataka (Dori i Hameiri, 1998; Schmidt, 1990; Furió, Azcona, Guisasola i Ratcliffe, 2000). Pojam mola je važan temelj za složenije kemijske pojmove, kao što su: koncentracija otopina, konstanta ravnoteže i pH (Staver i Lumpe, 1993). Tijekom godina predloženi su mnogi metodički savjeti i algoritamski planovi da bi se olakšalo poučavanje o molu i učenje toga pojma (Strömdahl, Tullberg i Lybeck, 1994). Yalçinalp i sur. (1995) su predstavili računalnu nastavu koju su nazvali dodatnom nastavom uz pomoć kompjutera, s ciljem prevladavanja teškoća u učenju pojma mola. Usporedili su računalnu nastavu s nastavnim satima u kojima su se rješavali problemski zadaci i zaključili da oba pristupa imaju svoje prednosti i nedostatke. Gabel i Sherwood (1984) su se u svojem istraživanju koristili analogijama, uz napomenu da analogije i srodni znanstveni pojmovi imaju sličnosti koje pomažu učenicima da razumiju znanstvene pojmove. Novick i Menis (1976) koristili su se strukturiranim intervjuima da bi prikupili podatke, a pitanja su bila zabilježena na kartici.

Staver i Lumpe (1993) imali su za cilj ispitati načine kojima se autori udžbenika koriste da bi predstavili, definirali i objasnili pojam mola u srednjoj školi i u udžbenicima koji se koriste na fakultetu. Tvrdili su da ako učenici žele konstruirati okvir složenih kemijskih pojmova i riješiti kvantitativne probleme koji uključuju takve notacije, moraju imati jasno definirane i dobro povezane konceptualizacije pojma mola. Zaključili su da učenici čije se učenje najbolje može opisati kao konkretno i intuitivno, a ne apstraktno i reflektivno, mogu imati poteškoća u učenju mola.

Primjena sistemika u poučavanju i učenju pojma mola

Fahmy i Lagowski zagovaraju razvoj obrazovnog procesa koji se temelji na primjeni „sistemika", odnosno „sistemičkih dijagrama", za koje vjeruju da mogu utjecati i na proces poučavanja i na proces učenja. Oni su alati koji su osmišljeni da bi pomogli nastavnicima poučavati, a učenicima učiti (Lagowski, 2009). Pod „sistemikom" podrazumijevaju raspored pojmova ili problema kroz interaktivne sustave u kojima su sve veze između pojmova i problema učeniku pojašnjene unaprijed, uz pomoć pojmovne mreže kao prikaza (Fahmy i Lagowski, 2002; 2003). Za razliku od uobičajene strategije pojmovnih mreža koja podrazumijeva izradu hijerarhije pojmova (pogledajte ponovno Sliku 1), taj pristup teži stvaranju više ili manje „zatvorenog sustava pojmova" koji naglašava međusobne veze između pojmova (Fahmy i sur., 2002). Slika 2 pokazuje sistemički dijagram za pojam mola.

Slika 2.

Možemo reći da je teže dobiti globalni pregled skupa pojmova pojmovnom mrežom ili linearnim prikazom nego sistemikom (prikaz koji pojmove predstavlja kao „zatvoreni skup"), koji naglašava sve veze između pojmova. Na primjer, iz sistemika prikazanog na Slici 2 možemo precizno promatrati vezu između „količine tvari" i „mase" ili „Avogadrove konstante", no takvu preciznost nemamo kada se koristi pojmovna mreža (Slika 1).

Provedena su također i neka istraživanja o primjeni sistemičkog pristupa u nastavi kemije. Fahmy i Lagowski (2003) su proveli istraživanje koje je obuhvatilo učenike šest srednjih škola iz Kaira i Gize (Egipat) koji su učili organsku kemiju – karboksilne kiseline i njihove derivate. Kontrolna skupina bila je poučavana primjenom standardnoga linearnog pristupa, a za eksperimentalnu je skupinu izrađen modul koji je bio sistemički orijentiran. Učenici koje su poučavali nastavnici koristeći se sistemičkim pristupom nastavi i učenju bili su daleko uspješniji na završnim ispitima u usporedbi s učenicima koji su bili poučavani na linearan način. Uspjeh je bio definiran kao ostvarivanje barem 50% točnih odgovora na završnom ispitu. Otprilike 80% eksperimentalne skupine bilo je uspješno, a samo je 10% učenika iz kontrolne skupine doseglo taj stupanj uspjeha. Na fakultetskoj razini obrazovanja Fahmy i Lagowski (2002) su proučavali sistemički pristup poučavanju i učenju u nastavi alifatske kemije na fakultetima farmacije i prirodoslovnih znanosti na dva egipatska sveučilišta. Proveli su istraživanje tijekom prvog semestra druge godine kolegija iz organske kemije na Sveučilištu u Zagazigu. Za nastavu u eksperimentalnoj skupini standardni udžbenici i nastavni materijali promijenjeni su tako da se koriste sistemičkim pristupom. Studenti u kontrolnoj skupini bili su poučavani na tradicionalan, linearan način. Uspjeh procesa učenja mjeren je razlikom u postignućima studenata na testu predznanja i završnom testu. Oba testa sadržavala su i linearna pitanja i sistemike. Rezultati istraživanja potvrdili su da je eksperimentalna skupina, koja je poučavana putem sistemičkod pristupa poučavanju i učenju ostvarila bolje rezultate od kontrolne skupine, koja je poučavana na tradicionalan način. Uspjeh se mjerio postignućima u sve tri kategorije: linearnim pitanjima, sistemicima i općim postignućem. Al-Bashaireh (2011) je proučavao učinkovitost nastave koja uključuje sistemički pristup, uključivši u istraživanje učenike petog razreda (u dobi od 11 do 12 godina) iz provincije Tafila (Jordan), kao i njihov uspjeh u prirodnim znanostima. Rezultati tog istraživanja potvrdili su prijašnje rezultate istraživanja koje su proveli Fahmy i Lagowski. Uzevši u obzir postignuća učenika na završnom testu koji se sastojao od 30 pitanja višestrukog izbora, učenici iz eksperimentalne skupine (poučavane sistemičkim pristupom poučavanju i učenju) bili su bolji od učenika iz kontrolne skupine (konvencionalna linearna metoda poučavanja). Sva ta istraživanja pokazala su da je sistemički prikaz doveo do boljih postignuća učenika nego što je to bio slučaj s tradicionalnim načinom poučavanja i učenja.

Svrha istraživanja

Svrha provođenja ovog istraživanja bila je utvrditi učinak poučavanja i učenja sistemičkim pristupom na uspjeh učenika sedmog razreda u jednoj nastavnoj jedinici u nastavi kemije – pojmu mola. Uz utvrđivanje mjere u kojoj su sistemici korisni u početnoj nastavi kemije, pitanje je može li primjena sistemika pomoći prevladati česte poteškoće koje se u učenika javljaju pri svladavanju pojma mola? Još jednom, te su poteškoće:

(1) poteškoće s Avogadrovom konstantom,
(2) poteškoće s osnovnim matematičkim principima,
(3) različite sposobnosti učenika u savladavanju problemskih zadataka koji se rješavaju kroz dva koraka i onih problemskih zadataka koji se rješavaju kroz jedan korak,
(4) poteškoće sa zadacima koji su promijenjeni dodavanjem znanstvenih notacija,
(5) poteškoće s razumijevanjem mola kao jedinice za količinu tvari.

Metode

Ispitanici u istraživanju

Uzorak u istraživanju sastojao se od učenika sedmih razreda osnovne škole („Kosta Trifković“) iz Novog Sada, u Srbiji. Odabrana je samo jedna škola da bi se izbjegao faktor interferencije na istraživanje, kao što je, npr. utjecaj različitih nastavnika. U školskoj godini 2011./2012. ti učenici sedmih razreda prvi su se put u školi susreli s kemijom kao nastavnim predmetom. Učenici su bili u dobi od 13 do 14 godina i pohađali su četiri različita razredna odjela. Ukupan broj učenika bio je 96, a nakon provedenog testa predznanja za istraživanje je bilo odabrano 50 učenika koji su pohađali dva zasebna razredna odjela. Nije bilo moguće provesti istraživanje na ukupnom broju od 96 učenika, jer nismo mogli izjednačiti ta četiri razredna odjela prema njihovu uspjehu na testu predznanja. Rezultati toga testa za dva razredna odjela koja su odabrana kao eksperimentalna i kontrolna skupina bili su najsličniji, što je statistički potvrđeno t-testom (Tablica 1).

Tablica 1.

Promatrajući rezultate prikazane u Tablici 1, možemo zaključiti da ne postoji statistički značajna razlika u postignućima na testu predznanja između učenika koji pripadaju eksperimentalnoj skupini i onih koji pripadaju kontrolnoj skupini, u intervalu pouzdanosti 95%. Budući da interval pouzdanosti sadrži vrijednost 0,00, p-vrijednost je veća od 0,05, a naša t-vrijednost je niža od kritične t_c-vrijednosti (t_c=1.68, za df=48 i α=0.05). Da bi se odredilo zadovoljava li distribucija podataka iz testa predznanja kriterij normalnosti s pouzdanošću od 95%, provjerene su vrijednosti standardiziranih koeficijenata asimetrije i spljoštenosti provođenjem Shapiro-Wilkova test. Možemo zaključiti da naši podaci dolaze iz normalne distribucije, jer su standardizirani koeficijenti asimetrije i spljoštenosti unutar raspona od -2 do +2, a rezultat Shapiro-Wilkova testa potvrđuje zaključak o normalnoj distribuciji podataka iz testa predznanja.

Test predznanja sastojao se od 10 zadataka, a maksimalan broj bodova bio je 16. Test predznanja sastavljen je u skladu sa zahtjevima kurikula kemije za sedmi razred osnovne škole u Republici Srbiji, kao i u skladu s preporučenim udžbenikom (Pravilnik o kurikulu, 2009; Mandić, Korolija i Danilović, 2009) za nastavnu cjelinu *Otopine*. Ta cjelina obuhvaća sljedeće nastavne jedinice: Pojam otopine i otapanja; Kvantitativni sastav otopina – maseni udio; Voda i njezina važnost za živi svijet. Nastavna cjelina *Otopine* obrađuje se u nastavi prije nastavne cjeline *Kemijske reakcije i izračunavanje*, unutar koje se obrađuje i pojam mola. Pojam mola obrađen je nakon provođenja testa predznanja, u drugom polugodištu u svibnju 2012. godine, što je bilo u skladu s kurikulom.

Plan i instrumenti

Istraživanje je bilo provedeno u obliku akcijskog istraživanja. Prikupljeni podaci koristili su se kao povratna informacija za određivanje rezultata istraživanja, a također i za planiranje nekih od sljedećih aktivnosti, kao što je kvantitativno istraživanje na većem uzorku.

Na temelju rezultata testa predznanja učenici su bili podijeljeni u tri glavne skupine, opisane kao: „odlična", „dobra" i „prihvatljiva", ovisno o kvaliteti i kvantiteti znanja koji su pokazali na testu predznanja. Svaka od tri skupine sastojala se od dvije podskupine: eksperimentalne i kontrolne, ujednačene prema prethodnom znanju o kemijskim pojmovima vezanima uz nastavnu cjelinu *Otopine*, a koje su obradili i naučili tijekom prethodnih nastavnih sati. Prvih pet učenika u eksperimentalnoj skupini koji su bili najuspješniji na testu predznanja opisani su kao „odlični“. Druga skupina od petnaest učenika u eksperimentalnoj skupini bila je opisana kao „dobra“, a posljednja skupina od pet učenika opisana je kao „prihvatljiva“. Isti postupak primijenjen je i u kontrolnoj skupini.

Tablica 2 pokazuje distribuciju učenika u skupinama „odlična“, „dobra“ i „prihvatljiva“, kao i u podskupinama: eksperimentalnoj i kontrolnoj.

Tablica 2.

Istraživanje je provedeno tijekom razdoblja od dva tjedna (četiri nastavna sata). Za to vrijeme učenici su obrađivali novu nastavnu cjelinu iz kemije – *Količina tvari, mol i molarna masa*. Tijekom ta dva tjedna proveden je i test predznanja i završni test. U ovom istraživanju upotrijebljena su dva pristupa da bi se uvježbala i ispitala postignuća učenika i njihovo razumijevanje pojma mola. Eksperimentalna podskupina učila je sistemičkim pristupom, a kontrolna skupina bila je poučavana konvencionalnim metodama. Za eksperimentalnu skupinu izrađeni su posebni sistemici u obliku panoa. Na prvom nastavnom satu učenja uz sistemike nastavnik je objašnjavao nove pojmove, nepoznate učenicima, pokazujući već ispunjene sistemičke dijagrame, kao što je onaj prikazan na Slici 2. Koristeći se sistemicima, nastavnik je smišljeno objašnjavao veze unutar skupa danih pojmova, da bi učenici mogli uočiti sve postojeće veze između novih pojmova. Tijekom drugoga nastavnog sata učenicima su pokazani novi sistemički dijagrami. Oni su se sastojali od praznih povezanih polja, koja su tada učenici morali popuniti, uz vodstvo nastavnika tijekom sata. Takvi sistemički dijagrami pokazani su na Slici 3 i 4. Slika 3 predstavlja prazan sistemički dijagram koji se može ispunjavati, a Slika 4 pokazuje već popunjeni sistemički dijagram za sljedeći zadatak: „*Uzorak trake magnezija ima masu od 96 g. Koliko mola magnezija sadrži taj uzorak*?“

Slika 3.i 4.

Osnovni podaci za raspravu prikupljeni su kao rezultat završnog testa, koji se sastojao od 12 zadataka, uključujući pojmove kao što su mol, količina tvari, masa, molarna masa, Avogadrova konstanta. Vrste pitanja u testu bile su:

– napišite izraz za traženu veličinu (zadatak 1)
– spojite povezane veličine (zadatak 2)
– zaokružite slovo pokraj točnog odgovora (zadatak 3)
– izračunajte traženu veličinu (zadaci 4, 5, 6, 7, 8, 11 i 12)
– odgovorite na pitanje nakon izračunavanja (zadatak 10)
– popunite tablicu (zadatak 9).

Za svaki zadatak koji su učenici točno riješili dobili su jedan bod, s mogućnošću bodovanja i djelimično točnih odgovora. Tako je maksimalan broj bodova bio 12 ili 100%.

Rezultati i rasprava

Prije nego započnemo raspravu koja je usredotočena na pogreške učenika i poteškoće koje se javljaju tijekom procesa rješavanja problemskih zadataka s pojmom mola, prikazat ćemo sažete rezultate t-testa, koji su potvrdili da postoji statistički značajna razlika u postignućima učenika na završnom testu u eksperimentalnoj i kontrolnoj skupini (Tablica 3).

Tablica 3.

Analizirajući rezultate iz Tablice 3, možemo zaključiti da postoji statistički značajna razlika u postignućima učenika eksperimentalne i kontrolne skupine na završnom testu, u intervalu pouzdanosti 95%. Kako interval pouzdanosti ne sadrži vrijednost 0,00, p-vrijednost je manja od 0,05, a dobivena t-vrijednost je veća od kritične t-vrijednosti (t_c=1,68, za df=48 i α=0,05). Da bi se odredilo zadovoljava li distribucija podataka o završnom testu kriterij normalnosti uz pouzdanost od 95%, provjerene su vrijednosti za standardizirane koeficijente asimetrije i spljoštenosti, pa je proveden Shapiro-Wilkov test. Možemo zaključiti da naši podaci dolaze iz normalne distribucije jer su standardizirani koeficijenti asimetrije i spljoštenosti unutar raspona od -2 do +2, a rezultat Shapiro-Wilkova testa potvrđuje zaključak o normalnoj distribuciji podataka o završnom testu. Stoga možemo zaključiti da su naši učenici iz eksperimentalne skupine, koji su bili poučavani putem sistemičkog pristupa, imali bolja postignuća (66.83%) na završnom testu od učenika iz kontrolne skupine (50.17%) koji su poučavani na tradicionalan, linearan način.

Nadalje, tijekom rasprave o rezultatima završnog testa najprije ćemo se baviti učenicima koji su opisani kao „odlični“ nakon ostvarenih rezultata na testu predznanja, zatim „dobrim“ učenicima, i na kraju onima koji su opisani kao „prihvatljivi“. Ispitat ćemo pogreške i poteškoće koje su se javile u dvanaest različitih zadataka u testu, zatim dalje razmotriti jesu li se te poteškoće javile i u eksperimentalnoj i u kontrolnoj podskupini. Sve poteškoće koje smo uočili u testovima koje su riješili naši učenici bit će uspoređene s poteškoćama koje su već prepoznate kao rezultat prije provedenih istraživanja.

Učenici opisani kao „odlični“

Prvi veći problem na koji smo naišli pregledavajući testove učenika bio je problem s brojem čestica N i Avogadrovom konstantom N_A. Tijekom rješavanja tih zadataka učenici iz kontrolne skupine uopće nisu pisali jedinicu za Avogadrovu konstantu (1/mol). Umjesto toga, pisali su samo $6 \cdot 10^{23}$. Stoga, na kraju zadatka, broj čestica N bio je izražen molom, kao da „količina tvari n“ i „broj čestica N“ imaju istu jedinicu – mol. Taj je problem, na primjer, uočen u 11. zadatku, pa se jedan takav pokušaj rješavanja zadatka javlja u sljedećem obliku:

$N(Br) = n(Br) \cdot N_A$

$N(Br) = 2\ mol \cdot 6 \cdot 10^{23}$

U ovom primjeru, opisujući poteškoće s Avogadrovom konstantom, možemo se složiti s Yalçinalpom i sur. (1995), koji su jasno naveli poteškoće koje učenici imaju u savladavanju Avogadrove konstante, navodeći notaciju apstrakcije kao glavni razlog. Kao još jedan problem nerazumijevanja uočen je i broj čestica N. Dok učenici, kako su u svojem radu opisali Novich i Menis (1976), vide mol kao masu, a ne kao količinu, naši učenici iz kontrolne podskupine vide broj čestica kao količinu tvari, a ne kao broj. Važno je istaknuti da se problem s N i N_A prije svega javio u kontrolnoj podskupini, dok su učenici iz eksperimentalne podskupine, opisani kao „odlični", te zadatke točno riješili.

Druga poteškoća javila se u 10. zadatku. Taj je zadatak specifičan jer učenici nisu isti takav zadatak radili na nastavi, nego je u određenoj mjeri bio promijenjen (npr. uvođenjem nekih znanstvenih činjenica u tekst zadatka, tako da tekst bude duži). Da bi se riješio taj zadatak, bilo je potrebno odraditi sljedeće:

– prikladno odabrati podatke
– ispravno kombinirati podatke.

Želimo naglasiti da su svi učenici opisani kao „odlični" u eksperimentalnoj podskupini taj zadatak točno riješili. Međutim, većina učenika u kontrolnoj podskupini nije uspjela točno riješiti taj zadatak. Nisu znali ni kako kombinirati, ni kako odabrati podatke dane u tom zadatku.

10. zadatak: „Da bi ljudsko tijelo normalno funkcioniralo, njegova dnevna potreba za vodom je 2 kg. Hoće li čovjek popiti dovoljno vode ako konzumira $150 \cdot 10^{23}$ *molekula vode taj dan?"*

Gabel i Sherwood (1984) zaključili su da se takvi problemi javljaju kada se u problemskim zadacima koristi znanstvena notacija ili su u njih uvedene neke jednostavne promjene, pa ih je učenicima tada puno teže riješiti.

Treći izvor poteškoća koji su uočeni u testovima učenika odnosio se na matematičke poteškoće s računskom operacijom dijeljenja. Kako učenicima koji su rješavali testove nije bilo dopušteno koristiti se kalkulatorom, taj se problem javio u obje skupine. Pitanje je jesu li učenici brzo prošli kroz test da bi ga što brže riješili, pa su te pogreške samo rezultat nepažljivosti, ili se radi o važnom matematičkom problemu.

Tablica 4 daje sažet pregled poteškoća koje su učenici imali u obje podskupine „odlične" skupine učenika.

Tablica 4.

Učenici opisani kao „dobri"

Uočen je značajan nedostatak razumijevanja molarne mase. U obje skupine primijećeno je da većina učenika ima poteškoće s nekim osnovnim kemijskim pojmovima kao što su: kemijski simboli, kemijske formule, atom, molekula, kemijski spoj. Stoga učenici nisu znali kada primijeniti relaciju $M=Ar \cdot g/mol$, a kada $M=Mr \cdot g/mol$. Na primjer u 11. zadatku:

M(Br)= Mr(Br) · g/mol

Ili u 4. zadatku:

M(Fe)= Mr(Fe) · g/mol

Također su imali poteškoća s jedinicom molarne mase g/mol. Pisali su je kao jedinicu relativne atomske mase, relativne molekularne mase i molarne mase. Na primjer u 8. zadatku:

Mr(NaCl)=58 g/mol

i također:

M(NaCl)=58 g/mol.

Ti učenici, opisani kao „dobri", nisu razumjeli pojam mola kao jedinice za količinu tvari. Pisali su količinu tvari bez njezine jedinice, mola. Na primjer u 9. zadatku:

$n(MgO)= 18 \cdot 10^{23}/6 \cdot 10^{23}$

n(MgO)= 3.

Kao objašnjenje tih primjera nerazumijevanja, spomenut ćemo zaključak Novicha i Menisa (1976) koji su ustanovili da učenici u dobi od 15 godina u Izraelu nisu dovoljno dobro razumjeli pojam mola.

U toj skupini učenika također su uočene i poteškoće sa zadacima čije rješavanje zahtijeva složen postupak koji se sastoji od više koraka. Za tu dob učenika (13-14 godina) dovoljno je da ovladaju zadacima koji se rješavaju u dva koraka. U našem testu, 11. i 12. zadatak bili su toga tipa. U kontrolnoj podskupini samo je petero od šesnaest učenika (31%) uspješno riješilo zadatke od dva koraka. U eksperimentalnoj podskupini postotak je nešto veći, no poteškoće su ostale. Gabel i Sherwood (1984) taj su problem povezali s poteškoćama koje su učenici imali s dijeljenjem, no u testovima ta dva problema nisu povezana. Učenici ne znaju kako povezati početnu (danu) informaciju s konačnom, traženom veličinom, pa je to glavni razlog neuspješnog rješavanja ovog tipa zadataka.

Nakon toga smo se suočili s novim problemom koji nismo uočili kod prethodne skupine učenika, a koji nije ni bio spomenut u prije citiranim radovima. U testovima mnogih učenika uočene su poteškoće s matematičkim znakovima, i u eksperimentalnoj, i u kontrolnoj podskupini. Učenici ne razlikuju znakove <, >, a ne znaju niti što znače pojmovi „povećanje u nizu" ili „smanjenje u nizu".

Osim toga, u skupini „dobrih" učenika također su navedene neke poteškoće koje su uočene i u skupini „odličnih" učenika. To su: poteškoće s N i N_A, kao i poteškoće uočene u 10. zadatku. No, dok se u skupini učenika („dobrih") takve poteškoće javljaju i u eksperimentalnoj i u kontrolnoj podskupini, u prije analiziranim skupinama učenika („odličnih") te poteškoće uočene su samo u kontrolnoj podskupini.

Tablica 5 pokazuje sažet pregled poteškoća koje su učenici imali, uključujući i one učenike koji pripadaju eksperimentalnoj i kontrolnoj podskupini „dobrih" učenika.

Tablica 5.

Skupina učenika opisanih kao „prihvatljivi"

U kontrolnoj podskupini učenici opisani kao „prihvatljivi" imali su poteškoća sa zadacima koji zahtijevaju kompleksnije računanje. Oni nisu izrazili masu tvari u gramima, nego u molima. Kada smo pogledali 8. zadatak u testovima učenika, primijetili smo da ti učenici ne poznaju jedinicu za molarnu masu, pa su stoga masi tvari pripisali jedinicu za količinu tvari (mol).

8. zadatak:
m(NaCl)=n(NaCl) · M(NaCl)
m(NaCl)= 4 mol · 58

Problem je već bio opisan u radu Novicha i Menisa (1976). Naše shvaćanje tog problema jednako je njihovom, jer su naši učenici u kontrolnoj podskupini također povezali mol s masom, a ne s količinom.

Željeli bismo naglasiti da se takve poteškoće nisu pojavile u eksperimentalnoj podskupini, kod učenika koji su bili poučavani sistemičkim pristupom, nego samo u kontrolnoj podskupini, kod učenika koji su poučavani uobičajenim metodama.

Nadalje, uočili smo poteškoće u skupini učenika opisanih kao „prihvatljivi", a koje su već bile spomenute u ovom radu kod učenika opisanih kao „dobri" ili čak „odlični". Na primjer, poteškoće s molarnom masom (prije spomenute u skupini „dobrih" učenika) bile su uočene samo kod učenika u kontrolnoj podskupini, dok učenici u eksperimentalnoj podskupini nisu pokazali znatne poteškoće s molarnom masom. Zatim, uočene su i poteškoće s N i N_A. Zaključili smo da su obje podskupine „prihvatljivih" učenika imale te poteškoće, već spomenute kod ostalih dviju skupina, no učenici u eksperimentalnoj podskupini su znali da je vrijednost N_A $6 \cdot 10^{23}$ 1/mol, a učenici iz kontrolne podskupine nisu znali tu vrijednost. Nakon toga smo primijetili da su učenici iz „prihvatljive" skupine imali iste poteškoće s osnovnim matematičkim operacijama (dijeljenje, <, >), što je identično skupinama „dobrih" ili „odličnih" učenika. Stoga možemo reći da su poteškoće s matematikom univerzalne poteškoće za sve tri skupine učenika. Što se tiče poteškoća sa zadacima od dva koraka, učenici u kontrolnoj podskupini nisu ih mogli riješiti, dok ih je polovina učenika eksperimentalne podskupine riješila potpuno točno. Zanimljivo je istaknuti da učenici iz skupine „dobrih" učenika (i eksperimentalne, i kontrolne skupine) nisu mogli riješiti te zadatke, a učenici iz eksperimentalne podskupine unutar skupine „prihvatljivih" učenika te su zadatke uspjeli riješiti. Na kraju, kad promotrimo tu skupinu učenika, nitko nije uspio riješiti 10. zadatak. Stoga je taj zadatak dobio atribut „najtežeg zadatka", jer su ga samo učenici eksperimentalne podskupine skupine „odličnih" učenika uspjeli točno riješiti.

Tablica 6 pokazuje sažet pregled poteškoća koje su učenici imali, uključujući i eksperimentalnu i kontrolnu podskupinu učenika opisanih kao „prihvatljivi".

Tablica 6.

Zaključci i budući rad

Na temelju rezultata istraživanja navodimo nekoliko zaključaka. Možemo zaključiti da se većina poteškoća koje su spomenute u citiranim istraživanjima također pojavila i u našem istraživanju. To su poteškoće s Avogadrovom konstantom, s osnovnim matematičkim principima, zadacima koji se sastoje od dva koraka, zadacima koji su promijenjeni u usporedbi sa zadacima koje su učenici rješavali na nastavi, kao i poteškoće s razumijevanjem mola kao jedinice za količinu tvari.

Opći je zaključak da bi sistemički pristup poučavanju i učenju trebalo primijeniti u početku nastave kemije da bi se učenicima olakšao proces učenja kada se s kemijom prvi put susretnu u nastavi. Vjerujemo da su sistemici, kao grafički oblik prikaza znanja u kojem su sve veze između određene skupine pojmova učenicima jasno naznačene, posebno korisni za one učenike koji su opisani kao „odlični" i „prihvatljivi". Većina učenika u eksperimentalnoj podskupini skupine „odličnih" učenika točno je riješila svih 12 zadataka. Jedine poteškoće koje su uočene kod tih učenika bile su matematičke prirode, no, da ponovimo još jednom, te su poteškoće česte kod mnogih učenika koji su sudjelovali u našem istraživanju. Ti su učenici jedini koji su kao skupina točno riješili 10. zadatak, bez poteškoća. No, i učenici eksperimentalne podskupine skupine učenika opisanih kao „prihvatljivi" pokazali su znatan napredak i prilično visoka postignuća nakon našeg istraživanja. Na primjer, točno su riješili zadatak s molarnom masom, nisu pravili pogreške s jedinicama, a polovina ih je potpuno ovladala zadacima koji se rješavaju u dva koraka. Samo učenici opisani kao „dobri" nisu ostvarili nikakav napredak tijekom istraživanja. Učenici i iz eksperimentalne i iz kontrolne podskupine napravili su iste pogreške. Stoga, ne možemo donijeti zaključke o bilo kakvom napretku vezanom uz primjenu sistemika unutar te skupine učenika. Razlog toga što se učenici koji pripadaju toj skupini nisu prilagodili novoj nastavnoj metodi mogao bi biti funkcionalna fiksiranost. Stoyanov (1997), koji je proveo svoje istraživanje koristeći se kognitivnim mapama (umne mape i pojmovne mreže) kao nastavnim alatima, nazvao je tu skupinu učenika „serijalnim tipom učenika", koji su usredotočeni na detalje i sve korake unutar postupka, te koji tipično kombiniraju informacije na linearan način. Oni se usredotočuju na male dijelove informacija, radeći korak po korak, od jednostavnog prema složenijem, zanemaruju važne veze i dolaze u stanje funkcionalne usredotočenosti – nemogućnosti shvaćanja da se jedan pojam može koristiti u više različitih svrha. Stoga oni ne mogu shvatiti kako određeni pojam može biti povezan s drugim na sistemičan način, jer su fiksirani na tradicionalne, linearne prikaze i interpretaciju pojmova i veza među njima. Međutim, učenici opisani kao „odlični" i „prihvatljivi" pripadaju „globalnom ili holističkom tipu učenika". Oni su usredotočeni na nekoliko aspekata problema, koriste kompleksne veze da bi povezali pojmove (Stoyanov, 1997) – što se više odnosi na skupinu „odličnih" učenika; njihova pažnja nije usmjerena na detalje (Stoyanov, 1997) – što se više odnosi na skupinu „prihvatljivih" učenika), fleksibilniji su i relativno se lako prilagođuju novim metodama.

Željeli bismo spomenuti da je ovo istraživanje imalo nekoliko ograničenja. Prvo, nastavnicima je potrebno puno vremena da bi naučili kako izraditi i primijeniti sistemičke dijagrame u nastavnom procesu. Osim toga, nastavnicima i učenicima koji imaju slabije vizualne vještine taj pristup može uzrokovati probleme. Uz to, upotreba panoa za sistemičke dijagrame ograničeno je zato što zamjena ispunjenoga sistemičkog dijagrama neispunjenim sistemikom povezanim s idućim zadatkom zahtijeva vrijeme, zbog čega neki učenici mogu izgubiti koncentraciju. To ograničenje moglo bi se riješiti primjenom računala, no još uvijek mnoge škole nemaju potrebnu opremu.

Sljedeće pitanje ostaje kao tema budućih istraživanja: Postoji li ikakav način da skupina učenika koji su opisani kao „dobri" ipak može imati koristi od učenja uz sistemički pristup? Trebalo bi provesti novo istraživanje na većem broju učenika, da bi se rezultati statistički potvrdili ili da bi se raspravljalo o novim rezultatima. Također, opisana metoda trebala bi se primijeniti na neki drugi dio obrazovnih sadržaja, kao i na neke druge razine obrazovanja. Glavni smjer našeg budućeg istraživanja bit će povezivanje sistemičkog pristupa s teorijom kognitivnog opterećenja, ili, točnije, s mentalnim naporom učenika uzrokovanim učenjem uz sistemički pristup, kao i određivanje mjere u kojoj sistemici utječu na trajnost znanja.

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