CHEMISTRY EDUCATION: RESEARCH AND PRACTICE IN EUROPE
2000, Vol. 1, No. 1, pp. 135-144

THE PRACTICE OF CHEMISTRY EDUCATION (PAPER)
Methods and issues of teaching and learning

Dragica SISOVIC and Snezana BOJOVIC
University of Belgrade, Faculty of Chemistry

ON THE USE OF CONCEPT MAPS AT DIFFERENT STAGES OF CHEMISTRY TEACHING

Received: 21 September 1999; first revision: 14 December 1999; second revision: 21 December 1999; accepted: 21 December 1999

ABSTRACT: This paper illustrates the use of concept maps in combination with demonstration experiments. At elaboration and systematization sessions, concept maps are combined with demonstration experiments to help students to apply their knowledge of concepts and their interrelations, as well as to formulate theoretical explanations for the observed changes. This approach is illustrated by two examples: (i) an introductory chemistry session in the seventh grade of an elementary school and (ii) the systematization sessions of the topic 'chemical reactions' in the ninth grade (first grade of *gimnasia* in Yugoslavia). Also, this paper shows how concept maps can be used to determine whether students, by themselves, connect the concepts taught within physics and chemistry classes. [*Chem. Educ. Res. Pract. Eur.*: 2000, *1*, 135-144]

KEY WORDS: *concept map, chemistry and physics, physics; demonstration experiments; chemical reactions*

INTRODUCTION

In the process of thinking, concepts are the most important of all the forms of knowledge for they are mental tools of thinking that enable one to understand both the physical and the social worlds, as well as to communicate intelligibly. Concepts permeate the cognitive process, and serve as organizers of all intellectual and cognitive activities, as well as of all kinds of communication (teacher-students, students-students, students-taught topics). Since they are the main tools of thinking, their organization in cognitive structures is of great importance.

The process of acquisition of scientific knowledge and the cognitive development of a student are dependent upon the interaction of his/her cognitive structures, and the structures of scientific knowledge organized into systems that are provided by the curricula. The internalization of a concept into a system enables its scrutinizing comparison with the concepts of higher and lower degrees of generality, a comparison according to similarities and differences, as well as the acquisition of scientific taxonomies and a full understanding of the principles.

A non-interrelated knowledge lacks the links and relations between concepts, as well as the unity of various levels at which a particular chemical concept is represented. The internalization of chemical concepts includes thinking at three different levels: macroscopic, microscopic, and symbolic, by the use of chemical symbols, formulae, and equations (Ben-Zvi, Eylon, & Silberstein, 1988; Gabel, 1999). In addition, the study of chemistry includes the use of mathematical formulae and equations by which links and relations between macroscopic and microscopic levels are represented. If a teacher passes unconsciously from one level to another during a lecture, the result will be students' failing to grasp different levels of a concept.

One of the means teachers can use to help students to understand chemical topics and concepts is a concept map. A concept map is a teaching aid by which connections and relations, as well as the hierarchy of concepts, are presented in an obvious way. It can help students to understand how concepts are linked, how one develops out from another, all of which enable students to extend and deepen their knowledge of chemistry, to understand its wholeness (Dawson, 1993; Regis, Albetazzi, & Roletto, 1996; Francisco, Nicoll, & Trautmann, 1998). The value of demonstrating connections and relations by maps lies not in the facilitation of learning by memorization of hierarchical maps, but in understanding and internalizing the system of concepts, i.e. the structure of the contents of the curriculum.

In our research we used concept maps with the following aims:

- to point out the connections and relations of chemical concepts from the very beginning of studying chemistry;
- to draw connections with the topics and concepts studied within various school subjects (this enables an integrated approach to school knowledge, and encourages students to make use of what they have learned within another subject, or in out-of-school life, in numerous different situations);
- to systematize the contents of extensive educational topics;
- to pinpoint the causes of students' eventual poor test results;
- to test to what degree elementary school pupils are able to connect concepts internalised through studying physics and chemistry.

This paper shows how concept maps can be used to determine whether students, by themselves, connect the concepts taught within physics and chemistry classes.

At elaboration and systematization sessions, concept maps are combined with demonstration experiments to help students to apply their knowledge of concepts and their interrelations, as well as to formulate theoretical explanations for the observed changes. This approach is illustrated by two examples. The first one shows the use of concept mapping on an introductory chemistry session in the seventh grade of an elementary school. The suggested map of chemical concepts can be used at all sessions when a new content is elaborated as an aid that helps students to establish connections of new concepts with those previously internalised. The second example is related to the use of preconstructed concept map at the systematization sessions of the topic ‘chemical reactions’ in the eighth grade (first grade of gymnasium in Yugoslavia).

PROCEDURE

Connecting chemistry with physics at the seventh grade

In our country, basic scientific disciplines start being taught within separate subjects in the fifth grade of elementary school (age group: 11 years). Biology starts in the fifth, physics in the sixth, and chemistry in the seventh grade. By an analysis of the contents of the curricula of these subjects, we discovered a lack of both terminology and time coordination. So far, our research has been concentrated on physics and chemistry contents correlation. These subjects share a number of concepts planned and provided for in both curricula. On the other hand, a number of concepts being taught only within physics are necessary for a full understanding of certain chemical concepts, and vice versa. For example, to understand completely the concept of a chemical bond, taught within chemistry, students have to know the concept of force, taught within physics.

The sixth grade physics introduces the concepts of matter, substance, physical field, force, substance structure (atom, molecule), mass, density, pressure, and temperature. The seventh grade chemistry starts with the concept of matter, goes on to basic chemistry concepts (substance, element, compound, mixture, physical and chemical changes of substances), then on to substance structure (atom, atomic structure, molecule).

At a stage just before the elaboration of substance structure, we wanted to examine whether students had connected its concepts, redefined at chemistry classes, with the concepts of atom and molecule they had been taught at physics classes the previous year. We asked students to draw a map of relations and connections between the concepts of matter, substance, physical field, physical body, atom, and molecule, as well as to explain these connections. 186 seventh grade pupils were tested.

21% of the seventh grade students drew completely correct maps. The correctness of a map was evaluated according to: (i) the links between the concepts; (ii) whether the map had been drawn according to the definitions, which gave precise contents, and depth of concepts as had been taught at elaboration sessions; and (iii) whether the direction of the links indicated a hierarchical, causal or sequential relationship between the concepts. An example of a student's

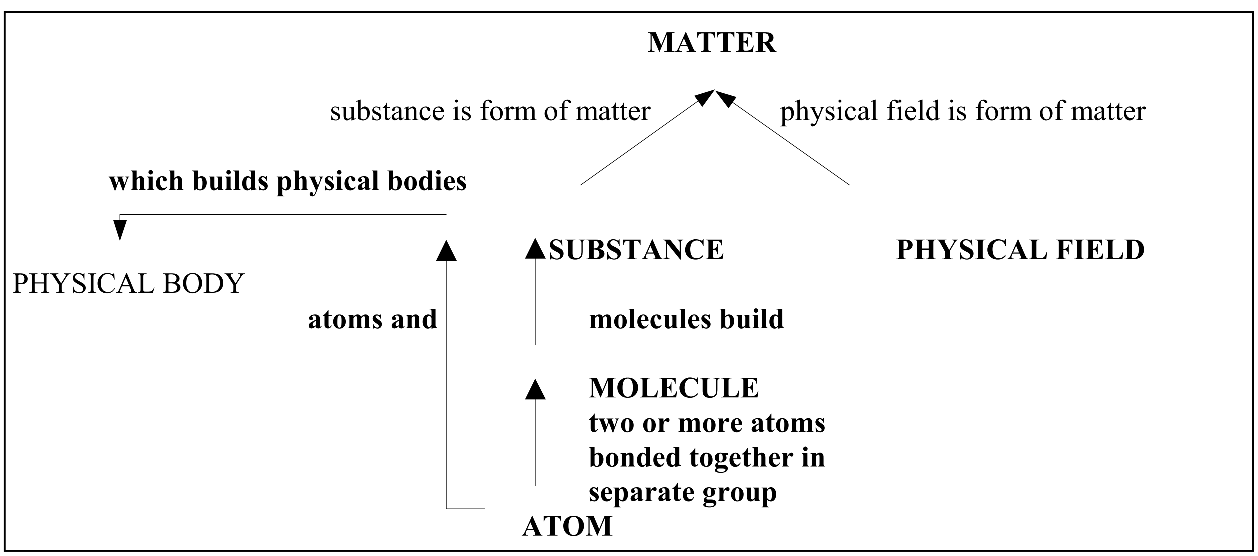


FIGURE 1. *An example of a student's correct answer.*

correct and accepted answer is given in Figure 1. Incorrect answers showed the lack of understanding of the connections and relations or the hierarchy of the concepts. In other words, almost 80% of seventh grade pupils did not connect the corpuscular structure of the substance, taught within physics, with the concept of substance, taught at the chemistry classes.

In the introductory part of this paper, we mentioned that chemical concepts are represented at three levels, and this applies to physical concepts, too. Students fail to comprehend and internalize different levels of concept representations due mainly to the way the curriculum structures educational contents. The analysis of the physics curriculum showed an intolerable mixture of macroscopic and microscopic levels, and vice versa.

Unless cause-effect relations between macro and micro levels are not pointed out (e.g., the connection between a macroscopically evident friction force and intermolecular forces), which has not been done in our textbooks and curricula, it is questionable to what extent the students will be able to establish them. It is not an easy task for a student in any subject, and it certainly can hinder the transfer of knowledge from one subject to another.

The problem of the lack of coordination between chemistry and physics arose again at the final testing of the eighth grade students. The test had certain requirements, connected with the experiments performed during the testing (Sisovic & Bojovic, 1997), which included the knowledge both of physics and chemistry. 80-96% students obtained correct observations of the experiment, but there were only 7.5 - 42% complete explanations.

These were the reasons why we decided to prepare a model for an introductory chemistry session, based on the connections of physics and chemistry (interdisciplinary connections). The aim of the model was to highlight, at the very beginning of studying chemistry, the connections between chemical concepts and the concepts of other scientific disciplines, physics in this case, which enables a full understanding and interpretation of various changes and phenomena, as well as a productive application of knowledge.

Concept maps were one of our teaching aids. We prepared a panel with the map of concepts taught within physics the previous year, and one with the concepts that would be taught within chemistry that year. The structure of the session was as follows: first the "physics" concepts were repeated and their interrelations established. Then we proceeded with demonstration experiments to connect these with concepts, which would be taught within chemistry. At the end, we marked the connections between the concepts of the two subjects on the panel. The result was a newly formed map of concepts as illustrated in the Figure 2.

Demonstration experiments that connect chemistry with physics

During the session, eight experiments were performed. The first one had the aim to study the relations between the concepts of matter, substance, physical body, and physical change, by showing the students a rectangular piece of paper and asking them first to explain the connections of the concepts of matter, substance, and physical body. Then we cut the paper into strips, and asked the students to answer, which concepts stayed the same, which changed, and if they knew a concept corresponding to the change performed. It was explained to the students that the demonstrated change was a physical one that it had not changed any of the essential properties of the substance, which they would study at subsequent sessions of chemistry.

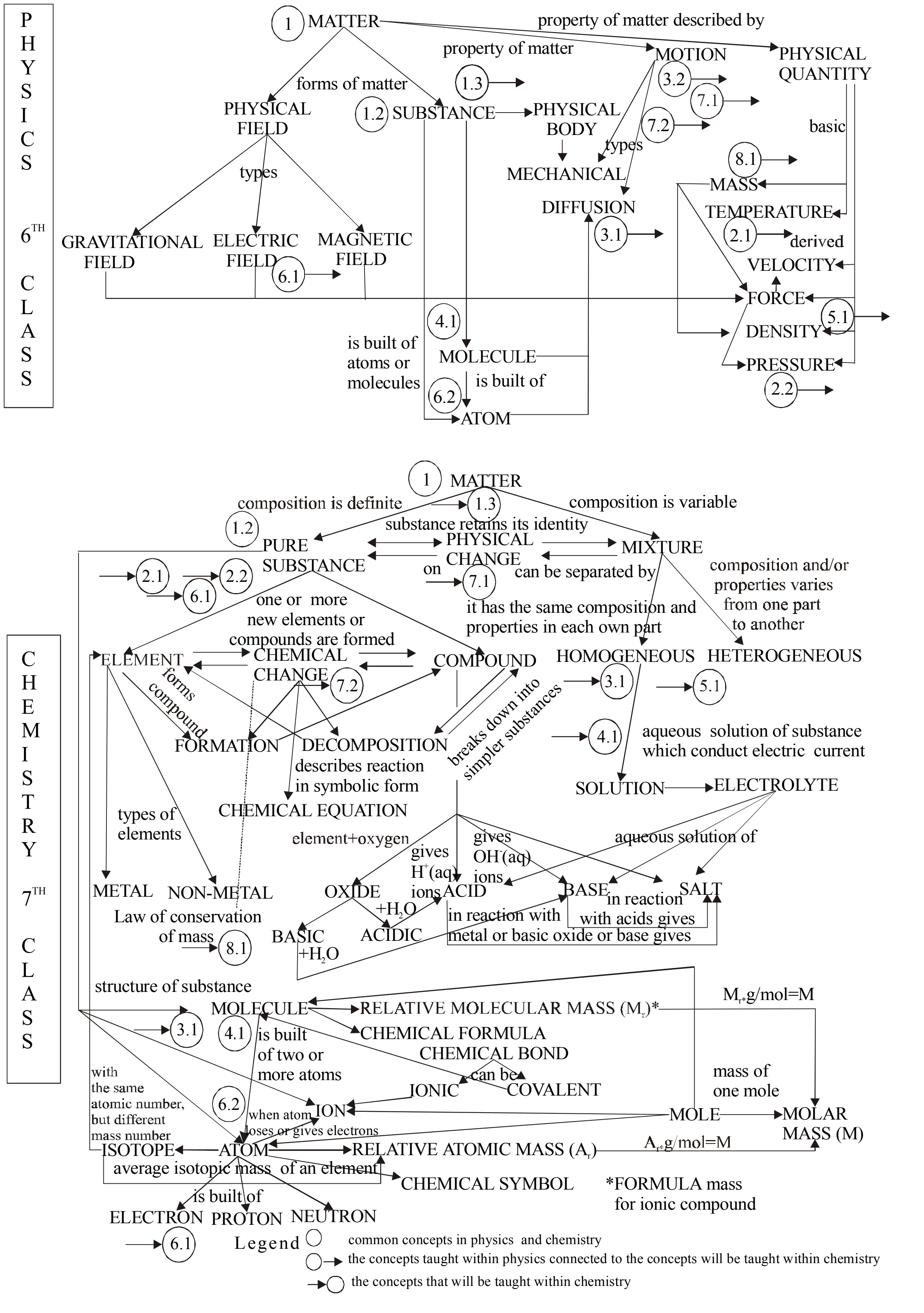


FIGURE 2: *The concept maps showing connection between the concepts taught within physics and the concepts that would be taught within chemistry classes.*

In the second experiment we used an inflated balloon, a glass of water, and a glass filled with ice cubes, to study the properties of different aggregate states. We talked about outer influences on the aggregate state of a substance (studied previously within physics), and pointed out that the connection between the aggregate state of a substance and its nature would be revealed further within chemistry.

The third experiment required several crystals of potassium permanganate in a cloth bag immersed into a glass of water. A shield was placed behind the glass. (In sixth grade physics, the concept of diffusion as a spontaneous process without any outer influences had been explained.) The result of this process is a solution (a homogenous mixture); these are concepts which would be taught within chemistry. After the experiment students were led, by carefully chosen questions, to a conclusion that motion is one of the essential properties of matter; that the process of a spontaneous mixing of substances shows that a corporeal entity we perceive macroscopically has, in fact, a particle structure.

In the fourth experiment, we poured the same volumes of distilled water and ethanol into a test tube, and marked the level of the fluid. After that we corked the tube, turned it upside down several times, and measured the level of the fluid again. The students compared the differences in levels before and after mixing. Then the discussion was led in the direction to discover the cause of volume reduction, i.e. towards the existence of spaces between the constituent particles of a substance. In this case, too, a homogenous mixture was obtained, because the properties of water and ethanol enable their mixing. Why? That they would be taught at chemistry classes.

By mixing different fluids, one does not always get a homogenous mixture. This was shown in our fifth experiment. Into a glass we poured oil first, and then distilled water. The students were asked why the oil went up and formed a layer on the surface of the water. A part of the explanation comes from physics: oil has lower density than water, and that is why it goes up to the surface. However, it is in chemistry that they will learn the differences in the nature of these substances, which prevent their mixing into a homogenous mixture.

Since the concepts of molecule and atom are studied within physics, while the structure of atom is studied within chemistry, the aim of the sixth experiment was to "show" the structure of atom. The explanation requires the use of the concepts of physical field and force. The teacher takes an inflated rubber balloon and takes it near to small pieces of paper. The students see that nothing happens. Then the teacher rubs the balloon against his or her hair to electrify it, and repeats the procedure. After seeing the result, the students discuss the following:

- the connections between electric field and the structure of a substance;
- what property a physical body (or a substance) has if it establishes electric field in the surrounding space;
- what causes the demonstration of that property if the molecules and atoms of a substance are electrically neutral;
- how charging a body can be explained.

The students are led to the conclusion that there are particles smaller than atoms, that they are charged, and that the number of positively and negatively charged particles is always the equal. Within chemistry they will study the structure of atom, and it will help them to understand the properties of substances.

The seventh experiment links the concept of the motion of particles with the concepts of physical and chemical changes. Furthermore, here the attention is drawn to heating as one of outer conditions that can trigger a chemical reaction. First the dissolution of sugar in water is shown, then the reaction of sugar burning. At the end, the product of sugar combustion is put into water to examine its solubility, which is, then, compared to solubility of sugar. The students became aware of the fact that a chemical change leads to a change of substance properties, i.e. that a new substance is formed.

The eighth and final experiment connects the concept of mass with the law that characterizes chemical reactions, the law of conservation of mass. A piece of paper is placed on the metal pan of a scale, and covered with a glass. The weights on the other pan show the mass when the balance of the scale is reached. Then the teacher lifts the glass, burns the paper, and covers it again.

After each experiment the connections among concepts that had been examined were marked on the panel. Such an approach of seeking the connections among concepts augments the understanding of not only the topics and concepts that are studied at school, but also of various phenomena and changes in everyday life. It also provides a basis for the application of knowledge.

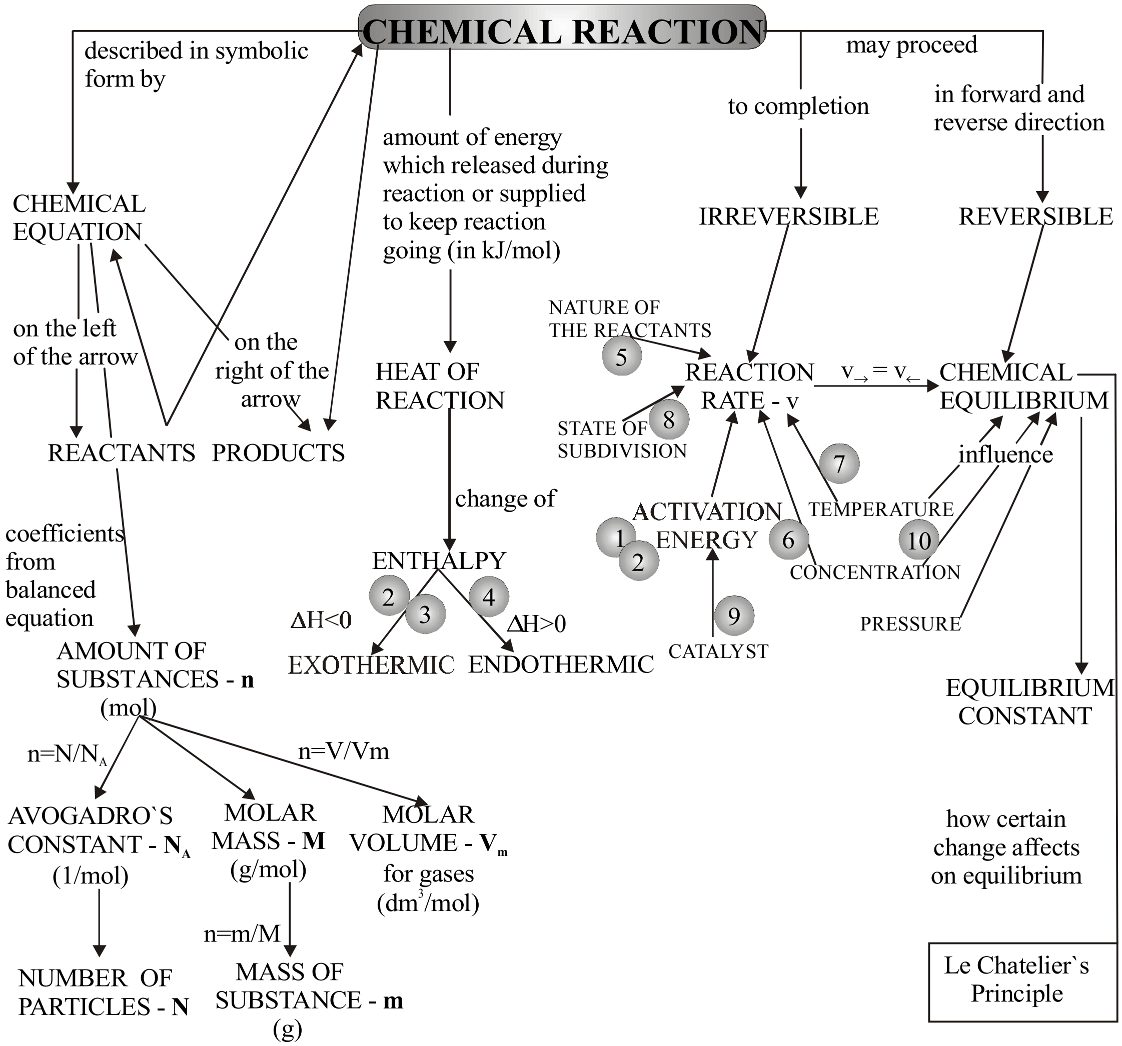
A map of concepts is not the only aid that contributes to the formation of the system of concepts, but our experience shows that, in combination with demonstration experiments, it facilitates the establishment of the connections and relations between the concepts, as well as their use when formulating explanations. On the other hand, our experience also shows that a mere demonstration of an experiment is rarely sufficient to incite a student's mental activities in the direction of the search for the explanation, nor can students self-organize these activities in that direction by themselves. The concept maps can serve as a foundation for possible ways to solve a particular problem.

The topic ‘chemical reactions’ for the ninth grade

Within different approaches selected with the aim to overcome the educational problems of students of the eighth grade, we also used concept maps. The ninth grade is the first year of general secondary education (*gimnasia*), during which students study general chemistry. One of the examples of the use of maps may well be with the elaboration and the systematization of the topic ‘chemical reactions’.

The curriculum includes the following topics: the quantitative meaning of symbols and formulae; relative molecular mass, formula mass; mole; molar mass and molar volume; stoichiometric calculations; particle mobility as a condition for chemical reactions; energy changes in chemical reactions (heat of reaction, exothermic and endothermic reactions); the rate of a chemical reaction; the influence on the rate of (i) the nature of a reactant, (ii) the concentration (law of mass action), (iii) temperature, and (iv) catalysts; chemical equilibrium; equilibrium constant; Le Chatelier's principle.

For the systematization of the mentioned topics, we prepared ten short experiments. During the class, the teacher demonstrated the experiments followed by a discussion about the



The list of demonstration experiments:

1. The explosion of the soap bubbles fulfilled with the oxygen-hydrogen gas mixture:
   $2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$
2. An ammonium dichromate volcano: $(NH_4)_2Cr_2O_7(s) \rightarrow Cr_2O_3(s)+N_2(g)+4H_2O(g)$
3. An exothermic reaction: $HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$
4. An endothermic reaction:
   $Ba(OH)_2 8H_2O(s) + 2NH_4SCN(s) \rightarrow Ba(SCN)_2(aq) + 2NH_3(g) + 10H_2O(l)$
5. The influence of reactants nature on the reaction rates:
   $2HCl(aq)+Mg(s) \rightarrow MgCl_2(aq)+H_2(g)$
   $2CH_3COOH(aq)+Mg(s) \rightarrow Mg(CH_3COO)_2(aq) +H_2(g)$
6. The influence of reactants concentrations on the reaction rates:
   $Na_2S_2O_3(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq)+ S(s) + H_2SO_3(aq)$
7. The influence of temperature on the reaction rates:
   $Na_2S_2O_3(aq) + H_2SO_4(aq) \rightarrow Na_2SO_4(aq)+ S(s) + H_2SO_3(aq)$
8. The influence of state of subdivision on the reaction rates:
   $2KI(s)+Pb(NO_3)_2(s) \rightarrow PbI_2(s)+2KNO_3(s)$
   $2KI(aq)+Pb(NO_3)_2(aq) \rightarrow PbI_2(s)+2KNO_3(aq)$
9. The influence of catalyst on the reaction rates:
   $2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$
10. An example of Le Chatelier's principle:
    $FeCl_3(aq) + 6KSCN(aq) \rightleftarrows K_3[Fe(SCN)_6](aq) + 3KCl(aq)$

FIGURE 3: *The concept map for the educational theme 'chemical reactions'.*

perceived changes. The students were led to formulate explanations, and to make connections and relations between the concepts under study. The concept map is presented in Figure 3.

CONCLUSIONS AND IMPLICATIONS FOR INSTRUCTION

This paper illustrates the use of concept maps in combination with demonstration experiments. A concept map, as an educational aid that can show the connections and relations between concepts in an obvious way, helps students to form a correct system of concepts, a necessary basis for understanding and usage of knowledge. In combination with experiments it stimulates the usage of already internalized concepts and their connections to formulate theoretical explanations for the observed changes. A concept map can help students: to analyze a problem from different angles, to develop a divergent way of thinking, to develop and enlarge their network of knowledge, as well as their abilities to make use of it. Also, concept maps can help the teacher to recognize the causes of students' eventual misconceptions, which is a valuable information for further planning and performing of the teaching process.

The introduction of each new concept in education should be performed by connecting it with other concepts of different levels of generality, by encouraging students to look after similarities and differences among the concepts of the same level of generality, by directing students to essential properties, instead of merely perceptive features of phenomena, and by constant stimulation of mental operations by which a concept can be developed. In educational systems such as in our country, where the study of scientific disciplines within separate subjects starts early, there is a problem of providing correlation of contents, and positive transfer of knowledge from one field to another. This is a necessary precondition for a solid knowledge, as is to train students to perceive and explain a phenomenon or a change from different angles, to be able to use their knowledge with other examples both in school or everyday life. If this is not done, the same concept taught within different subjects will have separate meanings (atom in physics versus atom in chemistry). Furthermore, we cannot expect success in studying a subject if we do not supply a student with a necessary basis provided for in another subject.

A large number of students do not continue studying sciences after elementary school, and such partial knowledge gets forgotten rapidly. Those who do go on with natural sciences will face many problems. To solve them, the application of various pieces of knowledge from the various scientific disciplines will be required, since the boundaries between these disciplines are not clear any more, and numerous border fields are emerging, waiting for research.

ADDRESS FOR CORRESPONDENCE: *Dragica SISOVIC, University of Belgrade, Faculty of Chemistry P.O.Box 158, 11001 Belgrade, Yugoslavia; fax: +38 1 11 63 87 85;*
e-mail: dsisovic@helix.chem.bg.ac.yu

REFERENCES

Ben-Zvi, R, Eylon B. and Silberstein (1988). Theories, principles and lows. *Education in Chemistry*, *25*, 89-92.

Dawson, C. (1993). Chemistry in concept. *Education in Chemistry*, *30*, 73-75.

Francisco, J. S, Nicoll, G. and Trautmann, M. (1998). Integrating teaching methods into a general chemistry classroom. *Journal of Chemical Education*, *75*, 210-213.

Gabel, D. (1999). Improving teaching and learning through chemistry education research: A look to the future. *Journal of Chemical Education*, *76*, 548-554.

Regis, A, Albertazzi, P. G, and Roletto, E. (1996). Concept maps in chemistry education. *Journal of Chemical Education*, *73*, 1084-1088.

Sisovic, D. and Bojovic, S. (1997). The contemporary examination of chemistry and physics knowledge by means of presentational experiments. *Proceedings of Second IOSTE Symposium Central and East European Countries*, pp. 80-84, Lublin, Poland: Maria Curie-Sklodowska University.