"It Happened, What's the Problem?" and "A Guide through the Problem" - A Model for Consideration of Ecological Issues in Chemistry Education

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Abstract: In order to improve the ability for application of knowledge of chemistry (acquired in the existing educational system) in real life the Model for Consideration of Ecological Issues was developed and applied in high school. The Model consists of the continuous text ("It Happened, What's the Problem?") and the test with non-continuous text ("A Guide Through the Problem"), which are prepared for consideration of the problem of eutrophication. The all results obtained (average achievement of 70.9±14.3 %) showed that the application of the Model enabled: understanding of an ecological problem based on scientific representations of the term eutrophication given in the continuous text, realization that the pollution of our environment may be directly related to modern life, application of acquired knowledge of chemistry to observe and understand the cause and effect of eutrophication in our environment, to draw a scientific conclusion, and understanding the importance of science and technology discoveries for solving ecological problems. In addition, Model contributed to the development of student's environmental literacy (ecological knowledge and cognitive skills), ability to think critically, and provided possibilities for classroom knowledge to become applicable in real life.

Keywords: Environmental education, Ecological problem-Eutrophication, Environmental literacy, Application of Chemistry Knowledge

Running title: ECOLOGICAL ISSUES IN THE CLASSROOM

INTRODUCTION

The results of PISA (the Program for International Student Assessment) and TIMSS (Trends in International Mathematics and Science Study) international evaluation of educational achievements are good indicators of the effectiveness of educational system in a country. In Serbia, in those studies, the overall achievement of Serbian eighth grade students in natural sciences was statistically significantly lower than that of an international average.[1-6] Causes for low students' achievements can be seen in the rather extensive curricula, in the fact that *"Practical knowledge in action"* (recognizing questions as scientific, identifying relevant evidence, critically evaluating conclusions, and communicating scientific ideas) is rare with students.[4,7-9] In regular school's classes insufficient attention was directed to teaching of concepts through their practical application in real life. Therefore, students find classes frustrating because material is difficult, boring, and irrelevant for their lives. Overall, students in Serbia have fairly good scientific knowledge of single facts (*"factual knowledge")*,[5] but difficulties emerge in: identifying and applying acquired knowledge in diverse life situations, perception of problem situations from the aspect of scientific concepts from different disciplines and scientific knowledge, solving tasks that demand analysis and deduction based on pieces of information presented in the form of continuous and non-continuous text.

The above mentioned difficulties have lead to the following question: What can be done in the existing state-of-the-art? The existing problems could be overcome by applying the experience attained by TIMSS and PISA testing in preparing the models appropriate to make the knowledge of science, especially chemistry, applicable in real life.[10,11] Taking into account that student's awareness of the connections between chemistry and real-life issues could be raised by learning chemistry in the context of a specific environmental problem,[12] the Model based on consideration of *ecological problems* was designed in this paper. The main goal of environmental education is to contribute to the development of an environmentally literacy (ecological knowledge, cognitive skills, affective, attitudes towards the environment)[13-16] and responsible citizen, so that they could have proper relationship with the environment they live in.[17-19] In Serbia, as well as in many European countries, environmental content forms part of several teaching subjects.[20] The pupils who provide environmental education only during regular class hours could be successful in components of environmental knowledge (factual knowledge and conceptual understanding), but did not perform as well in reasoning and analysis.[5] In addition, awareness and environmentally responsible behavior are difficult to be achieved,[21,22] even in eco-school pupils'.[13] Therefore, the goal of environmental education to increase environmental literacy was also included in the Model design. Students' environmental literacy is evaluated based on their ability in using and dealing with information on an ecological issue; and using chemical knowledge and skills to understand information about an everyday problem. The "problem-based approach" was chosen because of achievements and possibilities this teaching method provides.[23-25]

Thus, the Model was designed to let students read about a real ecological problem, apply scientific principles to find out its causes and effects and offer problem solutions. Such approach translates everyday situations into chemical problems and lead to the increase of student's awareness of the connections between chemistry and real life-issues, as well as their interest in science. Ultimately, the Model should provide an efficiency check in acquiring, understanding and applying knowledge, while, at the same time, serving as a guide for problem solving.

EXPERIMENTAL

Design of the Model

The Model which provided steps (partial goals presented in Figure 1) necessary for achieving the knowledge applicable in everyday life, was developed and used. For the realization of this Model it was necessary to:

- Select the problem from a real life context, which will interest students, and whose understanding requires the application of science knowledge (chemistry knowledge);
- Design of the texts related to the problem:
    - the continuous text with the information related to the problem *(„It Happened, What's the Problem?")*;
    - the test with a non-continuous text (*"A Guide Through the Problem");*
- Apply the Model in the classroom
    - Analyze results obtained.

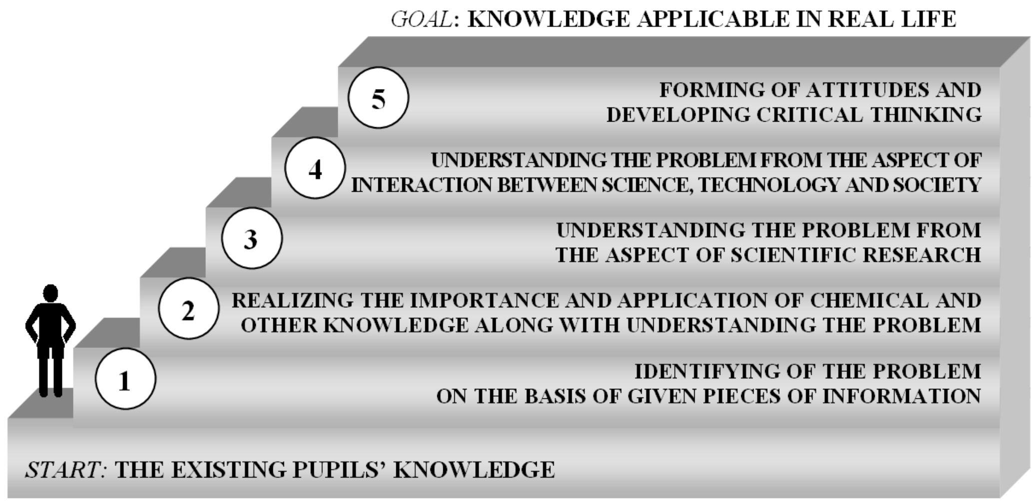

Fig.1. Steps in the Model for achieving the goal - make the existing knowledge applicable in real life

Preparing of the ecological problem texts

Continuous Text about the Ecological Problem: "It Happened, What's the Problem?"

Students are informed about ecological problems everyday through the media. An understanding of these problems requires application of knowledge of natural sciences. To accomplish the set up steps in the Model (Figure 1), pieces of information about the ecological problem (without many scientific facts and explanations) are given in the form of a continuous text "*It Happened, What's the Problem?"* Keyword, ecological problem and real life event (Figure 2, **I-III**) were selected before preparation of the text.

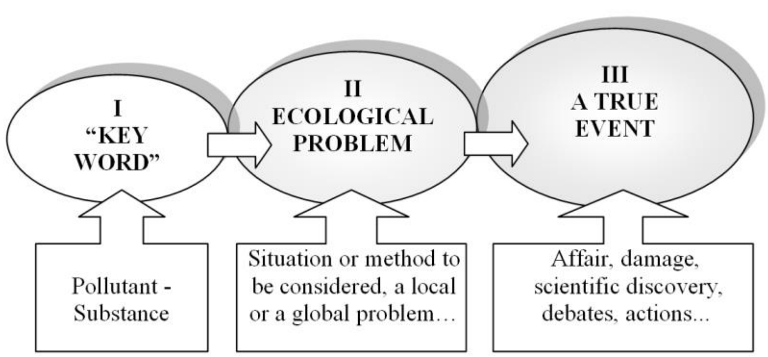

Fig. 2. Selection of content determinants in preparation of the continuous text "It Happened, What's the Problem?"

Keyword (a substance that is taught in regular chemistry classes) may be a direct or indirect cause for the emergence of ecological problem. Ecological problem may be chosen to illustrate the influence of humans (society) on the ecosystem from two aspects: “humans as a cause of the problem” and “humans (science) who solve the problem” (Figure 3).

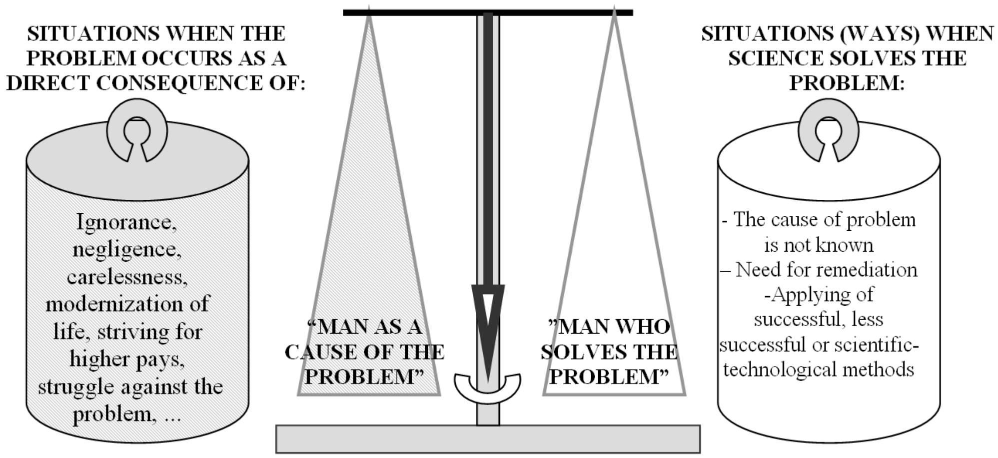

Fig. 3. Situation “Man as cause of problem” and “Man who solves the problem”

The true event may be chosen as: a historical event, i.e. the case that happened long ago but its consequences are still present in an ecosystem and lessons people have learned from it, and a contemporary event - a case of short- and long-term consequences at local and global level. It could be described from the two points of view: the consequences that people noticed, and “What does science say?” (scientific explanation of changes/consequences in the environment). If the cause of the problem was unknown, there follows the description of scientific-technological method applied in finding out a real cause (pollutant substance) without too many scientific facts. The content of the continuous text provides key information which, in combination with existing knowledge of chemistry (and other science subjects), enables conclusions about cause of ecological problems and making suggestions for solutions and future accident prevention. Structural elements of the continuous text and theses (**IV - VII**) that may be advanced in composing the text based on set goals (steps, Figure 1) are presented in Figure 4.

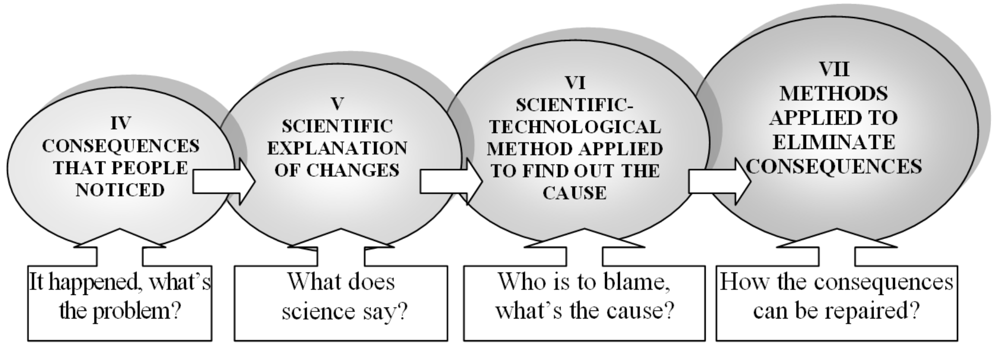

Fig.4. Structural elements and theses of the continuous text “It Happened, What’s the Problem?”

Such way of writing the text enabled the anticipation and understanding of the problem from the aspect of interactions in science-technology-society (STS):

a. Both benefits and harms that scientific-technological development brings about - *What is good and what is bad about a pollutant substance discovery-application*?

b. Differences between scientific proofs and personal opinion/attitude - *What is a difference between a layman’s and scientific view of a problem?*

c. Importance and role of science and technology - *How does science contribute to problem solving?*

d. Limits and relationships between science and technology - *What difficulties are involved in problem solving in science and technology?*

e. Alternative solutions - *Are there other solutions of the problem?*

In addition, such written text encourages formation of opinions and critical thinking development in students (step 5 in the presented Model, Figure 1).

The interrelation of partial goals in the Model (steps **1-5**, Figure 1) with structural elements of continuous text (**I-VII**, Figures 2 and 4), with the interactions which should be perceived and understood (**a-e**) was shown in Figure 5. Such presentation enabled anticipation how by stepwise approach through the text the goal could be accomplished: application of existing knowledge of science in real life.

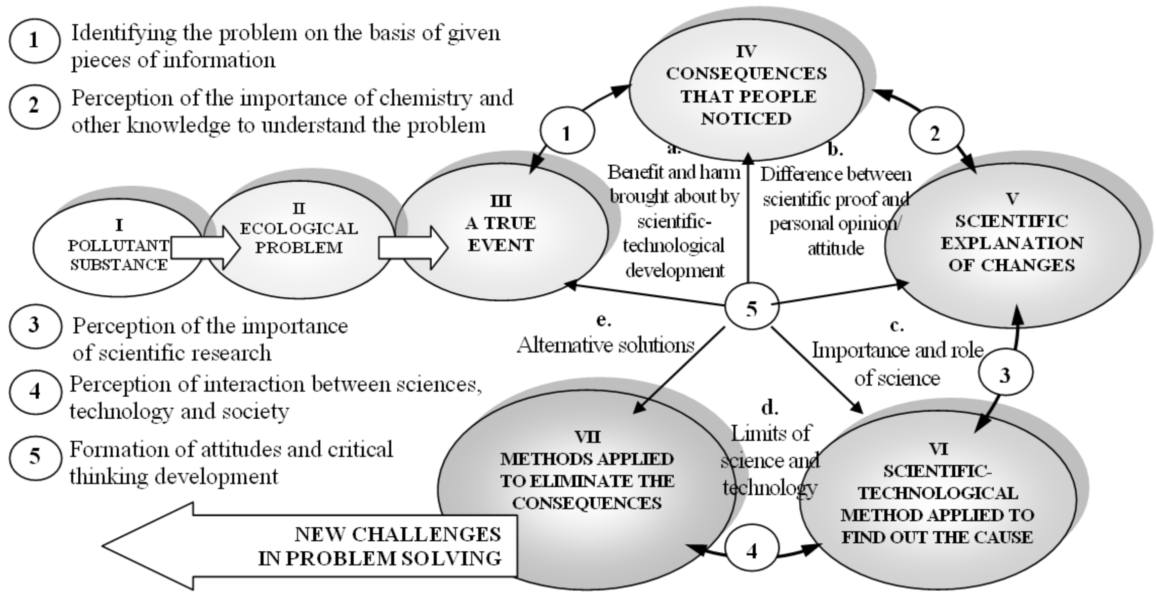

Fig.5. Relationship between set up steps (1-5) in the Model, structural elements of the continuous text (I-VII), and interactions to be perceived trough the text (a-e)

"It Happened, What's the Problem?"- Eutrophication as an Example

Detergent (keyword), *eutrophication* (ecological problem) and "*algal blooming*" (true event -"blooming of the sea" on the Adriatic coast of Montenegro) were chosen before the preparation of two continuous texts (documents 1 and 2).

First, students were presented with the ecological problem and the real life event through the document 1 which begins with the headline from a newspaper "SWIMMERS STOP! – THE BLOOMING OF THE ADRIATIC SEA IS IN PROGRESS". The following text describes *the outcome and changes* that took place in the sea from the point of view of tourists and swimmers, and then the eutrophication from *the point of view of science* (increase in biomass concentration, development of anaerobic conditions, decreased oxygen concentration and degradation of biomaterial down to methane, hydrogen-sulphide and ammonia).[26-28] The cause of eutrophication was not disclosed in document 1, rather it was called "a nutrient". As guidance for the nutrient's evaluation Radfield's discovery was presented that organic mechanisms (biota) control the movement of nitrogen and phosphorous in the ocean according to a constant atomic stoichiometry of 106C : 16N : 1P.[29] "Experienced formula" of algae ($C_{106}H_{263}O_{110}N_{16}P$) based on its chemical components was offered as *a scientific discovery* to solve the cause of eutrophication.[30]

Document 2 titled WHAT DO WE FEED THE SEA WITH?, deals with the history of detergent and softener use. In the conclusion of the text it was said that softeners are polyphosphates. This text does not point out the importance of Redfield's discovery for finding out the cause of eutrophication, but it was left to the students to use pieces of information they had read to discover the relationship between eutrophication, "experienced formula" of algae (document 1) and polyphosphate softeners (document 2). Schematic presentation of the text for considering the eutrophication according to given Model is given in Fig. 6.

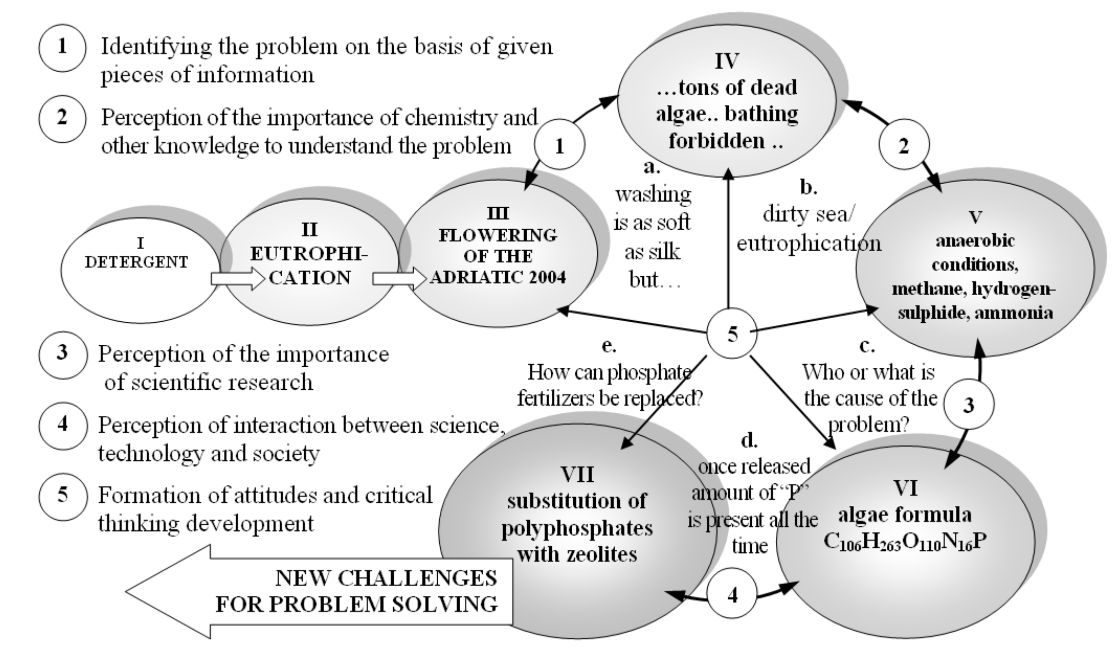

Fig. 6. Structural elements of the continuous text about eutrophication

The Test with Non-continuous Text "A Guide through the Problem"

The questions in the test (*"A Guide through the Problem")* contain either extracts from the continuous text or new pieces of information (given in the form of non-continuous text - graphs, pictures, schemes, tables…) about the pollutant substance and changes in the ecosystem. They help perceive the problem from the point of view of scientific knowledge, whereby all capacities are directed to essentially scientific perception of the problem. Form and sequence of questions are arranged to follow the story of continuous text and make students pass through set up steps presented in Figure 1. Questions are classified into six groups and interrelated with the steps (partial goals) in the Model:

First group: Existing student's knowledge about pollutant substance (start). Questions refer to general, special and single items of knowledge about the substance which is a direct or indirect cause of ecological problem occurrence ("keyword"). Questions help to connect chemical structure of pollutant substance with outcomes that may be caused in an ecosystem by the substance.

Second group: Identifying the problem based on pieces of information in continuous text "It Happened, What's the Problem?" (step 1, Figure 1). This group of questions examines the ability of understanding of what has been read, of collecting, using and interpreting information items given in the text.

Third group: Application of chemistry and other knowledge to understanding the outcomes and changes in the environment (step 2, Figure 1). Questions should encourage identifying and applying those teaching contents of chemistry and/or other scientific disciplines, which are crucial for understanding the essence of the described problem, as well as to interpret scientific arguments and results of scientific and/or technological measurements which explain causes and consequences of ecological problems.

Fourth group: Understanding steps in scientific research methodology (step 3, Figure 1). These questions require assuming a researcher's role, which involves hypothesis proposal, suggesting and testing of the method for solving the assumption and drawing of a conclusion.

Fifth group: Understanding interaction between science, technology and society in solving ecological problems (step 4, Figure 1). Responses provide the possibility to estimate the extent to which the problem is perceived over political, economic and ethical aspects of solving, whether limits of science and technology as well as likely risks are perceived.

Sixth group: Questions where statements of student opinions towards ecological problems, deduction and generalizations are expected (step 5, Figure 1). Responses should contain opinion on given or some other situations, on (un)acceptability of some method, as well as the suggestions of alternative solutions.

Applying of the Model in the classroom

The Model was used in the upper secondary school (‘’*St. Sava School’’, Belgrade, Serbia).* The total number of students was 60 (34 boys and 26 girls) from the senior chemistry class (ages 18-19). Before the application of Model students were not familiar with the term eutrophication. The application of the Model in the classroom had two steps. First, the students read the continuous test and solved the test with non-continuous text during 90 minutes. Afterwards, results obtained on the test were analyzed and discussed. The students were divided in groups with the task to discuss the questions and decide on correct answers within the group. After the representatives of each group presented their results a general discussion within the whole class was organized and coordinated by the teacher.

The students’ progress was evaluated by analysis of individual results and combined results of all (60) students. The success analysis done for each of (six) question groups gave progress report on the level of students’ chemical/environmental literacy.

RESULTS AND DISCUSSION

Assessment of the Model Applicability

In the first part of test the examination was performed on *chemistry knowledge of soaps, detergents and softeners* (their chemical composition and action) acquired in regular classes. The achieved results (77.3–92.4 %) show satisfactory student’s knowledge which could help them in search for an answer to the question: *What substances could be a cause of the occurrence of eutrophication and why?*

The next group of questions in the test was related to information items given in the continuous text about eutrophication. Multiple-choice task was used to check how much of this phenomenon was understood from information read in the text. The achieved result (81.8 % of correct answers) showed high understanding of the read text.

The term “nutrients”, mentioned several times in the continuous text, covers up the polyphosphate softeners, a real cause of eutrophication. 74.2 % of students chose polyphosphate softener as nutrients. Incorrect responses (22.7 %) indicated that a certain number of students did not have a clear understanding of the difference between changes and outcomes of the described phenomenon (algae and bacteria, 7.6 and 10.6 %, resp.), potential cause (detergents, 4.5 %) and real cause (polyphosphate softeners).

One question, with seven statements (given in the form of alternative choice) required *interpretation of scientific facts* based on reaction equation, which describes the generation of algae bioplasm ($C_{106}H_{263}O_{110}N_{16}P$) through photosynthesis:[30]

$$106\ CO_2 + 16\ HNO_3 + H_3PO_4 + 122\ H_2O \xrightarrow{\text{Energy and microelements}} C_{106}H_{263}O_{110}N_{16}P + 138\ O_2$$

The percentage of correct responses was in the 63.6-84.8 % range. The cause (small concentration of phosphate, 1 mol H_3PO_4) which leads to abrupt development of algae (biomass increase), i.e. that P is main limiting factor in control of the algal growth in water, was perceived by 84.8 % pupils. The lowest result (63.6 %) was achieved for the question referring to the action of oxygen on the algae decomposition.

Understanding of how science comes to discoveries was tested by four questions. Responses involved hypothesis formulation, proposal and testing the Method for solving the assumption and deduction. For the question *What makes Redfield's discovery of "algae formula" critically important for finding out a real cause of eutrophication?*, high percentage (81.8 %) of students deduced correctly how important the discovery of elements C, H, N, O, and P, necessary for algae forming was for identification of a substance causing eutrophication. Response to the question: *After "algae formula" had been discovered, scientists perceived the problem and asked the question: "Why don't algae reproduce in unpolluted waters?"* required the analysis of offered assumptions. Of the offered assumptions, 87.9 % of students chose correct hypothesis. The question: *After the proposed assumption, what would you do to find out a real cause of eutrophication?* a correct proposal for the choice of method to be used for hypothesis testing was given by 70.0 % of students. This figure should be supplemented by 6.1 % of students who expanded the correct response by their proposals, such as …'*test the role of surplus of those elements in the laboratory, not in clean waters at all", " decrease and increase phosphorus concentration*", "*make laboratory experiment with algae in the water with and without softeners*". The question: *The results of analysis of polluted and unpolluted waters indicated that in unpolluted waters eutrophication does not occur because…*had good responses (68.8 %).

Final testing of understanding and applying the concept of eutrophication was carried out through two tasks. Solving question involved the listing of other sources of pollution (substances) which may lead to eutrophication, apart from detergents (Figure 7). 51.5 % of students correctly listed substances that may be potential sources of phosphates (fertilizers and pesticides applied in agriculture, salts from factories wastewaters). Solving of the question, depended equally on knowledge of chemistry and geography and demanded relating them to pieces of information from the text, was slightly lower (45.0%).

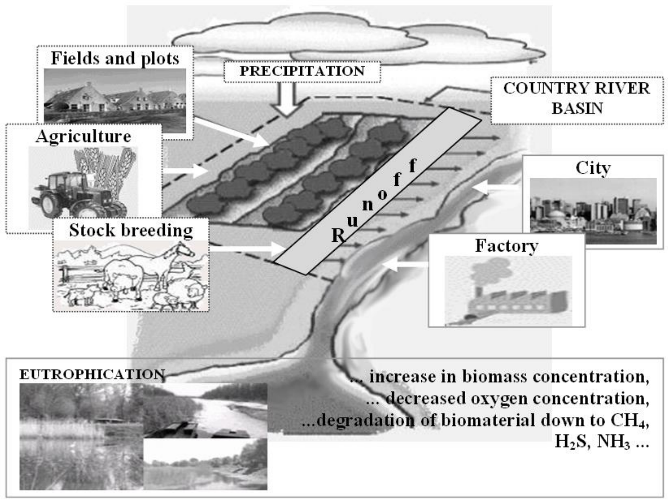

Fig. 7. Text of the question 12: There are estimates that rivers annually bring to North Adriatic about 28,000 tons of phosphorus in phosphate form and a large part (about 90%) is anthropogenic (man is the cause). Look at Figure above and deduce what *substances* can be a potential source of phosphorus in waters?

The final question of the test required actual deducing why danger of eutrophication was not entirely eliminated but only alleviated by replacing phosphates in washing powders with zeolites or polycarboxylates. That considerable amounts of phosphates run off with rain from the soil, where phosphate fertilizers were applied was confirmed by 83.3% of students. Slightly higher percentage (89.4 %) of students was familiar with the problem of non-filtering or insufficient filtering of a large amount of municipal wastewaters containing phosphates. A certain percentage (65.2 %) thought that the amount of phosphates once released was permanently present in water due to phosphates indestructibility and existence of their cycle in nature.

The all results obtained (Fig.8, average achievement of 70.9±14.3 %) showed that the application of the Model enabled:

- *understanding of an ecological problem* based on scientific definition of the term eutrophication given in the continuous text (biological indicators of eutrophication, elements inducing or limiting eutrophication, their origin in water, other factors influencing eutrophication).

- *realization* that the pollution of our environment may be directly related to modern life.
- *application of acquired knowledge of chemistry to observe and understand* the cause and effect of eutrophication in our environment to draw a scientific conclusion (from a hypothesis to a conclusion).
- *understanding the importance of science and technology* discoveries for solving ecological problems.

Misconceptions that students had (e.g. about a role of some elements in the eutrophication process) were corrected by the analysis of the test as described above. Such approach resulted in even better success rate of students and in their self realization of results achieved.

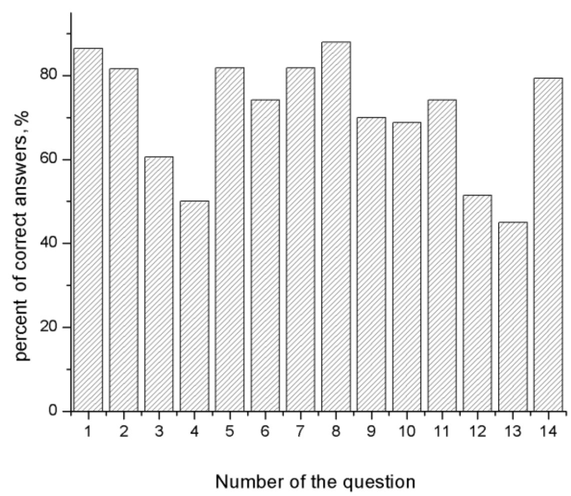

Fig. 8. Percent of correct answers obtained on the test with non-continuous text

All the results indicated that the Model studied fullfiled its goal, that it inspired students to think about the ecological problem described and enabled them to use and apply their scientific knowledge during the recognition and discussion of the problems from real life. It should be noted also that the Model contributed to the rise of student’s environmental literacy (ecological knowledge: knowledge and understanding of important concepts in ecology, principles of how the system works and its interaction with the environment of social systems; cognitive skills: the ability to analyze, synthesize and evaluate information on environmental issues).

Questionnaire

In addition, the importance of the quality of applied Model was confirmed by the questionnaire. Some of the questions (Q) and answers (A) were selected.

Q: Was the continuous text on eutrophication interesting for you?

A: Very much (61%), much (30%), little (8%), without answers (1%)

Q: Which characteristics of the text were the most imortant?

As: Story about real event; Chemical explanation on the use of softeners and the history of washing machines; There is not much chemistry; It is obvious that science is not perfect; Citations.

Q: How much the questions in the test helped you to understand the essence of the concept of eutrophication?

A: Very much (15%), much (65%), little (5%), not at all (2%), without answers (12%)

CONCLUSIONS

The general goals of the environmental education are to deepen knowledge about environmental problems, to develop cognitive skills for research and to develop awareness and attitudes towards the environment (i.e. environmental literacy). These goals are difficult to be achieved only during regular class hours of several teaching subjects. In eco-schools, in which the programme was adopted, the fully achievement of general objectives of environmental education was also failed. These objectives can be attained by way of realistic, active class work oriented towards problem-solving. Therefore, in this paper the Model suitable to provide students with tools to identify ecological issue, to use existing knowledge of natural sciences in consideration of an ecological problem and to explain phenomena scientifically was developed and applied. The didactic material *"It Happened, What's the Problem?"* made possible to add new knowledge of science to the existing one. The test with non-continuous text (*"A Guide through the Problem")* and the discussion enabled exercise of applying knowledge of chemistry, giving scientific explanations, generalization, whereby understanding of the essence of the studied problem was realized. All achieved results, over 70 % of correct responses, indicated that such method of work had been accepted. With such an approach, environmental education has a chance to encourage action competence in pupils, which is the basis for developing different behaviors and attitudes.

The environmental education in practice is completely in the hands of individual teachers, its realization depends on how prepared they are to adopt their subjects to environmental education. The examined Model could help to the teachers in the preparation and realization of their classes. Considerations of the ecology contents provide great possibilities for classroom knowledge to become applicable in real life.

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ИЗВОД

„ДЕСИЛО СЕ, У ЧЕМУ ЈЕ ПРОБЛЕМ?“ И „ВОДИЧ КРОЗ ПРОБЛЕМ“ - МОДЕЛ ЗА РАЗМАТРАЊЕ ЕКОЛОШКИХ ПРОБЛЕМА У НАСТАВИ ХЕМИЈЕ

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У циљу побољшања способности примене знања из хемије (стечених у постојећем систему образовања) у реалном животу, развијен је Модел који омогућава разматрање еколошких проблема. Састоји се од континуалног текста („Десило се, у чему је проблем?“) и теста са неконтинуалним текстом („Водич кроз проблем“), у којима је разматрана еутрофикација. Модел је примењен на часовима хемије у гимназији. Добијени резултати (средња вредност 70.9±14.3 %) показали су да је примена приказаног модела омогућила: разумевање еколошког проблема еутрофикације на основу научних одредница појма датих у континуираном тексту, сагледавање како загађење животне средине може бити директно последица модернизације свакодневног живота, примену стечених хемијских знања за сагледавање и разумевање узрока и последица еутрофикације у животној средини, за долажење до закључка путевима како то ради наука, као и

сагледавање значаја научно-технолошких открића за решавање еколошких проблема. Осим тога, примена Модела доприноси развоју ученичке писмености о животној средини (еколошко знање и когнитивне способности), способности критичког мишљења, и обезбеђује да знање стечено у учионици буде применљиво у реалном животу.

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