Multidisciplinary approach to teaching inorganic chemistry in high school: an example of the topic of metals

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We present in this article a multidisciplinary approach to teaching high-school chemistry in Serbia, illustrated by an example of the course topic of metals. The aim is to increase the level of interest in studying chemistry and acquiring knowledge that is applicable in daily life. The experiment was carried out in four classes of second-year gymnasium students. The redesigned materials can serve as a model for the preparation of similar materials for other course topics. Multidisciplinary approach in processing of the lesson on metals and the redesigned curriculum content significantly increased the interest of the students and improved their knowledge.

Keywords: Inorganic chemistry, high school, multidisciplinary approach, teaching, metals.

KNOWLEDGE stemming from natural sciences is necessary for the understanding of life, the world we live in and the daily occurrences and changes which take place in our surroundings[1].

Knowledge is acquired at different levels: macroscopic, microscopic and symbolic, which is true in the field of chemistry too[2–8]. Knowledge of chemistry, as a natural science, that is acquired in high school is primarily achieved at the microscopic and symbolic (abstract) level. The greatest problems occur in analyses at the microscopic and symbolic level. The curriculum contains abstract concepts. Understanding of these concepts is important for a further study of chemistry and other natural sciences and understanding the world that surrounds us[9–12]. The curriculum content dealing with natural sciences needs to be integrated, and for this we need to apply a multidisciplinary approach aimed at achieving clarity[13,14]. Knowledge of chemistry is related to knowledge that is acquired within other natural sciences in elementary and high school (biology, geography, physics). This knowledge provides us with various answers to the challenges of the modern world, and is necessary for the understanding of the use of chemical substances and processes in industry[15].

The multidisciplinary approach requires that teachers apply various modern methods, techniques and means in their teaching. The literature does not contain enough data on chemistry classes in schools in Serbia. The data mostly originate from the PISA testing which has been carried out in Serbia since 2003. In Serbia, 35% of the students do not reach the level of functional literacy in terms of science. Less than 2% of the students achieve a high level of achievement (5 and 6), which means that they can identify relevant scientific knowledge and apply it in a meaningful and productive way in various life situations. The results achieved on the PISA test in 2009 were approximately 5–7% higher than those in 2003 and 2006. What reflects negatively on students from Serbia is the fact that, on the average level of scientific literacy, in relation to countries of the OECD on the PISA scale, they lag behind their peers by one and a half school years. One year of schooling indicates an increase of approximately 40 points on the PISA scale[16].

On average, students from Serbia are most successful in solving problems at the level of knowledge acquisition, then the level of application, and weakest at the level of analysis and reasoning as a result of the traditional approach to teaching chemistry[17].

Thus, there is need for a critical approach to the problem of teaching chemistry and its possible improvements in that country.

Enabling clarity in chemistry classes requires a specially instructed proctor (instructed on technical and material matters), and also inventiveness and skill on the part of the teacher[18].

All this contributes to the realization of educational goals outlined by the standards in education, and producing chemically literate young people[19]. The concept of cooperative learning, on the topic of acids and bases, showed that students were more successful in organizing and carrying out their own experiments and in explaining the obtained results[20]. Concept maps in combination with demonstration experiments for teaching chemistry were

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used by Šišović and Bojović[21]. Demonstrations can help students understand some processes, and then apply the acquired observations and knowledge[21].

According to data in the relevant literature, better results in the acquisition of knowledge are achieved using an experimental approach in the processing of new material[22]. The use of modern-day didactic means also contributes to the acquisition of the material[23,24].

The aim of this study is the redesign of the curriculum content based on critical observations of teaching plans and results of tests on knowledge of the topic of metals. A multidisciplinary approach could be implemented to enhance the coursework with examples from everyday life, interesting illustrations as well as short and effective experiments. The goal is to increase interest in the study of chemistry and to raise the level of functional knowledge.

Pedagogical experiment

The topic of 'metals' was selected for the pedagogical experiment. This topic represents a part of the sophomore chemistry curriculum for high-school gymnasium students.

As a part of the selected topic, the goals to be achieved during teaching were defined, and include the following:

- Acquisition of facts on the distribution of metals on the earth and their mutual connection and distribution.
- Connection between the structures of atoms of metals and their physical–chemical features, predictions of reactivity and stability of the emergent compounds.
- Predict the interaction of metals with atoms of other elements and suggest formulae for possible compounds based on the location of the metals in the Periodic Table.
- Development of abilities for experimentation and use of information obtained through them.
- Development of the ability to use information obtained through various teaching means: textual, tabular, graphic, schematic – understanding of the practical significance of metals and their compounds.
- Connection between the characteristics of metals and their compounds, with their practical applications in real life.
- Acquisition of permanent knowledge which is applicable in real life.

Hypothesis

Teaching chemistry using a multidisciplinary approach does not lead to significant differences ($P < 0.05$) in the level of knowledge when compared to teaching by means of a traditional approach and does not evoke interest to study chemistry.

Participants

The pedagogical experiment was carried out in four classes with a total of 98 students (54 females and 44 males). The single-group method was applied, and the students studied chemistry following redesigned teaching material. The students were tested prior to and following the implementation of the programme.

Design of the pedagogical experiment

Figure 1 shows the structure of the pedagogical experiment.

Analysis of curriculum content – traditional method

Here we present results of analysis of the curriculum content pertaining to the topic of metals, which was included in the chemistry textbook for second-year high-school students attending a gymnasium[25]. All the metals to be

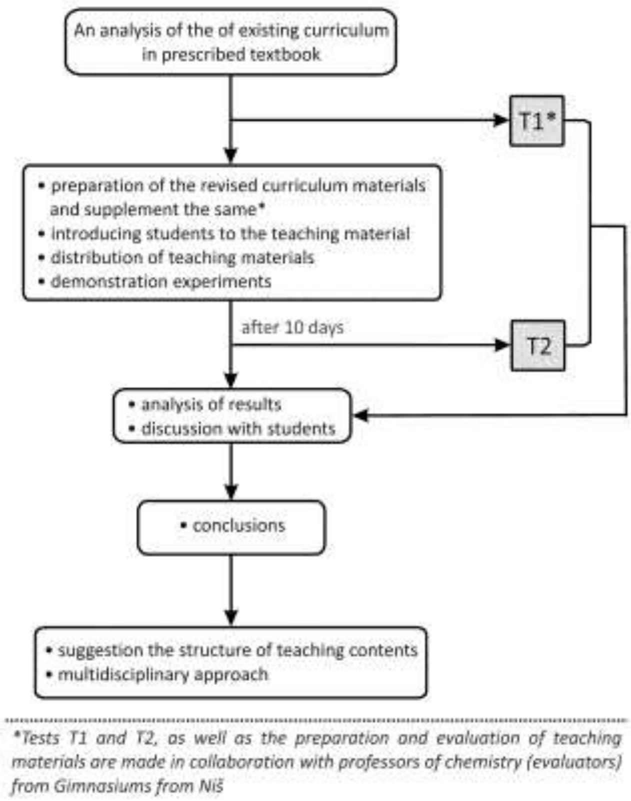

Figure 1. Scheme of the pedagogical experiment and research methodology.

studied were processed following the same pattern given in the course book:

- Their position in the Periodic Table of elements.
- Their physical–chemical and physical characteristics of the metals.
- Their chemical reactions and compounds.
- Their application and location in the environment.

Figure 2 shows the structure of the curriculum content as a percentage of frequency of occurrence in the recommended literature.

By analysing the curriculum content, it was found to be insufficiently related to the content of other high-school courses (biology, physics, geography) and daily life. Thus redesigning of the curriculum content was initiated, with the aim of connecting it to the other fields of science and daily life. Based on critical analysis of the curriculum content and the recommended literature, additional content was prepared, including application of a multidisciplinary approach.

Proposal of the redesigned curriculum content

When preparing the redesigned curriculum content, the following didactic principles were adhered:

- Clarity and abstraction;
- differentiation and integration;
- connection between theory and practice; and
- development of permanent knowledge, skills and habits.

Based on the critical approach to the material prepared for biometals Na and K, Mg and Ca, Fe, Zn, Cu; and toxic metals Pb, Cd and Hg, written material was prepared for each metal, amounting to approximately 15% of the overall content (percentage is expressed in relation to the total number of classes, which is designed for processing the teaching topic, i.e. metals). It consisted of an introductory part which included all the elements, with the addition of the content of biometals in the human body and other additions. The multidisciplinary approach to the topic consisted of the following:

- biological significance of the metals – a connection with biology and medicine;
- average human daily requirements – a connection with physiology;
- percentage found in groceries used in the daily human diet in the region – a connection with the human diet;
- consequences of its deficiency in the human diet – a connection with medicine and pharmaceuticals; and
- state of the metals in the environment – a connection with environmental protection[26–28].

Based on the analysis of the curriculum content from the state-sanctioned textbooks, we suggest a structure for the course material on the topic of metals (Figure 3).

The total number of hours is marked with 100%, and the number of hours in the special topics is indicated by a percentage.

Figure 3 shows the segments of the multidisciplinary approach used in this study. In the redesigned content, the frequency of metals on earth is shown in accordance with the geographic–geological data and in the human body based on biological data. An example is given in the Supplementary Figure 1.

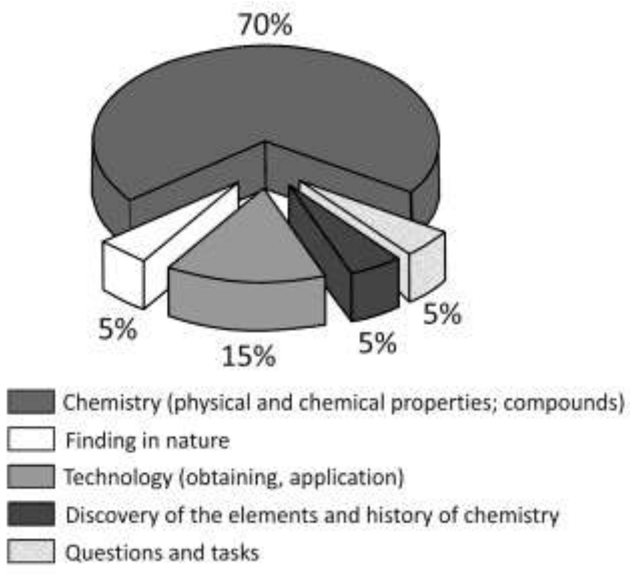

Figure 2. Existing structure of teaching materials.

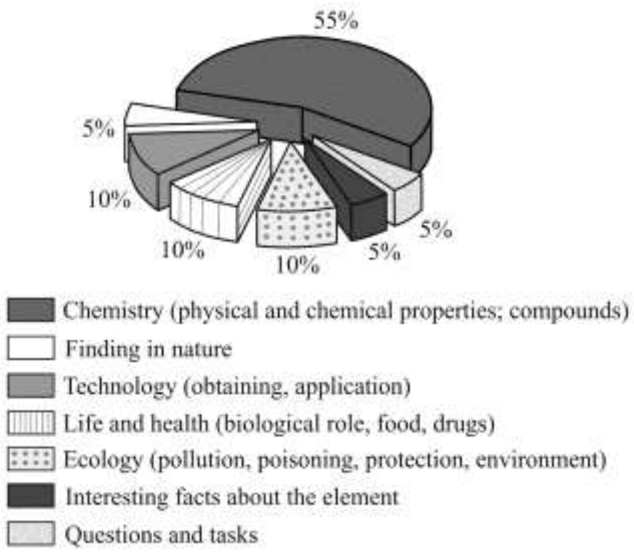

Figure 3. Segments of the multidisciplinary approach for studying the topic of metals.

The prepared material was distributed to all the students. During the class, suitable, short and effective demonstration experiments (see Supplementary Figure 2) were carried out.

Experiment 1: Simultaneous presence of calcium found in nature and the living environment (traces of Ca^{2+} ions in the ground, bones and eggshells) illustrates the frequency of the metals in various samples.

Experiment 2: Presence of traces of copper(II) ions in fruit stalk from plant fungicides illustrates the application of copper(II) compounds in agriculture.

Experiment 3: An intensively coloured complex compound of iron 'artificial blood' illustrates the characteristics of iron(III) and transition metals to build coloured complexes, analogous to haemoglobin which contains iron and transfers oxygen in living beings.

The selected experiments are illustrative, short, effective, harmless and do not require specially equipped laboratories[29]. These experiments were performed to improve the clarity of the chemistry classes. When performed individually, they can help develop experimentation skills, increase interest for the study of chemistry and enable acquisition of permanent and applicable knowledge. Following the realization of the class, tests for the evaluation of knowledge were distributed. All the tests were prepared in accordance with didactic and methodological requirements and based on the curriculum content.

In earlier studies, we used the method of parallel groups[22,30], and encountered significant problems while preparing pedagogical experiments (setting goals for the equalization of groups: pairing, forming homogeneous subgroups – top, middle, weakest with the aim to eliminate members who violate the balance, if it is impossible). The main disadvantage is that it is impossible to homogenize groups and exclude individuals who distort the balance.

Therefore, we applied the method of one group. The influence of the experimental factors was obtained by deducting the initial level of knowledge from the final level of knowledge.

In this way, we get the answer as to how much a procedure, or some method, influences the improvement of the level of knowledge. In this way, the group's inhomogeneity is avoided, which is the main disadvantage of the parallel group method.

The aim was to study the effect of the modified curriculum content being multidisciplinary at the level of student achievement in the production of metal topics.

Test T1 was designed and carried out based on the material being taught in regular chemistry classes in collaboration with professors from the high school as evaluators (Curriculum Chemistry, 1991). The overall number of classes, which was planned for the processing of teaching the topic of metals was 100%, and the individual segments were given as a percentage of the overall time needed to process teaching the topic of metals. All students first made an initial test (T1). Then the teaching material was presented and distributed. After 10 days students completed the final test (T2). Each test consisted of 10 questions and lasted for 20 min. The format of the initial (T1) and final (T2) tests is provided in Supplementary Table 1.

Statistical interpretation of the results

The results of the tests were processed for statistical significance. The statistical analyses were based on the means, standard deviation, degree of freedom, significance (*t*-test) and analysis of variance (ANOVA)[31].

Descriptive statistics was used to calculate the percentage of correct responses on the pre- and post-test. Paired sample *t*-tests were used to examine the mean score differences ($P < 0.05$) between pre-test T1 and post-test T2. Paired sample *t*-tests revealed significant differences between the results of tests T1 and T2. Statistical analyses were performed using the Statistical Package for the Social Sciences, 20.0.

Results and discussion

Figure 2 shows existing structure of teaching materials (traditional approach in accordance with the material provided in the course book) and Figure 3 shows structure of the redesigned curriculum content applied in accordance with the multidisciplinary approach. The percentage of the numerical physical–chemical data, chemical reaction and their compounds was found to decrease from 70 to 55. The redesigned material contained new aspects of the study of metals.

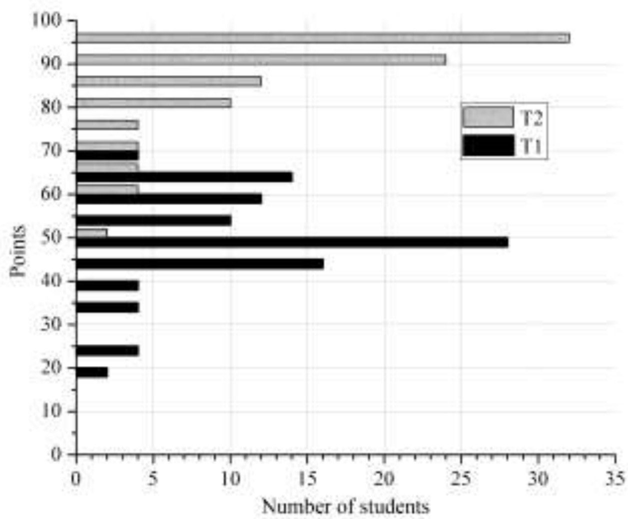

Figure 4. Distribution of results of students from the T1 and T2 tests.

Test T1 was designed according to the prescribed curriculum and adapted to the expected level of knowledge of second-year high-school students in collaboration with high-school professors (evaluators). Figure 4 shows results of test T1, which evaluated students' knowledge on the topic of metals after instructions based on the traditional method, in accordance with the existing curricula.

In the additional material, the biological significance of metals, finding in food, permitted quantities and toxicity is described. After individual study of the additional material students completed the T2 test.

Figure 4 also provides a comparison of the results from tests T1 and T2. Each correct answer is assigned one point and then the result is normalized to 100 points. The minimum number of points for test T1 is 20 and the maximum number is 70, on a scale of 1–100 points. The average number of points is 51.23.

The results obtained for test T2 range in the interval from 50 to 95 points. The mean value is 85.4 points, and the results obtained are significantly higher compared those of T1. This significant increase in knowledge, an increase of 31.17% (T2–T1), is probably the result of increased interest of the students due to the multidisciplinary approach[32].

The method of one group eliminates the influence of factors such as individual student differences, previous knowledge, and the time between the initial and final test.

The better results for test T2 probably may be due to the increased interest of the students in the course topic, since they had at their disposal redesigned curriculum material which was prepared based on the principle of a multidisciplinary approach. The redesigned material consisted of interesting illustrations, schemes, tables, examples from daily life and interesting experiments.

Changes in the contents of the curriculum were made in accordance to the structure of the redesigned curriculum and the results of the T2 test. Figure 5 shows the contents in class structure in accordance with the already existing curriculum and with our results.

The results of the *t*- and *F*-tests showed lower values than the critical ones, which indicates that the null hypothesis should be rejected. It can be concluded that there is significant difference in the knowledge of the students before and after application of the redesigned curriculum content. This indicates an increase in the level of interest for studying chemistry. A similar approach to the study of non-metals was used, and an improvement of no less than 10 points was achieved[32]. The use of additional teaching material based on multidisciplinary approach in elementary schools in rural and urban areas in the wider region of the city of Niš has contributed to increased interest and activities on the part of schoolchildren, which has in turn led to significant quantitative improvement in their knowledge of chemistry in general, and metals in particular[30].

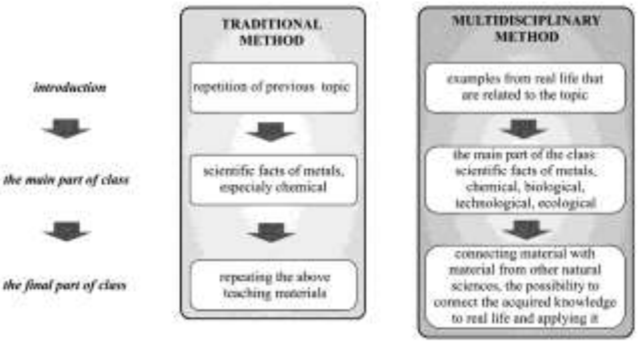

Figure 5. Modification of content that can be presented in different parts of the class.

In a similar study involving elementary schoolchildren a satisfactory level of knowledge was achieved (>50%) following the implementation of the expanded curriculum; improvement of no less than 20 points[33].

By comparing the percentage of improvement achieved in this study with that of other studies, we found that the percentage in this study was significantly greater[18,22,31,32]. This is probably the result of an interestingly designed additional material and effective experiments. In other studies where a similar methodology was used, an increase in knowledge of 8% was recorded[33].

A multidisciplinary approach could evolve interest in the study of chemistry in high schools, as well as interest in the preservation of the environment, in education, science, and so on.

Through the realization of the proposed pedagogical experiment, the following results have been achieved:

- connection between natural sciences within the innovated curriculum content;
- development of the ability among students to use information obtained through various teaching aids (illustrations, graphs, schemes, tables, experiments);
- increase in the level of health awareness and ecological awareness of the students;
- increase in interest for studying chemistry which can influence the professional orientation of the students; and possibility of acquiring permanent knowledge applicable in daily life.

The designed pedagogical experiment can be used as a model in the processing of other curricula contents.

The single-group method used for the redesigned curriculum content is suitable since, unlike the parallel group method, group homogeneity is not a prerequisite, which in real school conditions is difficult to realize.

Conclusion

The multidisciplinary approach to teaching the topic of metals contributes to a better connection between chemistry and other sciences. The redesigned curriculum content, based on the results of test T2, contributed to increase in the level of knowledge and acquisition of permanent knowledge applicable in daily life. In addition, the interest in students to study also increased, which can influence their professional orientation.

Recommendations

The application of this model on a larger sample with optimization of the curriculum content and methodology involved in the presentation of the material would contribute to higher quality realization of the national education strategy.

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