SCIENTIFIC THINKING IN SCIENCE EDUCATION

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Introduction

Scientific thinking is people's ability to form ideas and mental representations rationally and objectively. This type of reasoning is different from everyday, metaphysical or magical thinking. Scientific thinking begins with observations and experiences that generate research questions and hypotheses. Based on the questions and hypotheses, verification systems are developed to approve or reject them. Verification methods are based on experience and measurements.

This monograph deals with the formation of scientific thinking among students in science education. Defining the concept of scientific thinking in the context of education is not easy. A quote from an OECD book on the PISA principles describes the concept as follows: "Knowledge about science itself ... includes understanding the nature of science as a human activity and the power and limitations of scientific knowledge" (OECD, 2006). This is not a definition of scientific thinking in the strict sense, but rather of what every human being should know about science and the way it works. Also in Polish education, teaching scientific thinking is one of the main goals. A relevant provision on scientific thinking appears in the core curriculum for biology, chemistry, physics and geography. When we talk about developing students' scientific thinking, we mean improving their ability to plan and carry out observations and experiments, and to make inferences based on research results. Developing scientific thinking in students also means developing the ability to use information derived from the analysis of source materials, their reading, analysis, interpretation and processing.

In this monograph, in three parts and nine chapters, an attempt is made to describe various aspects of the education of scientific thinking.

The first part of the monograph describes research on various methods of developing scientific thinking in students. Described are non-formal workshops, the use of games, the IBSE method and how to use wrong answers in the education process.

The chapter SCIENTIFIC REASONING IN NATURAL SCIENCES - RESEARCH defines the concept of scientific thinking and describes in detail what skills, included in scientific thinking, should be achieved by a student after completing primary school. This chapter describes the tools to test students' level of scientific reasoning, in particular the Lawson test. This chapter describes the workshops for gifted and interested students, and discusses the results of the research on the development of students' competences in scientific reasoning after participating in these workshops.

The HIGH SCHOOL CHEMISTRY TASKS FOR IBSE chapter describes research into the effectiveness of IBSE-based science education. This chapter also includes ready-made materials (worksheets) on the topic of antioxidants (reactivity, stability of atoms and molecules, octet rule, radicals and resonance) from the point of view of general chemistry.

The chapter WE LEARN FROM ERRORS AND MISTAKES describes how the analysis of student errors can add value to the learning process. The authors analyzed four selected units on scientific competences and reading literacy from the PISA survey. In the chapter, they described a number of concrete possibilities for using the results of students' responses for teaching purposes.

The DIDACTIC GAME AS A MEANS OF DEVELOPING RESEARCH SKILLS chapter describes the results of research on the impact of educational games on the development of scientific thinking skills in students. In particular, games exercised the ability to ask research questions and teached the correct systematic asking of dichotomous questions. As a result of the research, it was also found that play increases students' interest in science and promotes the stability and depth of the acquired knowledge.

The second part is based on the assumption that in order to educate students in scientific thinking, teachers themselves should possess this competence. Therefore, in this part of the monograph there are two chapters which describe research on the scientific thinking skills of prospective teachers.

The chapter AN INVESTIGATION INTO FRESHMAN CHEMISTRY TEACHER STUDENTS 'DIFFICULTY IN PERFORMING CHEMISTRY CALCULATIONS, the authors focused on examining the skills of future teachers in solving problem tasks in the field of chemistry, as well as on general scientific tasks. The skills of students of the first year of BA studies (N = 27) and the last year of MA studies (N = 11) were compared. in the research, both groups were given three tasks for 15-year-olds.

The chapter RESULTS OF ANALYSIS OF SPECIFIC ELEMENTS OF SCIENTIFIC THINKING THROUGH CHEMICAL TASKS describes the research that is part of the science skills research carried out by the VEGA project. It was checked how effectively future teachers deal with solving tasks with chemical content, which are built on selected elements of scientific skills that require higher-order mental operations. As a research tool, the knowledge test was used, consisting of 12 non-standard tasks in chemistry, built on selected elements of scientific skills (Fradd et al., 2001).

The third part consists of theoretical considerations based on the analysis of source materials and pedagogical theories.

The chapter SCIENTIFIC THINKING IN LEARNING CHEMISTRY BASED ON THE CONCEPT SALTS details the relation of terms in the salts departmant. And the relation between the terms of the Salts department and terms in other departments is described. It was pointed out that the introduction of the concepts from the "salts" section actually contributes to shaping the scientific thinking of students.

In the SCHEME OF THE cleverCHEMHELPER PROGRAM BASED ON BLOOM'S REVISED TAXONOMY chapter, an idea for an interactive computer program was presented, which would enable the individualization of the process of teaching the ability to write chemical equations. The premise of this idea is that the complexity of the mental operations involved in writing and balancing an equation for a chemical reaction makes it difficult for students to acquire this skill. This chapter describes the program steps based on the revised Bloom Taxonomy.

Title of the last chapter of DOES TEACHING CHEMISTRY EDUCATE STUDENTS 'SCIENTIFIC THINKING? he is perverse. It is widely believed that teaching science and science develops students' scientific thinking. However, this chapter shows that there are many types of errors in chemistry textbooks: incorrect illustrations, chemical compound names not in accordance with IUPAC, outdated or incorrect definitions, using different definitions of the same concepts even in the same lesson, using previously undefined concepts, too many concepts introduced in one lesson, linguistic mess involving the use of colloquial terms, lack of precision and logic in sentences. The content presented in textbooks is very often contradictory. This situation not only confuses students' minds, but also disrupts learning to think logically and scientifically.

Literature

Assessing Scientific, Reading and Mathematical Literacy: A Framework for PISA 2006 (OECD, 2006).

Fradd, S. H., Lee, O., Sutman, F. X., Saxton, M. K. (2001). Promoting science literacy with English language learners through instructional materials development: A case study. Bilingual Research Journal, 25 (4), 479-501.

Małgorzata Nodzyńska

PART 1

Research on various methods of developing scientific thinking in students

SCIENTIFIC REASONING IN NATURAL SCIENCES - RESEARCH

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Abstract

Universal and high-quality mathematics and natural science education, including scientific reasoning, is a condition for progress and development of civilization. However, it cannot be assumed that its main goal is to educate future scientists, because we often refer to scientific reasoning in everyday life, e.g. by analyzing leaflets of medicines and cosmetics of food products. Nowadays, we are bombarded with information, many of which are false. Some authors try to undermine the credibility of science's claims (including, for example, anti-vaccine movements, negating anthropogenic global warming, rejecting the theory of evolution). These pseudo theories are often served in a pseudo-scientific relay to mislead low-critical audiences. Therefore, an extremely important goal of education in science education should be to equip students with tools for critical information analysis, i.e. teaching them scientific reasoning.

The test sheet consisted of 24 closed questions and was placed on the quizizz.com platform, containing free tools for teaching and learning on any device. The questions cover 10 topics in biology, chemistry, physics and mathematics. These were questions that tested not so much the knowledge as the students' way of thinking. The tasks contained a broad description of nature experiments with illustrations, and the students' task was to provide an answer based on this description and then its justification.

Key words

scientific reasoning, natural science, research

Introduction

One of the main currents of the European Union's policy is to support the development of a knowledge-based society, with a significant contribution of science and science education assumed to achieve this goal. One of the main goals of science teaching is to improve students' cognitive and mental abilities. Including skills to use scientific knowledge to identify and solve problems, as well as to formulate conclusions based on empirical observations. These skills allow you to identify and understand the relationship between the cause and its effect. Reasoning skills fall into three main groups depending on their level of complexity (Johnson-Laird, 2006):

- Basic reasoning skills - differently operational reasoning,

- Higher-order reasoning skills:

- Analogical reasoning,

- Inductive reasoning,

- Troubleshooting,

- Critical thinking,

- Scientific reasoning.

Scientific reasoning is defined as the use of abstractions and symbols to represent and describe phenomena using variables and dimensions. It is mainly based on arguments - which requires the organization of numbers and facts, performing various logical operations and finding cause-effect relationships between the observed changes. Scientific reasoning is characteristic of conducting scientific research and education in the field of exact, natural and technical sciences. however, it is also necessary for everyday life. We often refer to scientific reasoning in everyday life, e.g. by analyzing the leaflets of medicines and cosmetics of food products. Nowadays, we are bombarded with information, many of which are false. Some authors try to undermine the credibility of science's claims (including, for example, anti-vaccine movements, negating anthropogenic global warming, rejecting the theory of evolution). These pseudo theories are often served in a pseudo-scientific relay to mislead low-critical audiences. Therefore, an extremely important goal of education in science education should be to equip students with tools for critical information analysis, i.e. teaching them scientific reasoning. Scientific reasoning is often considered the most advanced form of human thinking.

The Polish Core Curriculum for the Elementary School in science subjects (biology, chemistry and physics) lists what skills in scientific thinking a student should achieve after completing this stage of education.

And so in Polish Core Curriculum for Chemistry, there is written:

• Interpretation of experience results and formulation of conclusions based on the observations carried out is intended to use the acquired knowledge to identify and solve problems.

• The student assesses the reliability of the data obtained.

• The student uses knowledge to solve simple chemical problems.

The Polish Core Curriculum for Biology includes:

• Asking questions and finding answers in accordance with the scientific method requires the student to acquire a number of skills such as analyzing various sources of information, planning and conducting simple experiments and observations at school and in the field.

• Biology as interdisciplinary science shapes students' scientific thinking and critical approach to information. These skills are useful both in everyday life and in further education.

• The student defines the research problem, formulates hypotheses, plans and conducts and documents observations and simple biological experiments.

• The student defines the conditions of the experiment, distinguishes between the control and research sample.

• The student analyzes the results and draws conclusions.

• The student reads, analyzes, interprets and processes textual, graphic and numerical information.

The Physics Core Curriculum includes:

• Concepts, laws and theories of physics shape the style of thinking and action based on the scientific method.

• The primary goal of teaching physics should be:

• shaping cognitive curiosity manifested in formulating questions and searching for answers using research methodology;

• developing the habit of expanding knowledge, using source materials and safe experimentation;

• using elements of research methodology to obtain and verify information;

• shaping the foundations of scientific reasoning including recognizing scientific issues, explaining physical phenomena in a scientific manner, interpreting and using scientific results and evidence;

• using information derived from the analysis of source materials.

Considering the skills recorded in the Core Curriculum, it could be assumed that students graduating from Primary School have the ability to think scientifically.

Research methodology

Hypotheses

It was assumed that selected, talented students interested in science and natural science who graduate from primary school have a high degree of scientific thinking. Another assumption was that laboratory classes conducted as part of non-formal education based on education through action, research and discovery would raise the level of scientific reasoning of students to a higher level.

Research description

Solving tasks aimed at determining the level of scientific reasoning skills among primary school students was carried out before and after the training with scientific thinking, planning and conducting science experiments. The training was conducted as part of the "Summer School for Young Talents" project. 50 primary school students took part in the project. They were selected students, gifted with achievements, interested in science and natural subjects. The students were divided randomly into five groups, each group consisted of 10 people. During the training, in each group, the same program was carried out, at the same time. The training lasted 3 days (19 h) and was carried out in the form of workshops and laboratory classes.

The overarching goal of the workshops was to shape students' scientific thinking and develop their interests in mathematics and science, as well as equip students with universal skills necessary for a career as a scientist and in the labor market. The expected effect of education was to increase the scientific thinking skills of the participants. After completing the workshop, students should be able to formulate a research problem and a hypothesis proposal, plan an appropriate experiment for a specific research problem, conduct careful observations and clear notes on the course of the experiment, process and analyze experimental data and draw conclusions from them. For this purpose, 5 topics were carried out: Become a Scientist, Become a Physicist, Become a Chemist, Become a Biologist, Become a Speaker. At the same time, students had time to carry out their own research projects within each of the topics. The results of work on the projects were presented during the last topic - Become a speaker.

Under Theme 1: Become a Scientist, the students participated in a brainstorming session on the topic: What is the purpose of science in the modern world? Then they independently developed the competency profile of the researcher. And then, as part of self-reflection, they answered the question:

What are my strengths and weaknesses to become a scientist? Using the “expert tables” technique, the students became familiar with the scientific method (the topics discussed were: observation, experiment, experiment; criteria of scientific knowledge; hypothesis, theory, research problem; dependent, independent and controlled variables). Then the students listened to a mini-lecture on the specifics of a natural science presentation. And in pairs, using the case study, they assessed the presentations in terms of their correctness.

For this topic, students also selected their own research project and developed a plan for it.

Under topic 2: “Become a Physicist”, students participated in laboratory activities:

- Laser - light and heat energy generator;
- Water - basic properties and role in nature;
- The density of selected substances.

As part of this topic, students also worked on their own projects and learned about the goals and principles of mathematical processing of measurement data and their implementation in spreadsheets.

In Theme 3: “Become a Chemist”, students also participated in laboratory activities:

- How can we conclude that a chemical reaction is taking place?
- Magnesium and vinegar;
- How much does blue weigh?
- How do you recognize sugar?

As part of this topic, the students also worked on their own projects.

As part of topic 4: “Become a Biologist”, students participated in laboratory classes:

- Laser microscope;
- Daphnia - a transparent organism.

As part of this topic, students also worked on their own projects, incl. preparing a presentation.

As part of the topic 5 “Become a speaker”, a conference was held which crowned the Summer School of Young Talents. Students presented their research projects using prepared multimedia presentations. The obtained results were discussed.

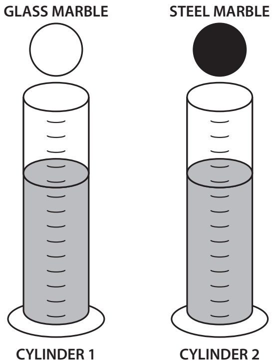
The means of measuring the participants' practical aptitude test was an on-line test before the start of the first topic and after the end of the last topic.

Research tool

One of the most commonly used tools for testing scientific thinking skills (reasoning and justifying your judgments) is Lawson's Classroom Test of Scientific Reasoning (LCTS) (Lawson, 2000a). The test consists of 24 multiple-choice questions covering knowledge of biology, chemistry and physics. To properly answer the questions contained in the test, no specialist knowledge of the above-mentioned sciences is required, however, scientific thinking skills are required. (Lawson, 1978, 2000a, 2000b, 2003, 2005; Pyper, 2011).

Lawson's Classroom Test of Scientific Reasoning

1. Suppose you are given two clay balls of equal size and shape. The two clay balls also weigh the same. One ball is flattened into a pancake-shaped piece. Which of these statements is correct?



a. The pancake-shaped piece weighs more than the ball

b. <u>The two pieces still weigh the same</u>

c. The ball weighs more than the pancake-shaped piece

2. *because*

a. the flattened piece covers a larger area.

b. the ball pushes down more on one spot.

c. when something is flattened it loses weight.

d. <u>clay has not been added or taken away</u>.

e. when something is flattened it gains weight.

3. To the right are drawings of two cylinders filled to the same level with water. The cylinders are identical in size and shape.

Also shown at the right are two marbles, one glass and one steel. The marbles are the same size but the steel one is much heavier than the glass one.

When the glass marble is put into Cylinder 1 it sinks to the bottom and the water level rises to the 6th mark. *If we put the steel marble into Cylinder 2, the water will rise*

a. to the same level as it did in Cylinder 1

b. to a higher level than it did in Cylinder 1

c. to a lower level than it did in Cylinder 1

4. *because*

a. the steel marble will sink faster.

b. the marbles are made of different materials.

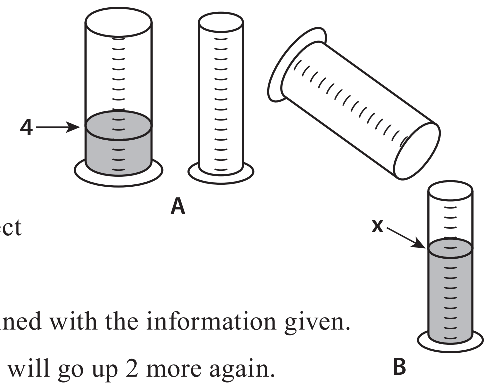
c. the steel marble is heavier than the glass marble.

d. the glass marble creates less pressure.

e. the marbles are the same size.

5. To the right are drawings of a wide and a narrow cylinder. The cylinders have equally spaced marks on them. Water is poured into the wide cylinder up to the 4th mark (see A). This water rises to the 6th mark when poured into the narrow cylinder (see B).

Both cylinders are emptied (not shown) and water is poured into the wide cylinder up to the 6th mark. *How high would this water rise if it were poured into the empty narrow cylinder?*



a. to about 8

b. to about 9

c. to about 10

d. to about 12

e. none of these answers is correct

6. *because*

a. the answer can not be determined with the information given.

b. it went up 2 more before, so it will go up 2 more again.

c. it goes up 3 in the narrow for every 2 in the wide.

d. the second cylinder is narrower.

e. one must actually pour the water and observe to find out.

7. Water is now poured into the narrow cylinder (described in Item 5 above) up to the 11^{th} mark. How high would this water rise if it were poured into the empty wide cylinder?

a. to about 7 1/2

b. to about 9

c. to about 8

d. <u>to about 7 1/3</u>

e. none of these answers is correct

8. *because*

a. <u>the ratios must stay the same</u>.

b. one must actually pour the water and observe to find out.

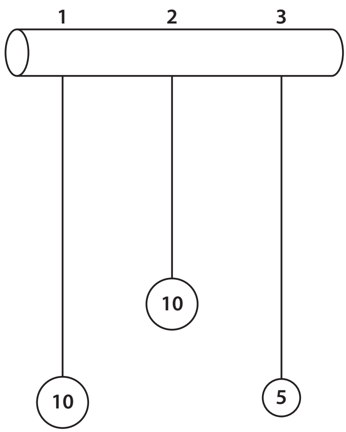
c. the answer can not be determined with the information given.

d. it was 2 less before so it will be 2 less again.

e. you subtract 2 from the wide for every 3 from the narrow.

9. At the right are drawings of three strings hanging from a bar. The three strings have metal weights attached to their ends. String 1 and String 3 are the same length. String 2 is shorter. A 10 unit weight is attached to the end of String 1. A 10 unit weight is also attached to the end of String 2. A 5 unit weight is attached to the end of String 3. The strings (and attached weights) can be swung back and forth and the time it takes to make a swing can be timed.

Suppose you want to find out whether thelength of the string has an effect on the time it takes to swing back and forth. Which strings would you use to find out?



a. only one string

b. all three strings

c. 2 and 3

d. 1 and 3

e. <u>1 and 2</u>

10. *because*

a. you must use the longest strings.

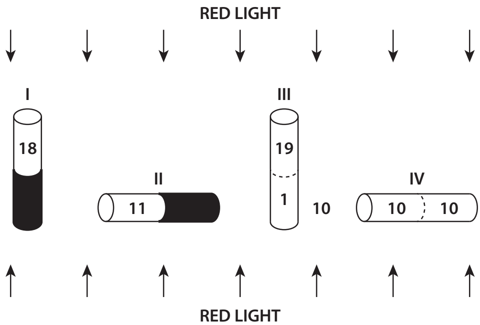
b. you must compare strings with both light and heavy weights.

c. <u>only the lengths differ</u>.

d. to make all possible comparisons.

e. the weights differ.

11. Twenty fruit flies are placed in each of four glass tubes. The tubes are sealed. Tubes I and II are partially covered with black paper; Tubes III and IV are not covered. The tubes are placed as shown. Then they are exposed to red light for five minutes. The number of flies in the uncovered part of each tube is shown in the drawing.



This experiment shows that flies respond to (respond means move to or away from):

a. red light but not gravity

b. <u>gravity but not red light</u>

c. both red light and gravity

d. neither red light nor gravity

12. *because*

a. <u>most flies are in the upper end of Tube III but spread about evenly in Tube II.</u>

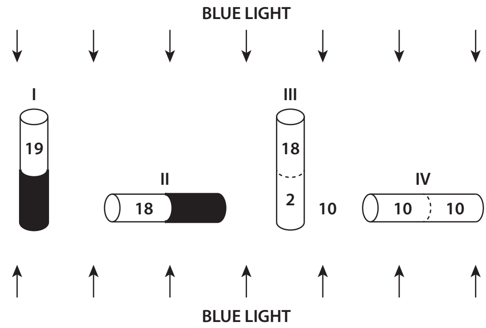
b. most flies did not go to the bottom of Tubes I and III.

c. the flies need light to see and must fly against gravity.

d. the majority of flies are in the upper ends and in the lighted ends of the tubes.

e. some flies are in both ends of each tube.

13. In a second experiment, a different kind of fly and blue light was used. The results are shown in the drawing.



These data show that these flies respond to (respond means move to or away from):

a. blue light but not gravity

b. gravity but not blue light

c. <u>both blue light and gravity</u>

d. neither blue light nor gravity

14. *because*

a. some flies are in both ends of each tube.

b. the flies need light to see and must fly against gravity.

c. the flies are spread about evenly in Tube IV and in the upper end of Tube III.

d. <u>most flies are in the lighted end of Tube II but do not go down in Tubes I and III</u>.

e. most flies are in the upper end of Tube I and the lighted end of Tube II.

15. Six square pieces of wood are put into a cloth bag and mixed about. The six pieces are identical in size and shape, however, three pieces are red and three are yellow. Suppose someone reaches into the bag (without looking) and pulls out one piece. *What are the chances that the piece is red?*

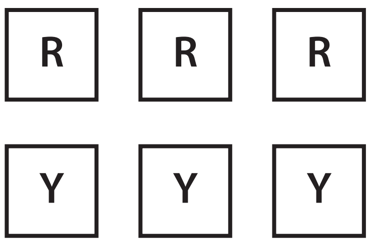
a. 1 chance out of 6

b. 1 chance out of 3

c. <u>1 chance out of 2</u>

d. 1 chance out of 1

e. cannot be determined



16. *because*

a. 3 out of 6 pieces are red.

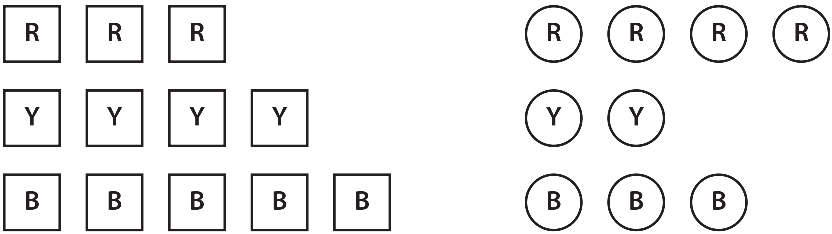
b. there is no way to tell which piece will be picked.

c. only 1 piece of the 6 in the bag is picked.

d. all 6 pieces are identical in size and shape.

e. only 1 red piece can be picked out of the 3 red pieces.

17. Three red square pieces of wood, four yellow square pieces, and five blue square pieces are put into a cloth bag. Four red round pieces, two yellow round pieces, and three blue round pieces are also put into the bag. All the pieces are then mixed about. Suppose someone reaches into the bag (without looking and without feeling for a particular shape piece) and pulls out one piece.



What are the chances that the piece is a red round or blue round piece?

a. cannot be determined

b. 1 chance out of 3

c. 1 chance out of 21

d. 15 chances out of 21

e. 1 chance out of 2

18. *because*

a. 1 of the 2 shapes is round.

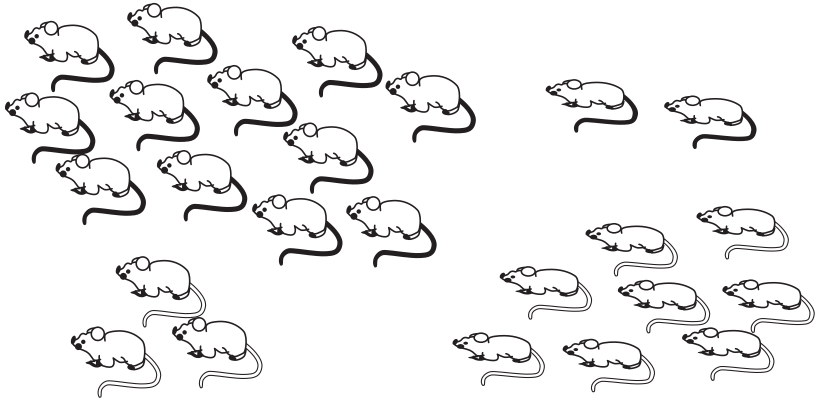
b. 15 of the 21 pieces are red or blue.

c. there is no way to tell which piece will be picked.

d. only 1 of the 21 pieces is picked out of the bag.

e. 1 of every 3 pieces is a red or blue round piece.

19. Farmer Brown was observing the mice that live in his field. He discovered that all of them were either fat or thin. Also, all of them had either black tails or white tails. This made him wonder if there might be a link between the size of the mice and the color of their tails. So he captured all of the mice in one part of his field and observed them. Below are the mice that he captured.



Do you think there is a link between the size of the mice and the color of their tails?

a. <u>appears to be a link</u>

b. appears not to be a link

c. cannot make a reasonable guess

20. *because*

a. there are some of each kind of mouse.

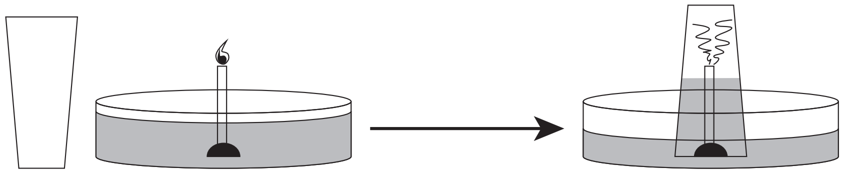
b. there may be a genetic link between mouse size and tail color.

c. there were not enough mice captured.

d. <u>most of the fat mice have black tails while most of the thin mice have white tails</u>.

e. as the mice grew fatter, their tails became darker.

21. The figure below at the left shows a drinking glass and a burning birthday candle stuck in a small piece of clay standing in a pan of water. When the glass is turned upside down, put over the candle, and placed in the water, the candle quickly goes out and water rushes up into the glass (as shown at the right).



This observation raises an interesting question: Why does the water rush up into the glass?

Here is a possible explanation. The flame converts oxygen into carbon dioxide.

Because oxygen does not dissolve rapidly into water but carbon dioxide does, the newly formed carbon dioxide dissolves rapidly into the water, lowering the air pressure inside the glass.

Suppose you have the materials mentioned above plus some matches and some dry ice (dry ice is frozen carbon dioxide). *Using some or all of the materials, how could you test this possible explanation?*

a. <u>Saturate the water with carbon dioxide and redo the experiment noting the amount of water rise.</u>

b. The water rises because oxygen is consumed, so redo the experiment in exactly the same way to show water rise due to oxygen loss.

c. Conduct a controlled experiment varying only the number of candles to see if that makes a difference.

d. Suction is responsible for the water rise, so put a balloon over the top of an open-ended cylinder and place the cylinder over the burning candle.

e. Redo the experiment, but make sure it is controlled by holding all independent variables constant; then measure the amount of water rise.

22. What result of your test (mentioned in #21 above) would show that your explanation is probably wrong?

a. <u>The water rises the same as it did before</u>.

b. The water rises less than it did before.

c. The balloon expands out.

d. The balloon is sucked in.

23. A student put a drop of blood on a microscope slide and then looked at the blood under a microscope. As you can see in the diagram below, the magnified red blood cells look like little round balls. After adding a few drops of salt water to the drop of blood, the student noticed that the cells appeared to become smaller.

Magnified Red Blood Cells **After Adding Salt Water**

This observation raises an interesting question: Why do the red blood cells appear smaller?

Here are two possible explanations: I. Salt ions (Na^+ and Cl^-) push on the cell membranes and make the cells appear smaller. II. Water molecules are attracted to the salt ions so the water molecules move out of the cells and leave the cells smaller.

To test these explanations, the student used some salt water, a very accurate weighing device, and some water-filled plastic bags, and assumed the plastic behaves just like red-blood-cell membranes. The experiment involved carefully weighing a water-filled bag, placing it in a salt solution for ten minutes and then reweighing the bag.

What result of the experiment would best show that explanation I is probably wrong?

a. the bag loses weight

b. the bag weighs the same

c. the bag appears smaller

24. *What result of the experiment would best show that explanation II is probably wrong*?

a. the bag loses weight

b. the bag weighs the same

c. the bag appears smaller

Results

46 students completed the entire pre-test and post-test. The preliminary analysis showed that, on average, students gave 51.3% correct answers in the pre-test and 74.8% in the post-test. Therefore, it can be concluded that on average the students' scientific reasoning skills increased by 23.5%.

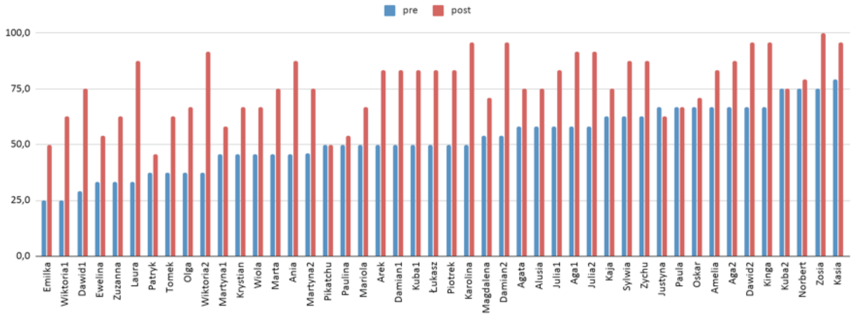


Fig. 1. Results of the pre-test and post-test of individual students.

The lowest pre-test result was 25% and the highest was 75%. In contrast, in the post-test, the lowest score was 50% and the highest was 100%. The highest increase in students between pre- and post-test was 54.2% and the lowest was -4.2%.

In the pre-test, question 1 turned out to be the easiest for the students. The most difficult question was question 11. Also, questions 5, 13 and 23 made the pre-test very difficult for the students. Questions 1, 2, 16 and 19 proved to be the easiest in the post-test. All the examined students answered them. And the most difficult question was question 12. Only 18 students answered it correctly.

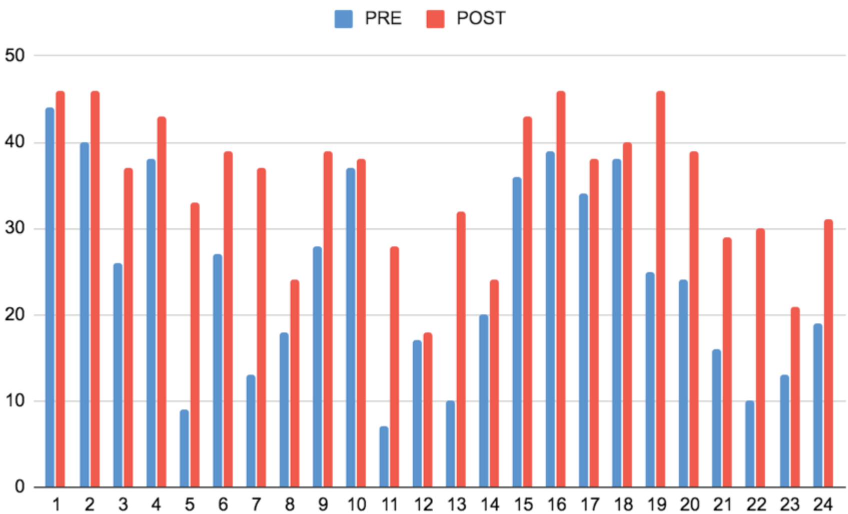


Fig. 2. The number of correct answers to particular questions.

However, the ability to reason mathematically implies not only choosing one correct answer out of many possible answers but also its correct justification. Detailed analysis of the answers to individual questions, in this case, looks a bit different. In the chart below, the answer to the question and the rationale are grouped together. The task was considered completed if the correct answer to the question was selected and the correct justification was indicated.

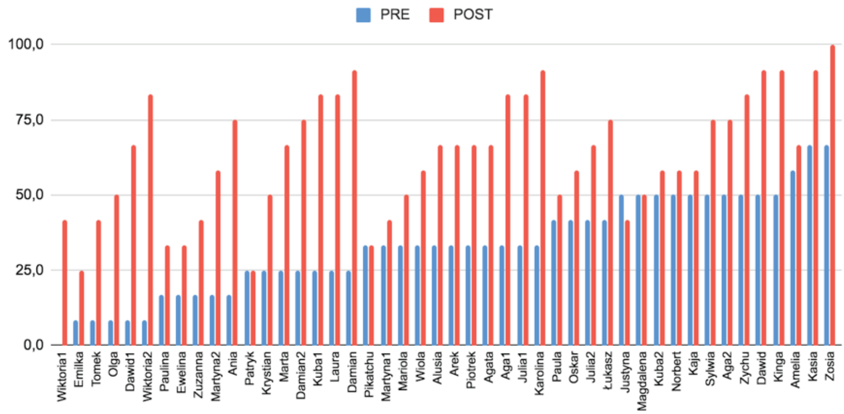


Fig. 3. Percentage of correct answers of individual students (the answer was considered correct if the correct answer to the question was selected and the correct justification was indicated).

In this case, the differences between the students' skills in the pre-test and the post-test are even more visible. In the pre-test, one student did not answer any of the grouped questions correctly. Five people obtained only 8.3% of correct answers and justifications. The next five obtained 16.7%. Seven people obtained 25% and eleven 33.3%. The next four students obtained 41.7%. That is, a total of thirty-three students (which constitutes 71.7% of the respondents) obtained a result below 50%. Ten people obtained 50%, and only three students obtained a result above 50% (one at 58.3% and two at 66.7%). The highest result achieved was 66.7%.

The students achieved much better results in the post-test. The lowest result was 25%. Two students achieved this result. The next three students obtained 33.3%, and 41.7% obtained five students. So only ten students were below the 50% limit (21.7% of the respondents). Five students obtained 50%, six students 58.3% and eight 66.7%. Another seventeen students (40%) achieved results higher than those in the pre-test (five achieved 75%, six 83.3%, five 91.7% and one 100%).

Analyzing the answers to individual questions, it can be noticed that choosing the correct answer and justifying it was easiest in the case of question 1 and justification 2. Both in the pre-test and post-test, most students answered correctly to this pair of questions. This seems obvious in the light of Piaget's theory. During its development, the child successively achieves an understanding of invariants. The understanding of number constancy appears the earliest. Subsequently, there are mass, surface and liquid quantity invariants. At the latest, the child achieves an understanding of the constancy of weight and quantity of solids. However, at the age of 12 (this was the age of the youngest student) the child is already at the stage of formal operations and 'invariants' are not a problem for him.

The following pairs turned out to be the most difficult in the pre-test:

- 11 and 12 (only 3 students answered correctly and justified their answer),
- 21 and 22 (4 students),
- 7 and 8 (5 students),
- 5 and 6 (6 students),
- 13 and 14 (6 students),
- 23 and 24 (7 students).

In the post-test, fewer than 20 students answered pairs 11 and 12, 13 and 14, 23 and 24 correctly.

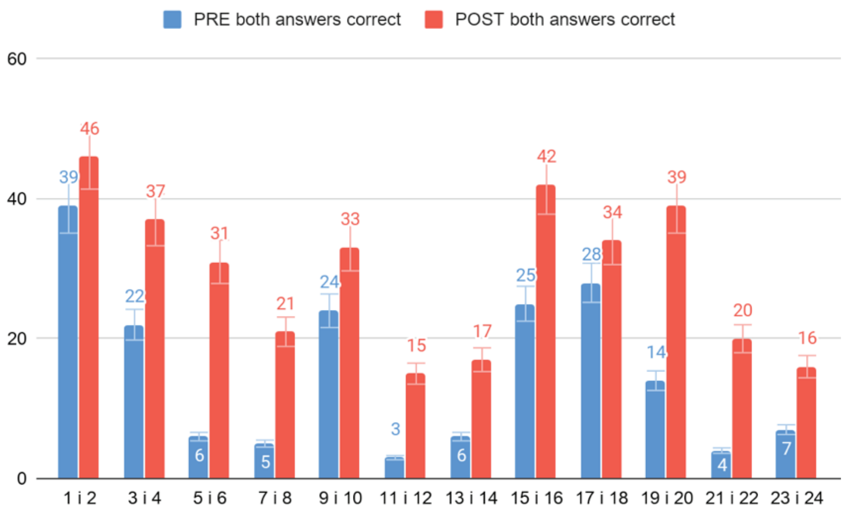


Fig. 4. The number of correct answers to a grouped question (question and justification).

Tasks 5 and 6, as well as 7 and 8, also refer to invariants (volumes of liquids), but in order to correctly answer these questions, one needs to be able to calculate the proportion. What many students could not do before the workshops.

Questions 11 and 12, as well as 13 and 14, require determining the behaviour of flies under the influence of 2 factors described in 4 pictures. These tasks seem too difficult for students. For questions 23 and 24, the difficulty probably was the formulation of the questions: Which result of the experiment would best show that the 'explanation I' is probably incorrect? Which test result would best show that 'explanation II' is possibly incorrect? The phrase "possibly incorrect" could be misleading.

Discussion of the results

The obtained data allow for the conclusion that hypothesis 1 was refuted. Despite more than 6-7 years of primary school education, students cannot think scientifically. However, hypothesis 2 was confirmed. Three-day workshops focused on the development of scientific thinking increased this competence in the surveyed students (on average from 51.3% correct answers in the pre-test to 74.8% in the post-test). The results obtained are slightly lower than those obtained by foreign researchers. Research using Lawson's tests conducted by Coletta and Pillips (2005) showed that:

- students obtaining an average result of 58% knowledge achieved an average result of Lawson tests of 91%,

- while the weaker students, whose average result from the knowledge test was 45%, obtained the average from the Lawson test 69%.

The results presented by Pyper (2011) show the achievements of physics students - the threshold above 80%. Despite this, their results were mostly lower than those of students participating in the Pyper (2011) and Coletta and Pillips (2005) studies. The average student score in the Musheno and Lawson (1999) study was 88%.

However, it should be taken into account that the present study was attended by primary school students who still had 6 years of education before they started their studies.

The effectiveness of the workshops for primary school students is also confirmed by comparing their results with the results of teachers (biology, chemistry and physics). These teachers took part in a five-day training course in IBSE methodology implemented under the SAILS project. As you can see in the chart below, the training did not bring the expected results - teachers' scientific thinking skills did not increase (and in the case of physics teachers, they even decreased!). On average, the teachers scored lower on the post-test than the students.

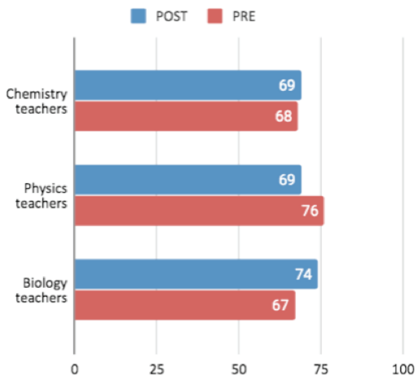


Fig. 5. Lawson test results for teachers before and after the five-day training in IBSE methodology as part of the SAILS project. (wwwl).

Reflections

The obtained results may evoke mixed feelings. On the one hand, the effect of the three-day workshop is a spectacular increase in the scientific thinking skills of students (23.5%). On the other hand, there is a question about the effectiveness of primary school education in Poland. It turns out that 3 days (19 clock hours) of informal education gives a better effect than 6-7 years of formal education (at school). So 25 lesson hours (45 minutes each) in the form of workshops taught students more than 900 hours of mathematics, chemistry, biology, physics and nature!

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HIGH SCHOOL CHEMISTRY TASKS FOR IBSE

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Abstract

Inquiry based science education (IBSE) is one of the novel methods in science education. We dealt with the role of motivation and the influence of the choice of an attractive topic in the IBSE over traditional teachnig as part of the pedagogical experiment in grammar school. Pupils and students were divided into two experimental groups. The first group has been solving tasks with the methodes of IBSE, the second group was taught by the means of traditional teaching with attractive topic. We measured students' factical knowledge and skills before and subsequently after the experimantal teaching lesson. Pretests and posttest were created, including the research-oriented tasks in the field of high-school chemistry. We emphasised interdisciplinarity and connection with everyday life, applicability and topicality of the learned matter. In this contribution the topic of antioxidants (reactivity, stability of atoms and molecules, octet rule, radicals and resonance) from the general chemistry point of view will be presented.

Key words

attractiveness of the topic, inquiry based science education, pupils' motivation, pedagogical experiment

Background, framework and purpose

It appears that presenting findings in the form of facts does not lead to knowledge, skills and competences of pupils in the 21st century (Pellegrino, 2012). This crisis and insufficient interest in courses representing natural sciences is often associated with low motivation on the part of pupils, the growing number of findings, inadequately perceived relevance and particularly the manners which are used to teach natural sciences in schools. Although the taught information is perceived by the pupils as important for the society, they still consider is unnecessary for their everyday life (Rocarkol, 2007; Osborne, et al. 2008; Janoušková, 2008).

The solution for this problem may be found in Inquiry based science education (hereinafter the "IBSE"). The emphasis is put on the pupil's activity in cooperation with a teacher. Various teaching strategies of active schooling are used while the pupils develop their knowledge and skills on the basis of solving problems, learning how to form questions and hypotheses, exploring facts, gathering data and their interpretation. The goal is to prepare the pupils for the real life, to teach them how to solve problems, to reach correct conclusions including the improvement of their emotional and social capacity. When it comes to the Bloom's taxonomy, these activities mainly include the development of higher cognitive levels – analyses, synthesis and assessment (Papáček, 2010; Dostál, 2013a, b). However, also this modern trend has found its critics who mainly point out the risk of reaching incorrect conclusions, the uneven level of involvement of pupils or the time demands (Kirschner et al. 2006; Hmelo-Silver et al., 2006). The key element for the IBSE effectiveness is motivation (Škoda et al., 2015). A question presents itself in this matter – whether the solution is just to develop the initial motivation within the classic teaching (i.e. to apply just the first IBSE phase), and thus to prevent the negatives associated with the IBSE.

Methods

Therefore, by using the method of pedagogical experiment, we have decided to assess what role do the selection of an attractive topic and the motivation play in the IBSE for pupils in the 4-year programs at grammar schools. For the experimental group (class), the lessons proceeded in the form of IBSE. For the control group (class) the lessons proceeded in the traditional transmissive method, however, with the initial development of motivation and activization of pupils while the given topic was introduced to them. For the purposes of the pedagogical experiment, a series of assignments was created for the IBSE (Hurný et al, 2020).

In this article, the first assignment titled 'From the atoms, through the compounds up to antioxidants – that all is the miraculous Vitamin C', which included the topics of reactivity, stability of particles, the octet rule, the polarity of bonds, radicals, and the resonance. When processing the topics by using the IBSE, the emphasis was placed on the mentioned interdisciplinarity, applicability and usefulness, drawing the topic closer to real life, using modern technologies and being up to date. At the same time, the proper order of 5 steps was also respected during this assignment (engage, explore, explain, elaborate, evaluate).

Structure of the assignment

The following series of tasks aims at allowing the pupils to discover the association between the reactivity of selected elements, their electron configuration and location in the periodic table of elements to begin with. Thereupon, the second part focuses on the stability of particles, free radicals and antioxidants. Initially, the motivation is supported by demonstrative experiments (sodium and potassium reacting with water) and by a video demonstration via a part of the All Quiet on the Western Front (referring to the use of chlorine during a gas attack in the course of World War I). This section is followed by a set of motivational questions.

The next phase requires from the pupils to read the text and complete the assigned tasks. They are allowed to use modern technologies during the process – internet resources, scientific articles and other sources of information such as tables and charts (similarly as researchers or scientists do). On the basis of uncovered facts and by using instructive questions, the define the hypothesis itself (the dependence of the reactivity on the electron configuration and the proton number in the group) which they then verify in a theoretical manner (they look the predicted hydrides in scientific literature) and an experimental manner (the reactivity of calcium and magnesium with water). The second experimental task focuses on the electronegativity, or rather the electropositivity. On the basis of their hypothesis, the pupils predict the distribution of elements based on their electronegativity, and then verify it through an experiment focusing on the polarity of a bond. While doing so, they use the fact that chloride ions may be demonstrated by using the $AgNO_3$ agent.

The second assignment is related to antioxidants and radicals. At the beginning, an article is presented to the pupils which originated at Novinky.cz, titled ‘Why is a diet rich in antioxidants so important for us?’ Furthermore, the teacher shall cut an apple in half early in the class and instructs the pupils to monitor the changes which start happening on its surface. Thereupon, the phase of presenting motivational questions follows (Where do the given radicals come from and how can we get rid of them effectively? Are antioxidants good for anything? Do antioxidants actually come from nature? …). The first task: working with a scientific text. The pupils are tasked to read a modified expert article handling the topic of radicals in the human body and the meaning of maintaining them in balance. They shall identify the opportunities for applying peroxide radicals when disintegrating the hydrogen peroxide as a disinfectant. An exploratory assignment follows which tasks the pupils with searching for a way to protect the apple from getting brown (by restricting its contact of oxygen, protection by using antioxidants or through inhibition of enzymes). Upon being instructed by the teacher, they shall choose the way of antioxidant protection and propose an experiment to verify such method. While handling the following issue, the pupils shall identify food which contains high amounts of Vitamin C and then verify its presence by experiments (lemon juice, red wine, Celaskon…). The second exploring activity focuses on the chemical basis – reductional effects of the ascorbic acid. The pupils shall make the ferric ions and ferrous ions react with selected agents and observe the characteristic changes in colors. Thereupon, they shall propose an experiment which will be able to verify the effects of Vitamin C. The last section is dedicated to temperature stability during which the pupils shall predict the consequences of heat treatment of foods containing Vitamin C. Thereupon, they shall verify this fact by another experiment.

The details resulting from the application of the task itself (comparing the experimental and control groups) are presented in a separate publication (Hurný et al., 2018; 2020).

Conclusion

For the purposes of a pedagogical experiment whose goal is to verify the role which motivation plays in the IBSE, we have prepared a set of explorational activities. In this article, the first assignment titled 'From the atoms, through the compounds up to antioxidants – that all is the miraculous Vitamin C!' was introduced. The goal was to connect unusual topics and to apply the modern approach of the IBSE to solving problematic and abstract passages of chemistry classes at grammar schools.

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Appendix

From the atoms, through the compounds up to antioxidants – that all is the miraculous Vitamin C!

1http://www.simonavignali.com/vitamin-c-a-powerful-natural-antioxidant.html

Part A

a) Watch the initial demonstrational experiment and a video.

Initial demonstrational experiment (and potentially also a video): reaction of sodium with water, reaction of potassium with water, a scene from the movie titled All Quiet on the Western Front.

Motivational questions: Why do some elements occur independently and other exclusively as parts of compounds? Why does the reaction of sodium with water proceed in such a rapid manner, even though noble gases usually are non-reactive? Why do individual elements combine with other elements in various ratios? Can we find general trends in the behavior of elements? Which hybrids will be created by elements of the 5th and 6th A group? Which ions will be created?

b) Read the following information on selected elements.

Elements of the I. A group (alkali metals)

Since alkali metals are very reactive, we can only find them in nature in the form of compounds ($NaCl$, $NaOH$, KOH…). They are strong reducing agents and create hybrids together with the hydrogen in the MeH formula. They react with water creating hydrogen and the given hydroxide.

Elements of the II. A group (alkaline earth metals)

Group II. A (or IIA) of the periodic table are the alkaline earth metals: beryllium (Be), magnesium (Mg), calcium (Ca), strontium (Sr), barium (Ba), and radium (Ra). They are harder and less reactive than the alkali metals of Group 1A. They are usually found in compounds (CaO, MgO, $CaCO_3$…). Group II. A combine with hydrogen to form hydrides (the general formula being MeH_2).

Elements of the II. A group (halogens)

The halogens do not occur in the free elemental state because of their reactivity, but they are both widespread and abundant in the form of their ions X- (KF, NaCl…). Chlorine gas was first used as a weapon on April 22, 1915, at Ypres by the German Army. Each of the halogens forms a binary compound with hydrogen, HX.

Elements of the IV. A group

Group IV. A of the periodic table includes the nonmetal carbon (C), the metalloids silicon (Si) and germanium (Ge), the metals tin (Sn) and lead (Pb). Diamond is the name given to one of the naturally occurring forms (allotropes) of pure C. The other allotropes of carbon are graphite, and various fullerenes. Carbon and silicon can form ionic compounds by gaining four electrons, forming the carbide anion (C^{4-}) and silicide anion (Si^{4-}), but they more frequently form compounds through covalent bonding. They are not very reactive. Carbon and silicon combine with hydrogen to form hydrides (methane CH_4 and silane SiH_4).

Elements of the IV. A group

Group VIII.A of the periodic table are the noble gases or inert gases: helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe), and radon (Rn). The name comes from the fact that these elements are virtually unreactive towards other elements or compounds. Group VIII. A elements are all colorless, odorless, monatomic gases.

c) Complete any missing data in the table (you shall find the necessary information in the table or on the internet).

Element/ion	Electron configuration	number of valence electrons	Ionization energy*	common oxidation states
Na				
K				
Na^{+}			--	--
K^{+}			--	--

* Ionization energy is the minimum amount of energy required to remove the most loosely bound electron of an isolated neutral gaseous atom or molecule.

Element/ion	Electron configuration	number of valence electrons	Ionization energy*	common oxidation states
Mg				
Ca				
Mg^{2+}			--	--
Ca^{2+}			--	--

Element/ion	Electron configuration	number of valence electrons	Ionization energy*	common oxidation states
F				
Cl				
F^{-}			--	--
Cl^{-}			--	--

Element/ion	Electron configuration	number of valence electrons	Ionization energy*	common oxidation states
C				
Si				
C^{4-}			--	--

Element/ion	Electron configuration	number of valence electrons	Ionization energy*	common oxidation states
He				--
Ne				--

d) Compare the manner in which individual elements behave – in which oxidation numbers does the given element take place most often?

Na, K:

Ca, Mg:

F, Cl:

C, Si :

He, Ne:

e) To which do the electron configuration of the given ions in task c) correspond?

Na^{+}

K^{+}

Mg^{2+}

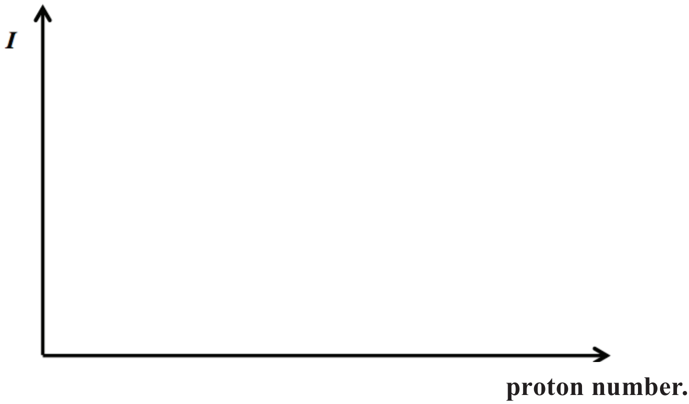
Ca^{2+}

F^{-}

Cl^{-}

C^{4-}

f) Complete the following chart with the dependence of the values of ionizing energies / to the proton number.



g) On the basis of the above-mentioned obtained information, try to determine on which the reactivity of elements in the periodic table of elements is based – define a hypothesis.

Hypothesis:

h) Which hydrides shall by created by the elements of the 5th and 6th A group on the basis of your hypothesis? Which ions shall be created? Which elements will have the tendencies to become reducing (provide electrons)/oxidizing (receive electrons) agents? Include your predictions in a table and then verify via expert literature.

	Your predictions	Verify via expert literature
Hydrides of the V. A group		
Hydrides of the VI. A group		
Elements -reducing agents		
Element - oxidizing agents		

i) Now, try to verify the validity of your hypothesis by using a properly chosen experiment by example of magnesium and calcium (you may find some inspiration in the initial demonstrational experiment with sodium).

Element	Electron configuration	Products of reaction with water		Increase in reactivity	
		Hypothesis	Experiment	Hypothesis	Experiment
Mg					
Ca					

j) Supply some chemical equations which shall take place during your experiment.

$Mg + H_2O \rightarrow$

$Ca + H_2O \rightarrow$

k) Electronegativity means the ability of atoms to draw binding electrons. It is marked by a capital X and there is no unit for it. On the basis of your hypothesis, try to predict which elements will bear a high level of electronegativity and which, on the contrary, will demonstrate a low one. Include the following elements in the table: Cl, Na, F, O, N, K, Ca, C.

Electronegativity	Elements
High values of electronegativity	
Low values of electronegativity	

l) This ability of elements affects the arrangement of electrons in the bond between bound atoms. There are three basic types of bonds: nonpolar, polar and ionic – depending on the difference of electronegativity of the combined atoms.

Type of bond	The difference of elektronegativity		Description
Nonpolar	$\Delta X < 0,4$	A - B	Electrons are shared equally by the bonded atoms.
Polar	$0,4 < \Delta X < 1,7$	$A^{\delta +}- B^{\delta -}$	The bonded atoms have an unequal attraction for the shared electron.
Ionic	$\Delta X > 1,7$	$A^{+} + B^{-}$	Electrons are completely transferred from one atom to another, forming ions.

Based on your distribution of elements due to their electronegativity, you shall find the bond type which binds the chlorine atom in hydrogen chloride, sodium chloride, monochloroacetic acid and trichloromethane. On the basis of this answer, try to predict which of the specified substances are ionized in water while chloride ions are being released. You shall verify your predictions in an experimental manner. As your assistance, use the information that the presence of the Cl- ions may be demonstrated by using the AgNO3 agent while a white precipitate emerges which then gradually gets darker and darker.

Compounds	Hypothesis		Experimental results		Verify your predictions
	Type of bond	Ionization to Cl^{-}	Water solubility	Proof of ions Cl^{-}	
NaCl					
HCl					
$CH_2ClCOOH$[b)]					
$CHCl_3$					

b) the experiment is performed by the teacher

m) In conclusion, you shall assess on the basis of your experiments whether you were able to verify the validity of your hypothesis.

Part B

a) In chemistry, we do not only meet atoms or ions, but also the so-called radicals. To begin with, read the following article from Novinky.cz:

Proč je pro nás jídelníček bohatý na antioxidanty tak důležitý

4. 10. 2017, 7:21 - das, Novinky

Facebook Twitter

Znečištěné prostředí, sluneční záření, stres, nesprávný životní styl, kouření, konzumace alkoholu, nevhodná strava, nedostatek aktivního pohybu, nebo naopak namáhavé pohybové aktivity. To vše jsou faktory, které stojí za vznikem celé řady civilizačních chorob v důsledku nadměrného množství volných radikálů v organismu a škodlivého oxidačního stresu. Přitom existují přírodní látky - antioxidanty, které si s volnými radikály dokážou poradit.

https://www.novinky.cz/zena/zdravi/clanek/proc-je-pro-nas-jidelnicek-bohaty-na-antioxidanty-tak-dulezity-40044941

Where do the given radicals come from and how to get rid of them effectively? Are antioxidants good for anything? Do antioxidants actually come from nature? Do you know what is the connection between the apples getting brown and antioxidants?

b) Read the following scientific article about radicals in a human body:

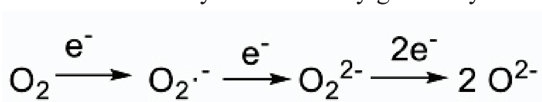
Why do we need oxygen at all?

The transformation of electrons from organic substances to oxygen releases a huge amount of energy which we need to live. We can describe this process through a reaction:

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$

During these processes, free radicals may be created. A free radical is any particle capable of independent existence which has one or two unpaired electrons. In our organism, oxygen is transformed from its so-called reactive form (ROS – reactive oxygen species): hydroxide-based (·OH), hydroxoperoxyde-based (·OOH), superoxide-based (O_2•$^-$) and other.

These radicals may be derived by gradually reducing the oxygen:



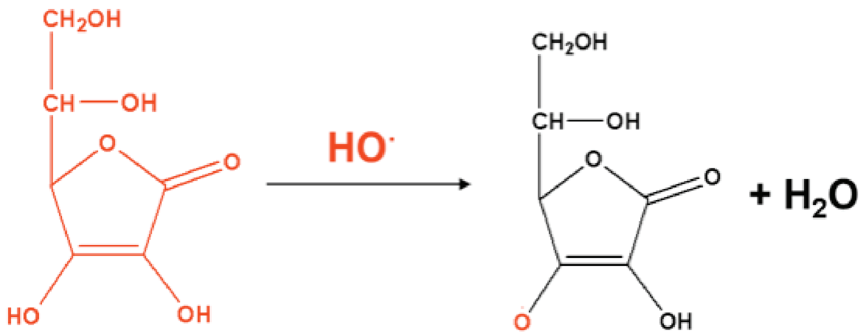
The ROS easily emerge from the hydrogen peroxide which is, at the same time, a by-product of a number of metabolic reactions in a living organism (most often, the ROS emerge in the respiratory chain). However, the ROS are compounds which are both harmful and beneficial for living beings. Therefore, our organism has to regulate the number of ROS and maintain them in balance, namely by using antioxidants which are substances protecting us from oxidative damage. If this balance is violated, then the so-called oxidative stress occurs (the disbalance between the production of free radicals and antioxidants). As for positive effects, these mainly include the defensive function against bacteria, antigens, parasites, etc.

The ROS also play the role during the process of a sperm fertilizing an egg. The superoxide and the hydrogen peroxide are necessary for the sperms. The superoxide is necessary for breaching an eggs membrane. The peroxide is created in the egg after it had been fertilized and prevents other sperms to enter it. The negative effects may manifest themselves in the form of protein deformation, lipid oxidation, DNA damage, emergence of cancer-based diseases or atherosclerosis. The number of the ROS is regulated by the organism by using antioxidants which then neutralize or stabilize the ROS. The molecules which create the radicals in a resonance or steric stabilized manner are then much less reactive than the original ROS and they are then unable to damage key cell structures.

c) However, we can also use the reactivity of peroxide radicals. Can you identify a substance called A_2B_2 which provides peroxide radicals in the form of dissociation in the presence of blood? Specify the dissociation in the form of a chemical equation. For what purposes is this substance used?

d) Now, we can move forward to see how is this related to the antioxidants mentioned at the beginning and the apples getting brown.

Vitamin C



One of significant antioxidants is Vitamin C – ascorbic acid. The ascorbic acid reacts with free radicals which cause oxidation. It oxides in the form of losing one electron for each radical ion. This reaction of the ascorbic acid

$H_2A + H\text{-}O\bullet \rightarrow HA\bullet + H\text{-}OH$

(H_2A) with a radical (R-O•) may be illustrated in the form of an equation. The emerging ascorbyl-radical is not able to case any further chain reaction (due to a resonantly stabilized nature of its own radical ion). The ascorbic acid is thermally unstable and it is disintegrated under temperatures above 50% while carbon dioxide appears (decarboxylation). Phenolic substances are located in plants and fruits which are phone to oxidation while quinones are being created which then further react with amino acids and proteins or polymerize spontaneously. The emerged products are colored in brown. The given oxidation is catalyzed by the polyphenoloxidas enzyme (peptide) which forms a natural part of plant cells.

e) How would you prevent an apple from going brown? Write down three manners (use the information specified above and do not forget that the polyphenoloxidase enzyme is a peptide).

1)

2)

3)

f) Propose experiments which would assist you in verifying the chosen manners. Based on the instruction of your teacher, proceed with the chosen approach.

Experiment: ...

g) Search the internet for the maximum of food which contains Vitamin C (common foods) and which label is used for Vitamin C when it is included as an additive – the so-called E….

Food which contains Vitamin C :

Label for vitamin C: E

h) Perform an experiment with other goods which are available to you and verify whether they actually contain any Vitamin C. Define a principle/hypothesis of such an experiment.

Principle/hypothesis:

Experiment:

i) Choose the correct variant: Vitamin C prevents oxidative reacts by oxidizing/reducing itself and causing the reduction/oxidation of other substances.

Now, we shall verify the given statement by a chemical experiment. Let's use the following fact. Fe^{2+} and Fe^{3+} ions (i.e. oxidative and reduced forms) lead to reacts of different colors with selected agents: potassium hexacyanoferrate (red blood salt) and potassium thiocyanate. Now, your task is to propose two experiments which will allow you to verify that Vitamin C has reductive effects. (For your assistance – verify at first which agents reacts with Fe^{2+} and Fe^{3+} ions).

Ion	Potassium hexacyanoferrate	Potassium thiocyanate.
Fe^{2+}		
Fe^{3+}		

j) How may the information acquired via the table above be used to prove the reductive effect of the ascorbic acid? (For your assistance: Consider the reduction of Fe^{3+} to Fe^{2+}).

Hypothesis:

	Hypothesis		Experiment	
Ion	Potassium hexacyano-ferrate	Potassium thiocyanate	Potassium hexacyano-ferrate	Potassium thiocyanate
Fe^{3+} with vitamin C				
Verify the validity of your hypothesis:				

k) Vitamin C is included in fruit and vegetables. However, when we prepare meals from them, these raw materials are often treated by heat. How can heat treatment affect the antioxidizing nature of Vitamin C? Propose an experiment which can support your hypothesis.

Principle/hypothesis:

Experiment:

Results and verify the validity of your hypothesis:

We learn from errors and mistakes

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Abstract

It seems that in school practice, wrong answers are too rarely used for educational purposes (Metclafe, 2017). Students' errors analysis can be very often an added value in the learning process. In this study we have dealt with incorrect answers of students in the test tasks.

We analyzed four selected units in science literacy and reading performance domains from the PISA (Programme for International Student Assessment, OECD) survey. Two categories of response format were used in this study: for the closed-ended questions - simple multiple choice (selection of a single response from four options) and open-ended questions for constructed response (items calling for written response). In the multiple-choice closed tasks, the percentage of students responses in each option was compared. In closed items it was discussed what information can be obtained about pupils skills or misconceptions by analyzing the choice of a given answer. In open assignments requiring pupils answers, the answers are sorted into error categories and possible causes of incorrect answers are discussed. The analyzes showed a number of concrete possibilities to use the results of students responses for teaching purposes.

Key words

PISA, science items, mistakes, survey

Background, framework and purpose

It seems that in school practice wrong answers are too rarely used for educational purposes (Metclafe, 2017). Students' errors analysis can very often be an added value in the learning process. We can say students have even right for making mistakes. It means they may choose wrong ways when they look for solution in the process of solving any problems. If they ask the scientific questions, they have to check various answers. The most important is trying and verifying hypothesis. In the scientific experiments making errors is a necessary risk in the job. We can even say it is a fuel that may be used to learn more in the future. The same is in a text interpretation, mathematical proving or making conclusions in history. The didactics based on the right answers can be used in teaching ready-to-use knowledge but is not useful in practicing an independent and individual thinking. There is one condition: we have to think, analyse and try to understand our mistakes.

The right for making mistakes is tied with the emotions. It's obvious that everybody fears errors. But, what is a paradox, experiencing faults is a perfect 'tool' for developing thinking. It is effective to memorise the way of searching solutions if we pass it independently with a risk of failure. The involving emotion in the intellectual work can very effective in learning solving scientific problems.

It is important in didactics but it can be especially interesting in using tests. Both: in diagnostic and in teaching process. Often teachers use tests only for diagnostic. They forget about another role of tests. An analysis the various ways of working out the tasks can be useful in searching answers for question on the right modes of solving problems and looking for students' misconceptions (Chrzanowski, Grajkowski, Żuchowski, Spalik, Ostrowska 2018; Markowska, Lechowicz, Grajkowski, Chrzanowski, Spalik, Borgensztajn, Ostrowska, Musialik 2014).

Teacher when preparing a tasks should be aware of the possibilities in the ways of students thinking. The distractors should be not only the wrong answers, they should be the results of unproper modes of understanding tasks and texts or considering scientific problems as well. The analysis of the wrong students' choices may give us two main benefits:

• for a teacher – an answer to the question what are the sources of students' failures,

• for a student – help in understanding what are the correct ways of thinking and why the other ways are wrong.

In this study we have dealt with incorrect answers of students in the test tasks. We analysed some selected units in science literacy and reading performance domains from the PISA (Programme for International Student Assessment, OECD) survey (OECD, 2019; Sitek, Ostrowska, 2020). Three selected items are presented and and discussed:

• Tobacco Smoking (OECD, 2009) and

• Genetically Modified Crops in the science category (OECD, 2007),

• Tall Buildings in their reading category (OECD, 2009).

Of course, the tasks from the PISA survey are only an example. Although the tasks presented here are available to the public (in contrast to most PISA tasks), teachers rarely make use of them because they are treated as an element of the survey rather than of the teaching source. However, they can be an interesting example, because they were created according to patterns that are used in developing tools for testing students' skills, both in school practice and during exams (Chrzanowski, Ostrowska, 2018). Each of the tasks is part of a larger bundle.

ITEM 1: TOBACCO SMOKING

Some people use nicotine patches to help them give up smoking. The patches are attached to the skin and release nicotine into the blood. This helps to relieve cravings and withdrawal symptoms when people have stopped smoking. To study the effectiveness of nicotine patches, a group of 100 smokers who want to give up smoking is chosen randomly. The group is to be studied for six months. The effectiveness of the nicotine patches is to be measured by finding out how many people in the group have not resumed smoking by the end of the study.

Which one of the following is the best experimental design?

A. All the people in the group wear the patches.

B. All wear patches except one person who tries to give up smoking without them.

C. People choose whether or not they will use patches to help give up smoking.

D. Half are randomly chosen to use patches and the other half do not use them.

The task is designed to check if the student is aware of how the scientific method works. Choosing one of the distractors, and thus making a mistake, means that the examinee does not know which method of conducting the experiment is the best, that is which one gives reliable conclusions.

In this context the analysis of errors is important for the learning-teaching process.

Tobacco smoking - errors types:

• The idea of testing the patches by giving them to everyone will not give any answer to the question of the effectiveness of the patches - it does not differentiate anything, the study group has no reference group.

Why did the student decide that everyone should wear patches in the experiment? At least two explanations are possible. The first one concerns the text about the experiment and the task itself. The text only says that a hundred people will participate in the experiment. It does not explain how the experiment will look like. It is for the student to decide which method of conducting the experiment is appropriate. If the student focuses only on the text, he or she will think that all participants will actually be wearing patches. However, for the credibility of the effect such a solution would be inappropriate, because without a control group it is impossible to assess the impact of a single variable in the form of patches. We can also find an explanation for the error which goes deeper. If the student does not have a well-established awareness of the scientific method, he can easily explain to himself that subjecting all participants to the same form of experiment will produce the expected information. If, for example, seventy out of one hundred people do not return to smoking, the student will conclude that the effectiveness of the patches is high. However, if there is no control group, we do not know whether it was the patches rather than some other factors which affected the participants. Analysing the error should lead to drawing conclusions both from the way the task is solved (understanding the text and questions) and from the awareness of what procedures are important in applying the scientific method.

• One person is not enough to make such a comparison, the results may be random (error in the control sample size).

The second error, consisting in the belief that only one person in a group of one hundred will not have a patch on, is easier to explain. A student who chooses such an answer may have some basic knowledge of the scientific method and the fact that it is necessary to introduce some sort of differentiation factor, but does not know the real meaning of the control group. Of course, such an answer may also result from inattention, but this cause is omitted here. The analysis of the error should lead to a reflection on the essence of the scientific method and on what a control group should look like, on the purpose of its introduction into the experiment, on the conclusions that can be drawn from a study in which the control group is too small (here, it consists of only one person) or non-existent.

• There may be various factors influencing the division into groups. No randomness in the selection of persons for groups, uncontrolled number of groups).

The third error also results from a miscomprehension of the scientific method. Leaving the participants of the experiment free to choose whether or not they want to put on the patches will make the result of the experiment not reliable, as the two groups cannot be compared. The student who chooses this answer probably knows that the participants of the experiment should be divided into two groups, but does not know the rules of such a division that will produce reliable conclusions.

The right answer:

• It is most sensible to randomly divide a group of 100 people in half and stick plasters on one. Random group selection, half is a control sample.

The right answer was suggested; probably some students would find it harder to describe the scientific method on their own in an open-ended task. A multiple-choice task is easier, but there is a certain amount of difficulty in it, because distractors can suggest wrong solutions. A person who knows the scientific method will choose the right answer from those suggested.

Working on errors can have not only a corrective, but also an educational function. It is necessary to check various methods of conducting the experiment given in the sentence and analyse their reliability. It is advisable to discuss what cognitive consequences result from adopting particular forms of conducting the experiment in order to demonstrate their inappropriateness.

ITEM 2: GENETICALLY MODIFIED CROPS

GM corn should be banned

Wildlife conservation groups are demanding that a new genetically modified (GM) corn be banned.

This GM corn is designed to be unaffected by a powerful new herbicide that kills conventional corn plants. This new herbicide will kill most of the weeds that grow in cornfields.

The conservationists say that because these weeds are feed for small animals, especially insects, the use of the new herbicide with the GM corn will be bad for the environment. Supporters of the use of the GM corn say that a scientific study has shown that this will not happen.

Here are details of the scientific study mentioned in the above article:

Corn was planted in 200 fields across the country.

Each field was divided into two. The genetically modified (GM) corn treated with the powerful new herbicide was grown in one half, and the conventional corn treated with a conventional herbicide was grown in the other half.

The number of insects found in the GM corn, treated with the new herbicide, was about the same as the number of insects in the conventional corn, treated with the conventional herbicide.

Question 2.1

What factors were deliberately varied in the scientific study mentioned in the article? Circle "Yes" or "No" for each of the following factors.

Was this factor deliberately varied in the study?	**Yes or No?**
The number of insects in the environment	Yes / No
The types of herbicide used	Yes / No

In most field studies, there are independent, dependent and controlled variables – parameters that can be influenced and those that are related, for example with the place of the experience or with the weather. When planning an experience, experimenter has to be aware of it. In the presented task the result of the experiment (dependent variable) is the number of insects. In order to find out if the new herbicide is more harmful to insects, scientists treated the number of insects as a variable parameter. Although the presented example refers to a specific study, the way in which reasoning is carried out is present in many everyday life issues. The students who marked Yes in the first line made the mistake of considering that scientists could change the number of insects in the environment. This type of error can be a beginning of discussions about dependent and independent variables. (OECD, 2007).

The reasons for choosing the wrong answer may be different.

1. Of course, some students probably did not understand the text or the question. The text consists of two parts. The first part presents a short article about the opponents of GM corn cultivation and their arguments. One of the arguments relates to the impact of weed-killing agents used in these crops on insects that are dying out. In the second part we have an article about a scientific experiment which aims to investigate the insect population in fields with GM and non-GM corn cultivation. The student may not understand the meaning of both articles, especially the purpose of the described experiment. However, it may also fail to understand the question where it is said that scientists deliberately differentiate certain factors.

2. However, if the student has understood both the text and the command, he or she may make a mistake due to a misunderstanding of the research question raised and the research methodology used. The aim here is to determine whether the measures used in the cultivation of genetically modified maize reduce insect populations. Therefore, the number of insects cannot, or even cannot, intentionally be differentiated. The student in this case confuses variable and constant parameters, test and differentiation factors.

Question 2.2

Corn was planted in 200 fields across the country. Why did the scientists use more than one site?

- So that many farmers could try the new GM corn.
- To see how much GM corn they could grow.
- To cover as much land as possible with the GM crop.
- To include various growth conditions for corn.

In the presented multiple-choice question, the student may solve the problem with the principle of elimination. To answer this question correctly, the student should note that the effect of different herbicides on insects also depends on environmental factors. Using 200 repetitions selected in an appropriate way increases the possibility to select factors influencing the observed process. The question concerns research methodology in terms of scientific clarification. It is worth noting that the skill measured by this question refers not only to the principles of conducting scientific experiments, but also, for example, to the principles of the scientific experimentation.

Incorrect answers may result from various reasons:

• The reliability of an experiment does not depend on how many participants could take part in it, but on the research, question posed and the methodology adopted. The student choosing this answer omits a basic foundation of the scientific method.

• The student did not understand what the research question was about. It is not the purpose of this experiment to determine how big the yields of individual fields are, but how many insects can be found on them depending on the type of crop.

• It may seem convincing that the experiment should simply be as far-reaching as possible. However, it is not the quantitative scope of the experiment itself that is important, but the advisability of the chosen solution.

ITEM 3: TALL BUILDINGS

'Tall buildings' is an article from a Norwegian magazine published in 2006.

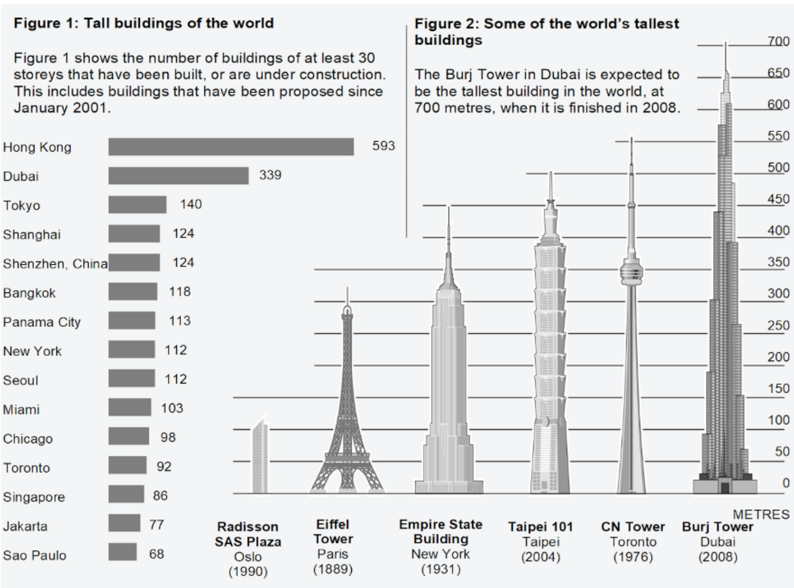

Fig. 1. 'Tall buildings' *Fig. 2. Some of the worrld's tallest buildings*

What kind of information does Figure 1 provide?

A. A comparison of the heights of different buildings.

B. The total number of buildings in different cities.

C. The number of buildings above a certain height in various cities.

D. Information about styles of buildings in different cities.

Tall buildings - errors type

The student is to understand the general, but not explicit, meaning of the text. To achieve this, he or she needs to understand the description of the drawing, but in the second step a student should make a generalisation, because the information that it is about the number of buildings exceeding 30 floors needs to be transformed into information that it is about buildings exceeding a certain height. Error analysis can help students learn to read attentively.

• The answer can only be given if a student read the command and the text carelessly. We need to look at the reason for the students inattentive reading. Of course, it can be a simple distraction. However, it is more important to look for deeper reasons for failure. It is clearly stated in the description of the drawing that it shows the number of buildings with at least 30 floors in selected cities. There is no question of comparing their height. So why could someone choose such an answer? The misunderstanding may come from the neighbouring drawing, where different buildings are presented side by side. What is important, however, is that the reader who chose this answer did not understand the description of the first drawing. Probably he did not read it to the end. In addition, only bare numbers are given and an inattentive reader can supplement them with meters or feet. A cognitive disturbance is introduced into the act of reading, consisting on the one hand in the lack of focus on the text, and on the other hand in imposing information from outside the text.

• May result from a misinterpretation of Figure 1 when it is not taken into account that only buildings exceeding 30 floors are mentioned. Also this answer is due to an inattentive reading of the description of Figure 1. However, here the reason for the miscomprehension is simpler. The reader omits an important passage saying that the number of buildings exceeding 30 floors is shown. It is a common mistake in reading when unjustified selection of information is made. In the analysis of the error, the reason for such a reading must be taken into account. It is often a hurry, but it can be a distraction or a dyslexic disorder that makes it difficult to decode the writing.

• Correct answer. The correct answer can be arrived at by understanding the description of the drawing and transferring its meaning to another form of expression, in which specific information is presented in a generalised form (certain height, various cities). It is therefore important not only to be able to understand the message (simple in this case), but also to abstract the information.

• Figure 2, which shows objects in different styles, can be misleading. This answer is possible only if you do not fully read the descriptions of the drawings, if you stop seeing them, and also if you confuse them. This would mean a very inattentive reading. It may result from a cognitive dysfunction, but it may be a result of insufficient training in the reading skills.

The analysis of errors in this case may have an important diagnostic function, as there may be various causes of failure. However, the didactic function is important. It is about learning to read carefully and accurately. The student should see what he or she omitted in the text or which part of the text he or she misunderstood. This can lead to more conscious reading. A competent reader not only gets to know the text, but also knows that any omissions, misunderstandings, assigning meanings absent in the text, imposing meanings from other texts - all these introduce a disturbance and interpreting the message in a way incompatible with its shape.

An analysis of errors in each item shows what difficulties may have students in solving scientific problems or in understanding text. The solutions we can use in didactics where we have to know what obstacles we can meet in the process of right thinking.

Authors of the presented paper are aware that it is not enough to indicate an error in the teaching-learning process. Just pointing out a mistake and giving a bad mark is itself an error. In such a situation the student only gets an information that he or she has not met some expectations (of the teacher or of the exam system). This is only an evaluation, which in the student's opinion concerns not only this specific failure, but also himself or herself as a person. Meanwhile, awareness of the mistake and the reason for it can and should be an element of the learning process. Analysing an error is a very good form of learning. The process of thinking is then reconstructed and the moment of making the mistake is discovered. Thanks to such an analysis, the student can not only see the reasons for his or her failure, but also has a chance to remember what leads him/her to the error and how to avoid it. Analysing mistakes in the classroom, of course without pointing out who makes them so as not to stigmatise anybody, can help to jointly face the traps involved in thinking and cognition. The emotional aspect is also an important factor. A mistake gives rise to emotion. Just pointing it out is a didactic failure. The student remains alone with a negative emotion, does nothing with it, he/she only receives a message that cannot cope with some type of task. Meanwhile, channelling this emotion, as well as its positive reinforcement by showing the way to avoid the error, can help in easier memorisation and consolidation of forms of correct thinking. Paradoxically, working an error through may be better for mastering skills than an easy success.

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DIDACTIC GAME AS A MEANS OF DEVELOPING RESEARCH SKILLS

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Abstract

This paper introduces two didactic games, which focus on the memorable reproduction of knowledge, including the simple/complex thought operations, and the support of key competencies. The specified didactic games contain a short annotation, a set goal, defined rules, playing cards and a game plan. By implementing these games, the pupil learns to use effectively their memory, cognitive and social strategies. The demand to explore didactic games as extra support for pupils when undertaking scientific research, emerged from the results obtained in the SGS project research. The research found that pupils have a problem with asking research questions correctly, as well as correctly naming the chemical glass, recording the procedure and the results of observations. In a game called "Do I Know What You Are?" the pupil learns how to systematically ask dichotomous questions to opponents in order to identify an unknown substance or separation method. The board game called "Party chemias" includes several activities that can be implemented separately, such as expressing chemical terms by description, drawing and describing the scientist and his significant discoveries. Furthermore, game players (pupils) can compile a meaningful sentence by using a chemistry curriculum term and through verifying the vocabulary of chemical terms via an alphabet letter. The results showed that playing didactic games increases pupils' interest in learning and promotes the permanence and depth of acquired knowledge.

Key words

Didactic games, motivation, key competences, teaching methods, Inquiry Based Learning

Introduction

Our research emphasises the introduction of innovative teaching methods in a high proportion of the participating pupils. One of the goals of science education is the development of a science-literate person who can grasp how natural science works and the role it has in society. Previous studies found that when a pupil actively uses their knowledge in research tasks, it motivates them to seek answers to questions such as: why? and on what principle? Consequently, the pupil‘s newly acquired knowledge and skills become more permanent and therefore can be used in everyday life situations (Kireš, Ješková, Ganajová, Kimáková, 2016). One of the ways to teach pupils how to solve real-life problems, as well as research tasks, is to stimulate their brain through games (Stojanović, Zivkovic, Ristanovic, 2019; Doorman, Jonker, Wijers, 2016; Sitná, 2013). Through the various processes of playing, the pupil acquires important competencies for the 21st century: critical and innovative thinking, communication and cooperative skills (Kvizdová, 2019; Ganajová, Sotáková, Siváková, 2016).

Didactic play is a voluntary activity, which is the product, or consolidation of learning educational material (Zormanová, 2012). However, any didactic playing game must have a clear goal and rules (Maňák, Švec, 2003), the requirement of ongoing management and a final evaluation (Průcha, Walterová, Mareš, 2003). The game stimulates and motivates pupils and teachers to take a more positive approach to teaching (Vojteková, Vojtek, 2018; Šmejkal, Šmejkalová, 2009). In addition, it contributes to improving pupils’ results in understanding the topic and increases the activity of weaker pupils (Holodňáková, Haláková, Kucharová, 2014). Also, it contributes to the development of convergent and divergent thinking (Stojanović, Živković, Ristanović, 2019; Vališová, Kasíková et al., 2007), along with physical, free and aesthetic competencies (Maňák, Švec, 2003). In general, games stimulate creativity, cooperation and competition among pupils (Vojteková, Vojtek, 2018; Neuman, 2014; Sitná, 2013). Most didactic games increase pupils’ involvement through a problem simulation, in which the pupil uses their life experiences, broader knowledge and skills (Průcha, Walterová, Mareš, 2003).

Methodology

The results from the tasks of our Research Days within the SGS project (Student Grant Competition) were used as preparation for the didactic games. During task testing, we found that pupils had difficulty to name the chemical glass and they could not determine the research problem (ask research questions), or justify the results of observations (Trčková, Bujok, 2019). To eliminate some of these difficulties, didactic games that require creative thinking and a high level of social and communicating skills from pupils, have been designed.

1st Game: "I know what you are!"

The aim of this game is to teach pupils to ask questions correctly. Laminated playing cards are essential for the game. The game is intended for 5 pupils or 5 groups of pupils in the 8th year of primary school, or the relevant years of multi-year grammar schools. Each printed laminated card consists of five fields, of which four fields contain images unknown to the opponents and one field with a question mark (Figure 1), which hides the unknown substance. By asking dichotomous questions to the opponents with either a " YES-NO " answer, the substance is revealed. Pupils take turns in asking questions and the signal for changing the questioner is a wrong answer. The winner is the one who guesses first the unknown substance behind the question mark. The game ends when all students, or all groups have guessed the unknown substance (Lukášová, 2020).

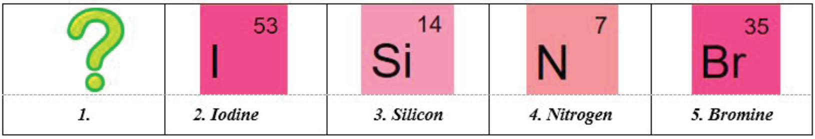

Fig. 1. Example of a playing card with an unknown substance 1, ?, 2. Iodine, 3. Silicon, 4. Nitrogen, 5. Bromine.

The game is played by individuals or groups:

• Five-member groups are created. Each student chooses their playing card and plays for themselves.

• Pupils are divided into groups and choose their speaker. Each group receives one playing card and the individual groups compete with each other.

During the game, the pupil solves tasks requiring simple thought operations by using their current knowledge, describing facts, categorizing, and performing analysis and synthesis. This game develops competencies for learning, problem solving and communicating, both in a social and personal context. The game "I know what you are!" is highly recommended. Examples of proposed variants of this game are shown in Figure 2, 3 and 4.

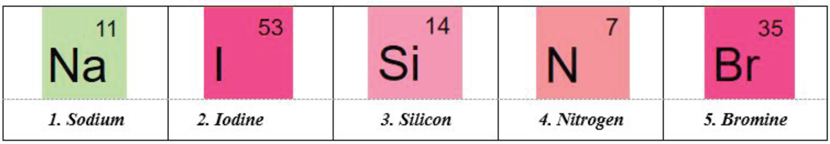

Fig. 2. Samples of all the pictures on the playing card variant of the game "I know what you are". On the topic "Elements and their compounds" there are different combinations on five playing cards of four known substances of the opponents and one unknown substance marked with a question mark in position 1.-5.

				
1. Copper	*2. Silver*	*3. Zinc*	*4. Aluminium*	*5. Gold*

Fig. 3. Samples of all the pictures on the playing card variant of the game "I know what you are". On the topic "Metals" there are different combinations on five playing cards of four known opponents' substances and one unknown substance marked with a question mark in position 1. -5. Author of photographs: Kubný (2018).

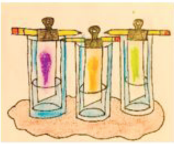				
1. Chromatography	*2. Filtration*	*3. Distillation*	*4. Crystallization*	*5. Sedimentation*

Fig. 4. Samples of all the pictures on the playing card of the game variant "I know what you are". On the topic "Dividing methods" there are different combinations on five playing cards of four known opponents' substances and one unknown substance marked with a question mark in position 1.-5. Author: Lukášová.

2nd Game "Party chemias"

The aim of this game is to teach pupils to use, define, compare and to put into context technical concepts. "Party chemias" is a chemical board game that has more complex rules and is more time consuming than the previous game. This didactic game offers a lot of activities that can be done in the classroom separately. An essential tool for the game "Party chemias" is a game plan measuring 42.5 x 42.5 cm (Figure 6), five different types of printed and laminated playing cards (Figure 7 and 8) – with a symbol of hands, a pencil, a camera, music, an alphabet, an overview card (Figure 7), 4 game pieces, an hourglass (or stopwatch), blank papers, a pencil and a roulette arrow, which needs to be made by grinding the stick from the popsicle into the shape of an arrow and painting it black. In the middle of the arrow you have to drill a hole with a diameter of 8 mm, into which you insert a screw of the same diameter, then place the roulette into the star in the middle of the circle with the numbers 1, 2, 3 on the game board with a screw and two washers located under the screw head and M8 nut).

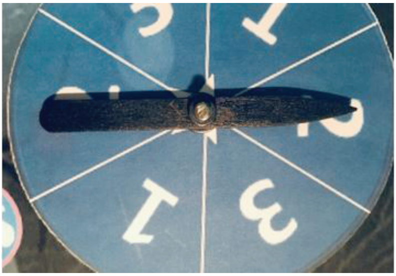

Fig. 5. Demonstration of a roulette placed on a game board.

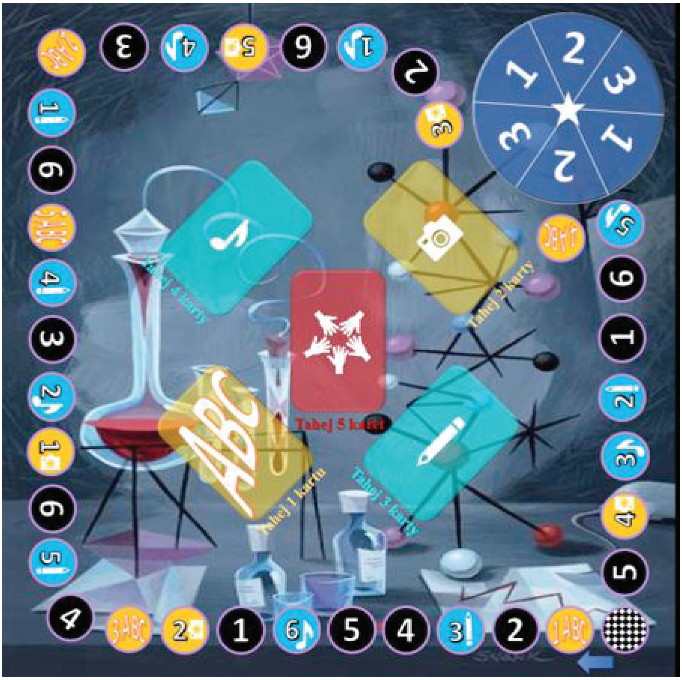

Fig. 6. Game plan of the "Party Chemias" game, available from: https://cz.pinterest.com.

This is a game played with 2-4 students in a maximum of four groups. The pupils' roles of one group are divided into one round of the game and in the next round the roles are reversed. One pupil describes the game concept to their teammates and measures the time limit of their opponents.

During this game, the pupil solves tasks that require the memorial reproduction of knowledge, simple thought operations (performing analysis, synthesis, finding out the relationships between facts) and tasks regarding the communication of knowledge (drawing diagrams). The game develops competencies for learning, problem solving, communicating, both in a social and personal context. It is necessary for "Party chemias" to be included in the motivational or fixation phase in order to repeat the concepts.

Rules of the game:

• The game begins by turning the roulette wheel and placing the piece on the field 1, 2 or 3 clockwise from the start located in the lower right corner.

• Depending on which square the piece occupies, the player chooses the pile from which they take the appropriate number of playing cards (five cards with a hand symbol, four cards with a music note symbol, three cards with a pencil symbol, two cards with a camera symbol and one card with an alphabet symbol).

• The words that they will explain are always given by the number of the box on which the figure stands.

• The playing field indicates how the pupil will work with the number of the terms, on the selected playing cards during the time limit. (1 minute is measured using a stopwatch or hourglass). Activities of this game include:

• Expressing chemical terms by description (playing field with number, card with a hand symbol).

• Expressing chemical terms by drawing (playing field and card with a pencil symbol).

Words	5 cards
	At most 5 points
Sentences	4 cards
	At most 4 points + roulete
Drawing	3 cards
	At most 3 points + roulete
Personalities	2 cards
	At most 2 points + roulete
Alphabet	1 cards
ABC	If 10 words → 2x roulette (at most 6 points)

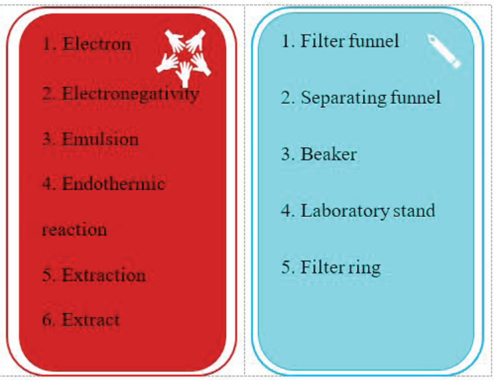

Fig. 7. From left, the overview card, example of a playing card with a hand (the figure stands on a field with hands and the number 4, the player describes the 5th concept from the playing card) and a pencil symbol (the figure stands on a field with a pencil and the number 5, the player describes the 5th concept from the playing card).

• Description of the scientist and his significant discoveries (playing field and card with a camera symbol).

• Compilation of a meaningful sentence for a term on a card (playing field and card with a note symbol).

• Vocabulary verification of chemical terms (playing field and card with an alphabet symbol).

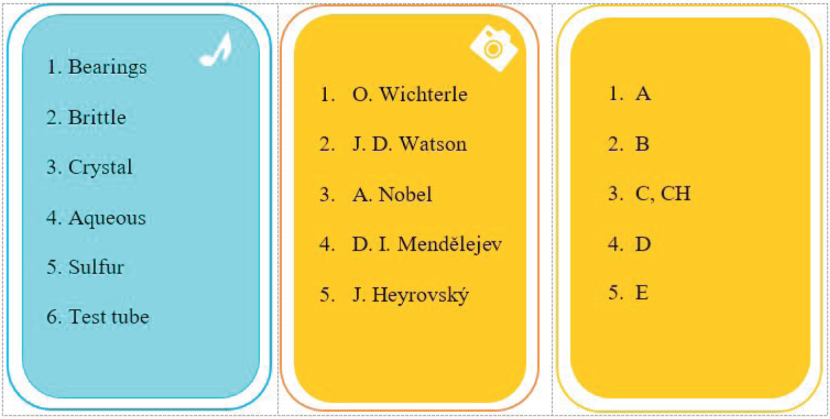

Fig. 8. From left, example of a playing card with a music notes (the figure stands on the field with the note and the number 6, the player describes the 6th concept from the playing card), a camera (figure stands on the field with the camera and the number 1, the player describes the 1st concept from the playing card) and an alphabet (the figure stands on the field with ABC and the number 1, the player enumerates terms beginning with the 1st letter of the game).

• One round for one group ends:

• If pupils guess all the selected words from the playing cards before the time limit expires, they get points for the number of guessed words and a roulette spin bonus. The total number of points indicates the number of squares by which the game piece is moved.

• If the time limit expires (1 minute), then the figure shift indicates the number of guessed words.

• The team whose figure reaches the finish line first wins.

Conclusions and Implications

We believe that the implementation of our proposed didactic games in teaching, can positively influence the development of pupils' research skills. The pupil will gain new knowledge and experience in a fun and interesting form. In addition, they will learn to improvise, plan, generalize and draw conclusions. By introducing this constructive educational method into teaching, we can motivate, pupils: influence their concentration, support their creativity, cooperation, the development of inductively deductive thinking, as well as their communication skills.

The next steps of the authors will be to test the success of solving research tasks in two groups of pupils - control and experimental. To support research skills the aforementioned games will be included in the teaching of the experimental group only. Subsequently, the success of solving research tasks will be statistically compared in both the control and experimental groups.

Acknowledgements

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PART 2

Research on scientific thinking skills of prospective teacher

AN INVESTIGATION INTO FRESHMAN CHEMISTRY TEACHER STUDENTS' DIFFICULTY IN PERFORMING CHEMISTRY CALCULATIONS

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Abstract

Chemical calculations are considered one of the critical areas at lower - (Bilek et al., 2019) as well as upper-secondary schools (Rusek, 2014). Naturally, these are also reflected on the university level. In (chemistry) teacher training, however, these skills need to be deepened as they are supposed to facilitate students' learning of chemistry calculations.

The research is focused on freshman chemistry pre-service teachers' ability to solve chemistry calculation tasks. According to Scott (2012), this ability is affected by the students' mathematical skills. The pre-service chemistry teachers (N = 32) were given 2 sets of two-tier tests. The first focused on chemical calculations, the second on analogous mathematical operations. Whereas 56% students reached over 50% of the maximal test-score in the maths test, only 3 students (9%) reached over 50% in the chemical calculation test. Medians of the students' performance self-assessment show neutral values in both tests, i.e. the students are neither confident nor unconfident with their results. The performed Wilcoxon test results show the students' results differ between the chemical calculation and maths tests ($p < .001$). The effect size of the difference is large (.585). The students' mathematical skills seem not to be the main reason for their underperformance in the chemistry calculation test. Students' failure is therefore probably caused by other intervening factors which must be considered and further investigated.

Key words

chemistry calculations, chemistry teacher students, math skills

Introduction

Chemical calculations are an integral part of the skills needed not only in chemical laboratories (Srougi, Miller, 2018). They are considered one of the critical areas at lower- (Bílek et al., 2019) as well as upper-secondary schools (Rusek, 2014). Rusek, Jančařík, and Novotná (2016) argued about chemistry calculations being a necessary evil or an important part of chemistry education. Naturally, this is also reflected on the university level. Unfortunately, according to our experiences, even pre-service teachers struggle with the chemistry calculations. In (chemistry) teacher training, however, these skills need to be deepened as they are supposed to facilitate students' learning of chemistry calculations and co-create their students' attitudes towards this field. A chemistry teacher who is not proficient in chemical calculations cannot teach it well which creates a vicious circle.

According to Scott (2012), the ability to solve chemistry calculation tasks is affected by the students' mathematical skills. Basic necessary mathematical skills for chemical calculation were defined by Denny (1971) as follows: computation; use of parentheses; signed number usage; use and manipulation of fractions; use of decimals; use of exponents, manipulation of numbers with exponents and logarithmic equivalence; use of percentage; manipulation of onevariable equations; use of ratio and proportion; and, producing and interpreting x, y graphs. In correspondence with the content of the chemistry calculations, it is necessary to state also mathematical skills as an understanding of assignments in the form of a word problem and specific skills such as transfer of units.

Scott (2012) in his research used of two tests: one on chemistry calculations and second on analogous mathematical skills without chemistry content. Scott considered students' insufficient level in basic mathematical skill such as division and multiplication, calculation with fractions and ratios as one reason of their failure in chemistry calculations. The research results showed mathematics was not the main reason, because the students were slightly better in analogous mathematics tasks in comparison to chemistry tasks (Scott, 2012).

Leopold and Edgar (2008) administered mathematics assessment on logarithms, scientific notation, graphs, and algebra with multiple-choice to students at the beginning of the second semester. Significant correlations were observed between these MA scores and final course grades. According to the authors, an inadequate degree of mathematics fluency can limit the development of abilities needed to firm conceptual understanding of quantitative introductory chemistry. Similarly, Drummond and Selvaratnam (2009) noted an insufficient level of mathematics in research dealing with the intellectual abilities needed for learning and application of chemical knowledge. According to their research, those skills include language skills, mathematical skills, graphical skills, three-dimensional visualization skills, information processing skills and reasoning skill. These skills were tested on freshman chemistry students. The results showed most students' poor intellectual skills. This could lead to a lack of selfconfidence and negative attitudes. For example 70% students were unable to perform basic mathematical operations on numbers given in scientific notation; 85% students could not convert a physical quantity from one unit into another (mol · cm^{-3} to mol · dm^{-3}); 80% students were unable to apply a simple law (law of conservation of mass) to perform two calculations (Drummond, Selvaratnam, 2009).

With chemistry calculations being one of the first courses freshman students take, it is important to consider they are on a different level coming from various types of upper-secondary and many also from universities. A deep knowledge of hurdles they may face in this course has the potential not only to improve their results in the course, but also make their first semester more pleasant and set their university studies on a track.

Goals

After several years of experience with freshman pre-service teacher training, a need to investigate the reasons behind the students' performance in chemistry calculations emerged. The students are expected to have mastered the its basics, nevertheless, the reality is often different. For this reason, the goal of this research was to: a) find out the level of freshman preservice teachers' skills regarding basic chemistry calculations and b) evaluate a possible influence of mathematical skills on these students' performance in chemistry calculations.

These goals are concretized by the following research questions:

RQ1: How successfully do freshmen chemistry teacher students solve chemistry calculation tasks?

RQ2: How successfully do freshmen chemistry teacher students solve mathematical tasks containing analogous operations?

RQ3: To what extent, if any, do the students' mathematical skills affect their performance in chemical calculations?

Methods

Research sample

The research sample consisted of 32 freshman chemistry teacher students who enrolled in the study programme at the Faculty of Education, Charles university.

Research tools

To answer the research questions, two sets of two-tier tests: one concerning chemistry calculations and one concerning analogous mathematical operations were used. The first tiers in the calculation tasks concerned the following types of calculations: dilution problems, mass fraction, molar concentration, balancing chemical equations, equation of state, calculations from chemical equations and calculation of pH. Students' previous experience with particular types of calculation was also asked for. The first tier of the mathematics test included: calculation of percentages, conversion of units, direct and inverse proportionality, expression of an unknown variable from the formula, logarithms, solving equation by one unknown, word problems for the previously-mentioned skills. The second tier was represented by a 5-point Likert scale item (1: not at all – 5: absolutely) to investigate the students' self-efficacy concerning the correct solution of each task. One extra item was added to each item which asked about the students' previous experience with the particular type of calculation.

Procedure

At the beginning of the academic year 2019/2020, the students were given the chemistry calculations and mathematics tests, both in separate lessons. The tests took about 60 minutes each. The tests were evaluated, results transcribed and analysed.

Data analysis

Descriptive statistics was used to evaluate each of the tests. With respect to the nature of the data, a paired test was considered. First, the Shapiro-Wilk test for normality was performed. Its results allowed to reject the hypothesis about normal distribution of the data.

To measure the relation between the students' results in the two tests a linear regression was used. To compare the students' results in the two tests a non-parametric Wilcoxon signed-rank test was used to investigate differences between the students' success rate in chemical calculation and mathematics test. To provide the effect-size, Pearson's r was used.

Results and discussion

Chemistry calculations – RQ1

Majority of the students (78%) correctly solved only one to three tasks (total nine). Only three students (9%) managed to solve more than half of the test – reached more than half of the score. Non managed to solve more than six tasks. The most numerous group of students (27%) solved correctly only one task - simple mass-fraction calculation or balancing an acid-base equation, i.e. tasks which are possible to solve only by a logical reasoning without deeper understanding of chemical problem behind the task. The students answered neutrally (Mdn = 3) on the questions about their certainty with the correct answer. Nevertheless, significant differences were found among individual tasks (see Tab. 1).

Tab. 1. Chemistry calculations tasks results.

Calculation type	Students' success	Previous experience	Certainty with correct answer (Mdn)
balancing (acid-base reaction)	78%	84%	4
mass fraction	78%	84%	3
calculation of pH	31%	66%	3
calculation of molar concentration	16%	69%	2
dilution of solutions	16%	78%	2
balancing equations (redox reaction)	16%	84%	1
calculations from chemical equations	9%	56%	2
equation of state	9%	41%	2
calculation of pOH	3%	72%	3

The most successful were the students in balancing an acid-basic equation and mass-fraction calculation. Most of the students also mentioned previous experience with this type of calculation. In the more complex versions of the same task types, however, a considerably less students succeeded. The same applies for both balancing equation as well as for the task on dilution of solutions. Especially with this type of calculation a considerable number of students mentioned their experience, nevertheless only 16% succeeded to solve it correctly. This is probably due to the need of deeper understanding which these students might not possess. Such a conclusion is supported with the lower expressed certainty with the task's solution (Mdn = 2).

The least of the students succeeded in pOH calculations (only one student solved it correctly), although 72% mentioned previous experience with such a task and expressed neutral certainty with the correctness of the solution. It was assumed lower based on the results. The students typically used the correct formula, nevertheless failed to calculate with the ion concentration instead of concentration of the hydroxide. This points to them having learnt a procedure without deeper understanding either to the formula or the meaning. Significantly more students (31%) succeeded in this type of calculation where pH was at stake. The students were supposed to calculate the concentration based on an acid's pH – use the logarithm. 66% of the students mentioned their previous experience with this task. Compared to the 72% mentioned in the case of the pOH task, it seems these students experienced only the plain pH calculation based on the knowledge of concentration kind of tasks.

Results in mathematics – RQ2

In comparison to the chemistry calculations, the students' results in the mathematical tasks were considerably better (see Table 2). 56% solved more than half of the tasks correctly, no of the students solved less than a quarter of the test (4 out of 15 tasks). The students' certainty with correctness of their solution was also on the neutral level (Mdn = 3). Nevertheless, the students mentioned their certainty with the correct solution (Mdn = 4 or 5) in more than a half of the tasks.

Tab. 2. Mathematical tasks results.

Calculation type	Students' success	Previous experience
Word problem (proportions)	94%	4
Word problem (direct proportionality)	91%	4
Fractions	78%	5
Expression of an unknown variable from the formula (simple)	75%	4
Word problem (indirect proportionality)	72%	3
Word problem (substitution into a formula)	66%	2
Word problem (percentage)	63%	4
Solving linear equation with one unknown	50%	4
Percentage	47%	4
Solving linear equations with two unknowns	47%	4
Logarithms	44%	3
Word problems (fractions)	41%	3
Completion of units	31%	3
Expression of an unknown variable from the formula (advanced)	25%	1.5
Transfer of units	22%	3

Most of the students successfully solved the word problems oriented on proportionality (94%), resp. direct proportionality (91%). On the contrary, the least of the students succeeded in the tasks on the transfer of units (22%), advanced expression of an unknown variable from the formula (25%) or completion of units (31%). As these operations are typical for majority of chemical calculations, problems with their performance can negatively influence the students' results in chemistry calculations.

Is mathematics to blame? – RQ3

With respect to Scott's research (2012), the dependence of the students' results in the mathematics and chemistry test was observed.

The linear regression p-value (.019) enabled to reject the zero hypothesis, i.e. the two samples are statistically different. The R square value (.165) showed that only 16.6% of the students' results in the chemistry calculation test could be explained by the students' mathematics skills. A qualitative analysis showed two out of the three students who scored more than half of the chemistry calculation test appear also in the top of the mathematics test. On the contrary, eight of the students who scored below 33% in the mathematics test, appeared in the low tercile in the chemistry calculations test too. The influence of mathematics skills seems not to be the only factor which influences the results in chemistry calculations.

The results of the Wilcoxon's single-rank test ($z = -4.279$, $p = .000$) confirmed a statistically-significant difference between the students' performance in chemistry calculation test (Mdn = .22) and mathematics test (Mdn = .53). The effect size of the difference ($r = .762$) was large. The students' performance in the mathematics test was significantly better.

Limits of the study

Naturally, the research sample represents only a certain group of students. In order to make general conclusions, the sample needs to be bigger and include students from other universities and faculties in corresponding study programmes. Also, to propose changes in the concerned courses, interviews concerning the tasks, students' difficulties and experience need to supplement the tests. Last but not least, retrospective think-aloud method could be used to map the students task-solving process and understand it better.

Conclusion

In general, the students failed in chemistry calculations, whereas the mathematics test results were significantly better. The students' mathematics skills did not prove to be the main reason of the students' failure in chemistry calculations. This was probably caused by other factors and needs to be further investigated. Possible factors include the context of the tasks, students' willingness to solve tasks they are not familiar with or their reading skills.

The students' self-assessment did not reflect their actual performance even when they were familiar with the majority of the tasks from their previous studies.

This research offers basis for proposing improvements in the chemical calculations course at the university level as well further research questions which need to be answered to optimize the course.

Acknowledgement

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RESULTS OF ANALYSIS OF SPECIFIC ELEMENTS OF SCIENTIFIC THINKING THROUGH CHEMICAL TASKS

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Abstract

It should be a fundamental in the teaching profession the learning and developing of higher thinking operations in preparing next generation for life in the 21st century. This research is a part of an extensive study of science literacy carried out within the VEGA project.

Through the presented research we wanted to get an overview of how successfully students of the Faculty of Education are in solving tasks with chemical content which are built on selected elements of scientific skills which required higher-order thinking operations.

Within our empirical research based on methodology of survey we was gathering data about the presently existing conditions of future teachers´ in field of selected elements of scientific skills. As a research instrument we used knowledge test consists of 12 non-standardized tasks from chemistry build on selected elements of scientific skills based on the system of scientific literacy (Fradd, et al.,2001).

We present the results of the current state of selected elements of scientific competencies of future teachers. During the analysis of tasks we identified the areas of scientific competencies that made the most or the least problems in solving respondents.

The results show that it should integrate more into the teacher education the development of scientific and any other literacy based on thinking operation.

Keywords

chemistry education, scientific literacy, scientific skills, teacher education

Introduction and the theoretical background

The nature of scientific thinking and scientific skill

Science has a significant impact on personal life in a global society as well as in its economy. Scientific literacy is part of 21st-century skills (Djamahar, et al., 2018) therefore, students are expected a good level of scientific literacy (Glynn, Muth, 1994), which should be strengthened through nature education (Ristanto, et al., 2018), (Jenisová, 2015).

Education based on a scientific approach belongs to the modern world (Wieman, Gilbert, 2015), but it cannot work well without the support of good educational media. Knowledge is really important, but only when it is adaptable to real situations. Therefore, it is necessary to develop through cognitive abilities and skills that are adaptable, flexible, and effective in the real world. The complex nature of science reflects the need to change the paradigms of education from a perspective that will allow us to holistically understand our evolving socio-technical world (Boy, 2013).

Scientific literacy is the knowledge and understanding of scientific concepts and processes, which includes specific types of skills and abilities, such as to able to describe, explain, and predict natural phenomena. In the context of scientific literacy, we can encounter the terms "scientific skills" (Burmeister, Rauch, Eilks, 2012), "scientific competences" (Held, et al., 2011), „research skills" (Bortnik, et al., 2017), "inquiry skills" and „science process skills" (Taylor, Rogers, Veal, 2009; Ganajová, Sotáková, Siváková, 2016). Scientific literacy means an organic unit of science-as-logic, science-as-theory, and science-as-practice which requires scientific thinking. Under the concept of scientific thinking, we generally understand the mental processes used in a scientific context, or that we apply in activities of a scientific nature. Scientific thinking is often associated with mathematical thinking. As every problem-solving process, scientific thinking is also based on mathematical thinking, but in tripartite of science logic-theory-practice, it requires to apply the wider field of mental processes and other transdisciplinary science cognitive skills (Szarka, Juhász, 2019).

Current state of scientific literacy in Slovakia

The overall results of the average performance of Slovak pupils show a progressive trend in the international measurement PISA 2018, "improvement" in comparison with the results of previous years. However, in reading literacy and science literacy the results are stagnant (Miklovičová, Valovič, 2019).

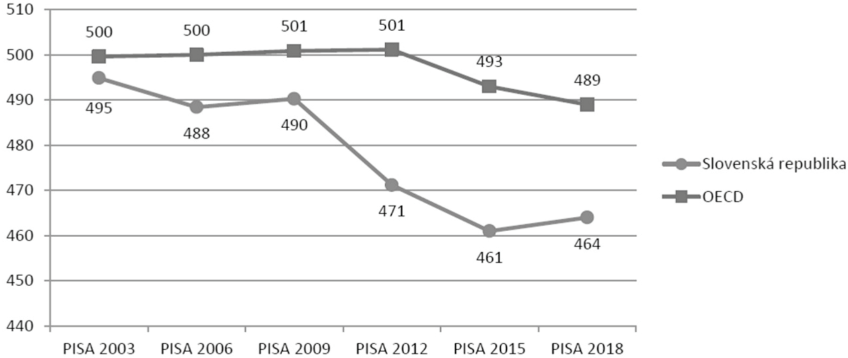

Fig. 1. Average performance of students in the Slovak Republic and OECD countries in science literacy in individual cycles of the PISA measurement (Miklovičová, Valovič, 2019).

As a possible cause of failure Slovak pupils, the authors see the low level of pupils´ science literacy. The results of PISA have long shown that although students have sufficient content knowledge, they are often unable to apply it in solving of non-traditional problem tasks (Miklovičová, et al., 2017) and over more, they do not have experiences in solving tasks in which need to argue (Kiss, Velmovská, 2020).

Research problem

Some authors say about the quality of education that it determines not only by the curriculum or due to various innovative approaches in the field of education, but also the quality of its implementation. At the same time, they point to the importance of supervision from various educational, from the side of an expert of other fields and the field of practice, as well as other stakeholders. However, the success of education lies not only in improving and updating or innovating the content and infrastructure of education, but also in the professional development of teachers (Purnomo, 2017). Studies show that teacher professionalism contributes significantly to improving the quality of education (Day, 2013; Häkkinen, et al., 2017; Szőköl, 2020).

In order for future teachers to be prepared to develop scientific thinking involved higher-order thinking of their pupils within their future teaching practice, they also need appropriate pedagogical training in developing lower- and higher cognitive skills not only at the theoretical level but in pedagogical practice during their didactical training. They also should encounter examples that are adequate to develop higher-order thinking; they need to be given the opportunity to solve such kinds of tasks and make a didactic analysis of task and their solutions, and at the same time create tasks focused on the development of higher-order thinking.

This research is a part of an extensive study of science literacy carried out within the research project VEGA (No. 1/0663/19).Through the presented research we wanted to get an overview of how successfully students of the Faculty of Education are in solving tasks with chemical content which are built on selected elements of scientific skills that required higher-order thinking operations.

Methodology of the research

Empirical research focused on the analysis of selected elements of scientific skills through school chemistry tasks.

Research sample

The sampling strategy we decided to use have had limitations. The research sample selection was based on the availability of respondents, and it was necessary to have taken into consideration the intention or purpose of our research. We involved 70 master's degree students in the Faculty of Education at J. Selye University, of which 26 full-time students and 28 part-time students in the Teacher Training for Primary Education study program and 16 full-time students in the teacher education study programs in various combinations of subjects' approbation.

Research methods and tools

In connection with the research-based concept of education, there are various models of systematization of scientific skills (Held, et al., 2011). The analysis was based on the system of scientific research skills of the author team (Fradd, et al., 2001), based on which we created a set of chemical tasks oriented to individual scientific skills (Table 1.).

Tab. 1. Assignment of tasks of a research tool to individual scientific skills.

Fields of scientific skills	Scientific skills	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11*	F12
K1 - initial research formulations	K1a – formulation of the research question / problem												
	K1b – hypothesis formulation		*										
	K1c – formulation of predictions	*											
K2 - planning	K2a – planning methods and procedures												
	K2b – identification of the necessary materials and resources				*								
	K2c – design of research procedures						*		*				
	K2d – determining research steps			*									
	K2e – identification and control of research variables					*			*				
K3 – realization	K3a – implementation of the research plan												
	K3b - observation												
	K3c – data collection												
	K3d – treatment and solving problems within research							*					
	K3e – explanation why the apparatus and design for the given research has been chosen								*				
K4 – analysis of results, drawing conclusions and interpretation of results	K4a – data analysis												
	K4b - explanation											*	
	K4c – drawing conclusions	*								*	*		*

Thematically, 10 areas of chemical education were processed in the tasks, like chemical reactions - stoichiometry, solutions, methods for separating mixtures, thermochemistry, Beketov's metal displacement series, galvanic cell, synthesis of carbon dioxide and chlorine, Pasteur-effect - reproduction of yeast, chemical odorization of natural gas.

Research Results

We received 70 solved science skill tests from the involved 70 respondents during the research, consisting of a set of twelve chemical examples, all of them were evaluable and subject to analysis and subsequent statistical processing.

In addition to solving the task, the respondents gave also the length of their previous chemical education. 48 respondents answered that they had been learning chemistry in high school for at least 1 year, 21 did not have chemistry during high school and 1 respondent did not state any answer.

The science skill test contained various tasks, not only regarding the science skills on which the tasks focused, but also regarding the number of items of individual tasks. Therefore, the tasks also differ in the maximum number of possible points obtained.

The analysis of the research data focused on two areas, namely, to find out

• what proportion of respondents solved correct, incorrect resp. did not give any solutions;

• by the regards of the maximum number of possible points obtained, on average, what percentage did the respondents obtain, i.e. what percentage success of the individual tasks were solved.

Tab. 2. The number of respondents with correct solutions for individual tasks and their percentage in point of the total number of respondents.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Number of respondents who correctly solved tasks out of the total number of research sample N = 70	2	5	0	5	12	3	4	0	9	6	8	5
Percentage of the research sample of respondents [%]	2.9	7.1	0.0	7.1	17.1	4.3	5.7	0.0	12.9	8.6	11.4	7.1

Table 2 shows the number of respondents who correctly solved the individual tasks and their percentage in point of the total number of respondents. From these data, we see that respondents have had the biggest problem in the case of solving task F3 (area of scientific skills K2) and F8 (area of scientific skills K2 and K3). During assessing these tasks, we did not get completely correct solutions from the respondents, i.e. students have had difficulty with designing research procedures by planning and determined research steps, identifying and controlling research variables, as well as explaining the choice of the research setting. We received the largest number of correct answers in the case of task F5 (scientific skills area K2), F9 and F11 (both tasks in scientific skills area K4), where respondents had to identify and control research variables, formulate conclusions.

In the next, we were interested in what proportion of respondents solved correct, incorrect resp. did not give any solutions in individual areas of scientific skills or did not give any answer or the response was not evaluable (Table 3.).

Tab. 3. Percentage of respondents concerning the evaluation of their answers in individual areas of scientific skills.

	Percentage of the research sample of respondents [%]		
	Correct answers	Incorrect answers	No response or no evaluable response
K1	31.67	49.76	18.6
K2	33.8	41.9	24.3
K3	26.4	50.1	23.5
K4	18.0	58.5	22.7

The worst results in solving tasks we have got in the areas of scientific skills K3 and K4, where we noticed the lowest percentage of respondents who correctly solved tasks in the given areas and at the same time the highest percentage of respondents who solved incorrectly the tasks or did not give any answer. The results show that in all areas of scientific skills, more than 60% of respondents either handled tasks incorrectly or gave no answer. Even in the case of the area of scientific skills K2, where the largest percentage of respondents solved the tasks correctly (33.8%), the most of respondents had a problem with solving such tasks.

We present the graphical interpretation of the results using of Figure 2, where we illustrate the percentage of respondents with correct, incorrect, and no answer in individual areas of scientific skills by the size of bubbles.

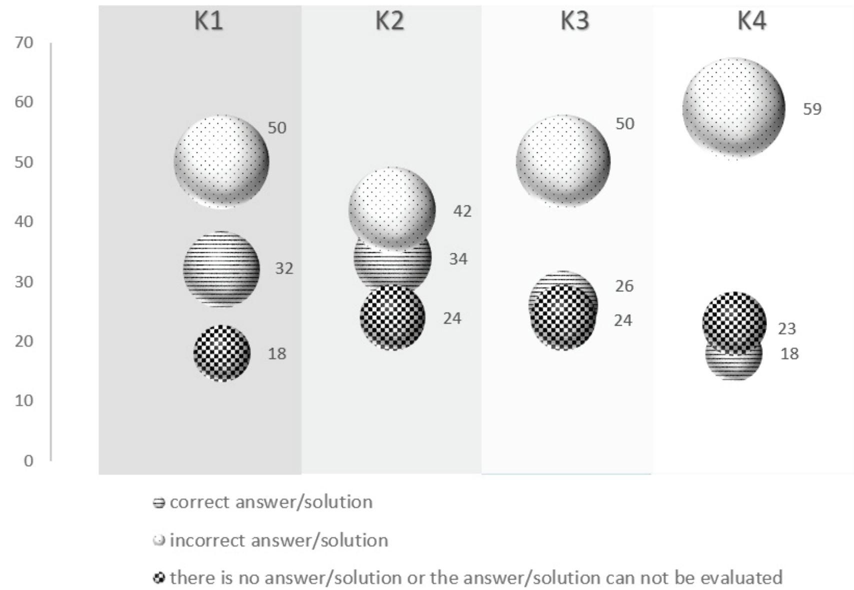

Fig. 2. Distribution of percentage of respondents with correct, incorrect and no answer in individual areas of scientific skills.

When analysing the success of the tasks solution, we observed how many percentages of points from the maximum number of possible points obtained respondents averagely got. The results of our findings are presented in Table 4.

Tab. 4. Maximum number of possible points obtained in individual tasks and percentage of achieved points from the maximum number of points.

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Maximum number of possible points obtained	6	1	5	9	3	1	5	3	2	1	2	3
Percentage of points achieved in point of the total number of points by respondents [%]	41.2	7.1	30.0	55.9	41.4	4.3	45.7	28.1	30.7	8.6	37.1	26.7

The results show that the respondents got of the lowest percentage of the point from the maximum number of possible points obtained in the case of task F6 (4.3%), where respondents had to add into the flowchart the separating methods and components of the mixture, which could be the product of separation process, and such way they had to create a chemical design of the mixture separation experiments. We observed that respondent obtained the largest percentage of points from the maximum possible points in the case of task F4 (55.9%), where the respondents had to select the needed tools for the experiment from a set of objects for measuring the electrical voltage in the fruit galvanic cell. It was interesting that while in the case of tasks F3 and F8 none of the respondents gave a completely correct solution, the percentage of average points that respondents could get from the maximum number of possible points, these tasks are not among the tasks with the worst point gain.

We have also analysed the successes of respondents based on a set of selected scientific skills. Table 5 shows the maximum number of points that respondents could achieve for tasks in individual areas of selected scientific skills and the results of average points they obtained of the maximum number of points (expressed as a percentage).

Tab. 5. Percentage of the average number of points achieved out of the total number of points

	Maximum number of possible points obtained	Percentage of the average number of points achieved by respondents out of the total number of points [%]
K1	7	36.3
K2	20	40.6
K3	6	47.1
K4	8	28.0

We present a graphical interpretation of the results of Table 6 by means of Figure 3, where the size of bubbles also illustrates the ratio of the percentage of successes of respondents in individual areas of scientific skills.

The results show that the respondents were the least successful in the field of scientific skills K4, what means they had problems with analysis of results, drawing conclusions and interpretation of results within the tasks. However, they were the most successful in the field of scientific skills K3, where respondents had to solve tasks focusing for skills of research implementation. Unfortunately, the results also show that the performance and successes of respondents in all areas of selected scientific skills is below 50%.

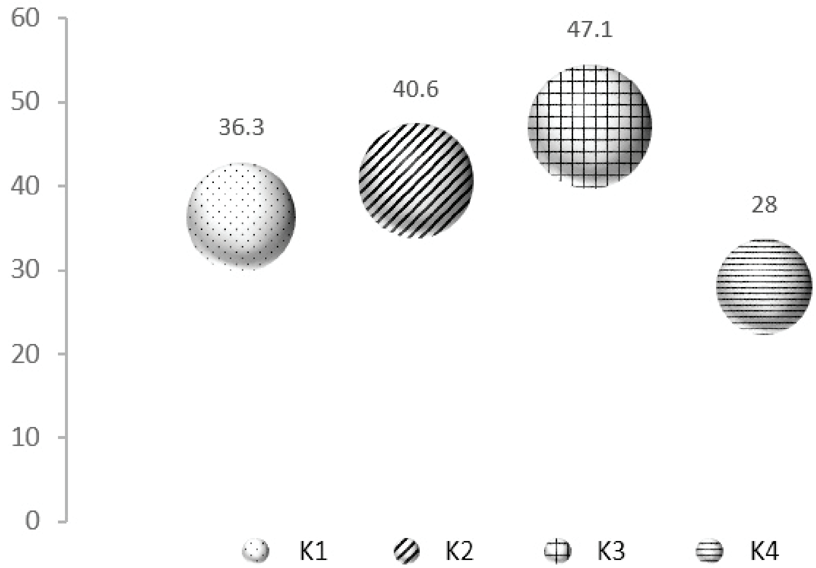

Fig. 3. Distribution of average result of respondents'performance in individual areas of scientific skills [%].

Conclusion and implications

We are aware that we cannot draw far-reaching conclusions from the presented research results, as the analysis of the state of selected scientific skills of students was performed only in the context of chemistry and on the available sample. However, the results can be very authoritative and important in planning the concept of training future teachers in the next accreditation period. The presented results show that the development of scientific skills based on higher-order thinking operations in the future should be more integrated in the training of future teachers, not only at the theoretical level but also during their didactic training, where they come to familiar which tasks can develop the higher-order thinking; they can get the opportunity to didactically analyse the tasks and their solutions and at the same time create tasks oriented to the development of higher-order thinking.

Acknowledgment

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PART 3

Theoretical considerations based on the analysis of source materials and pedagogical theories

SCIENTIFIC THINKING IN LEARNING CHEMISTRY BASED ON THE CONCEPT SALTS

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Abstract

In the Polish core curriculum, the salt chapter, in a way, closes and summarizes the teaching of inorganic chemistry. To be able to achieve educational success related to this department, the student should have systematized and consolidated knowledge from many previously discussed departments. In rotation, the relations between the terms from the salts section are discussed in detail. And the relationship between the terms from this section and others. Attention has been paid to the fact that introducing the concepts from the section "salts" actually contributes to the formation of scientific thinking in students.

Key words

scientific thinking, salt

Introduction

The world of chemistry that students get to know in primary school and later also in secondary school causes them a lot of trouble. The reason for this may be inappropriate approaches to learning chemistry, including the lack of systematic work, resignation from scientific thinking to making attempts to memorize the material or learn to mechanically write formulas, reaction equations, perform calculations, without understanding the essence of the phenomenon, properties of the particular group of compounds or behaviour of a specific substance (Nodzyńska, Paśko, 2008; Cieśla, Paśko, 2008). Another problem is learning chemistry in a very limited way, often limited to carrying out single experiments and formulation of general conclusions which are inadequate to the learned fragment of the issue (i.e. Bilek, Nodzyńska, Kopek-Putala, Zimak, 2018, Rychtera, Bilek et al., 2019).

One of the problematic topics that usually causes many problems for students is the concept of salt. The paper is an attempt to analyse how large part of chemistry this topic covers and proves that it is impossible to master this issue without scientific thinking, problem analysis, looking for cause-effect relationships, and synthesizing knowledge from various other chemical issues.

The definition of the salts which is used in primary and secondary education looks very simple. In the IUPAC (International Union of Pure and Applied Chemistry) Compendium of Chemical Terminology (GoldBOOK, 1997) salt is "a chemical compound consisting of an assembly of cations and anions". However, the simplicity of the definition covers a very complex educational problem. On one hand such a simple definition, and at the same time broad in meaning, also includes substances which, although made of ions, are not classified as salts. The ionic structure is also present for example in hydroxides, many metal oxides, and some metal hydrides. Thus the definition of salts for educational purposes must be more precise. In many school-books, salts are referred to as compounds built of metal cations or cations which are a group of atoms and anions of acid residue.

On the other hand, the diversity of possible cations and anions makes the salts a very diverse group of chemical compounds. Moreover, there are also different methods of obtaining them. Sometimes the methods of obtaining a given salt in the laboratory differ from the methods of obtaining the salt in industry.

Complete mastery of the concept of salts in school education includes the following topics:

- Structure and writing chemical formulas of salts.
- Nomenclature.
- Water solubility and electrolytic dissociation.
- Laboratory methods of salt obtaining:
- designing and doing chemical experiments;
- writing chemical equations on both "molecular" and ionic level.
- Properties of various salts.
- Applications of various salts.

Moreover in the secondary school in addition to mentioned above:

- Some industrial methods of salt obtaining.
- Hydrolysis of salts and pH of water solutions of salts.
- Electrochemical processes.

The learning process

Let's consider the learning of salt concept more thoroughly.

At first a student has to make an analysis of the definition of salts. According to the definition the student finds out that salts are ionic compounds, electrically neutral, so in order to get a salt both positively and negatively charged ions are required - cations and anions respectively. The required basic knowledge to understand it is at least understanding the concepts of atom, ion, and types of chemical bonds, and hence electronegativity.

In the next step the pupil has to think what kind of chemical compounds will let him get the salt. The cation is a simple metal ion or a polyatomic ion which can be a group of atoms or complex cation (Fig. 1.), so in the next step the student has to think what kind of chemicals those ions can be obtained from. A good practice is to represent those compounds in a form of concept map stimulating visual thinking.

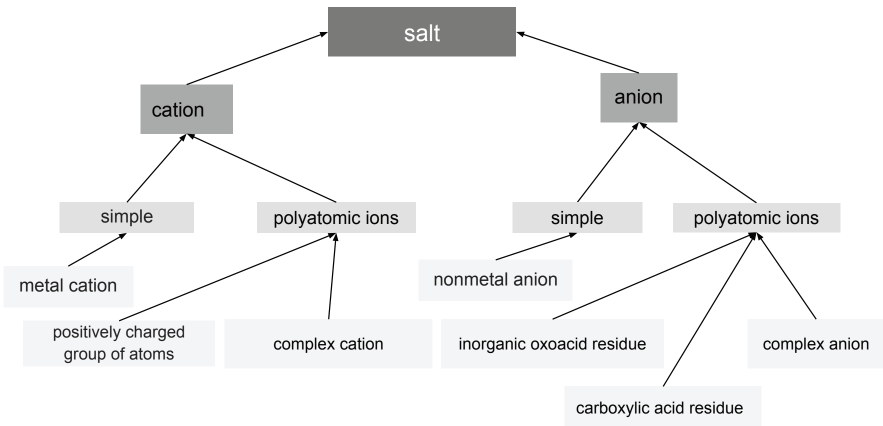

Fig. 1. Mental map - the salt concept

At primary school level students familiarize with simple metal cations and the only polyatomic ion - ammonium one. If we consider simple metal cations and ammonium ions only, the number of possible salts they can create is still very large. Additional knowledge to cover this part of information is needed - these are metals, metal ions and a difference between them. Moreover some information about ammonia properties and ammonium ions. To take into account also other polyatomic ions and complex ions, further background knowledge will be required to understand their structure and chemical properties. In figure 2 the possibilities where the metal cations can be obtained from are presented.

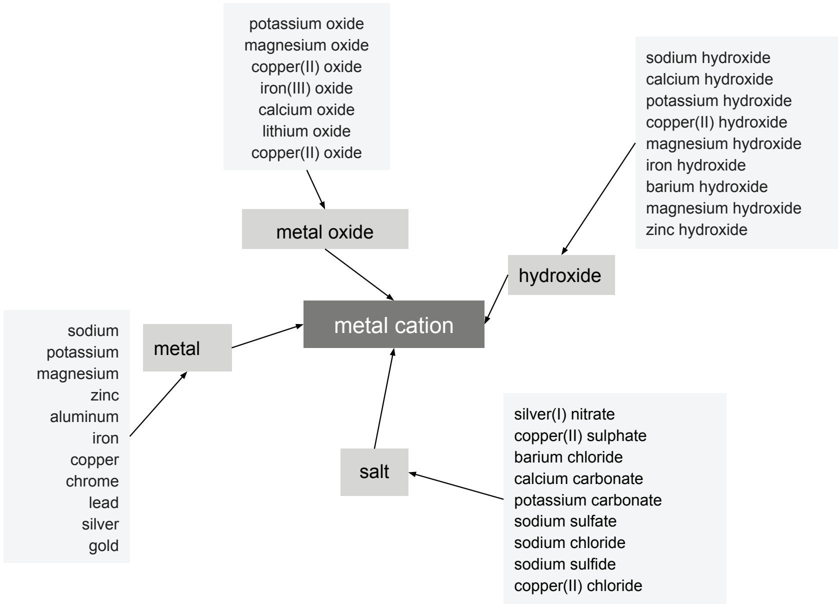

Fig. 2. Mental map - the ways of obtaining metal cation.

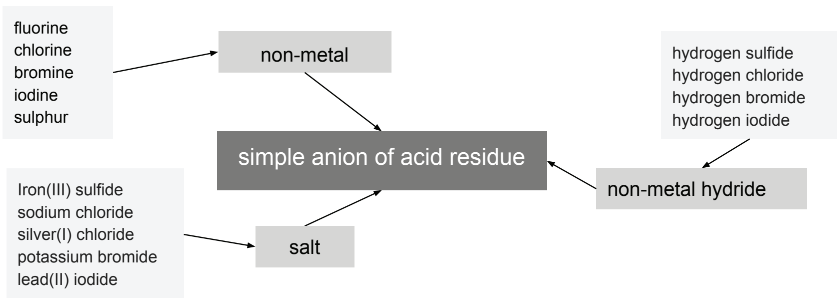

Fig. 3. Mental map - the substances from which inorganic simple anion can be obtained.

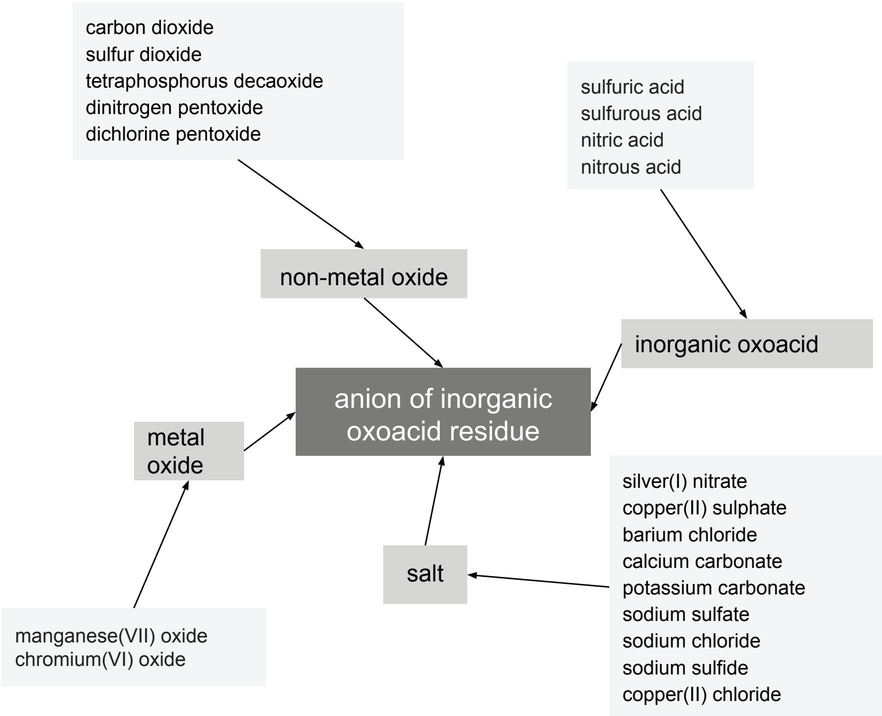

Fig. 4. Mental map - the substances from which inorganic oxoacid anion can be obtained.

As scientific thinking is based on the analysis, synthesis and finding cause-and-effect relationships, basic knowledge is necessary. Learning salts through scientific thinking and with real understanding the topic requires very wide basic knowledge as it has been shown above. That knowledge has to be gained by pupils' own work or/and at chemistry lessons. In contrast to some other subjects chemistry knowledge is built step by step, brick by brick. Unfortunately pupil has to understand and remember every brick to be able to move forward with the learning process effectively. Moreover the process must be very well designed and scheduled to be able to assimilate such a huge piece of chemical knowledge. At every stage of this process scientific thinking can be useful, however appropriate background knowledge must be given or at least some sources of information must be available for a pupil.

In the figure 5 suggested steps in learning chemistry in order to get background knowledge before learning salts is presented. Most of the presented steps refer to complex topics, so they could be split into more detailed ones corresponding to more detailed chemical issues.

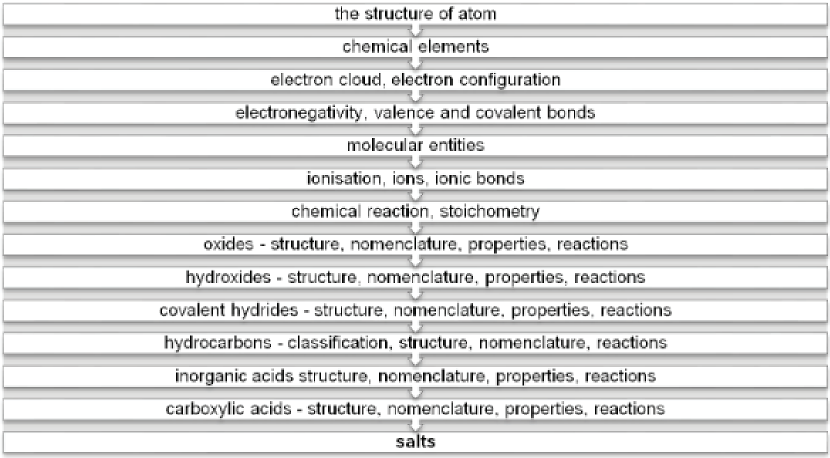

Fig. 5. Suggested pathway of learning chemistry to get appropriate knowledge to learn the term salt.

Getting to know the above material, regardless of the chosen form of implementation, takes time and is usually completed within about 100 hours of study. One can argue as to the order of implementation of particular issues by adopting various arguments, but any of the issues cannot be skipped. For this reason, it is extremely important to systematically work the student and return to the information already known, as well as use the previously acquired skills to be up to date with this knowledge, because the new knowledge is constructed on the basis of the previous topics, not as an independent topic.

There are various approaches to introducing the salt concept, however one seems to be used the most frequent. As an introduction to the salt concept the reaction between acid (usually hydrochloric acid) and base (usually sodium hydroxide aqueous solution) is used which is led in the presence of pH indicator, usually phenolphthalein like in alkalymetric titration. Based on the observations pupils with a teacher are discussing the results of the reaction and pH changes. The discussion leads to defining the salt concept. After that pupils are trying to understand the structure of salts and are practicing writing formulas and names of particular salt. It is usually a theoretical lesson only, however teachers are using various learning techniques or tools, for example educational games, own work with worksheets and the jigsaw technique. The research led by Jyż-Kuroś and Paśko (2008) has shown that the correct notation of the formula of a salt is mainly influenced by the ability to correctly write the formula of a corresponding acid. Such approach is a natural consequence of previously learnt content. In the following lessons, students will learn more advanced content, including methods of obtaining salt.

Another approach to learning and understanding salt structure is to combine laboratory work with solubility table analysis. It is based on the precipitation method of salt preparation. Students have different salt solutions and a solubility table at their disposal, as well as a set of test tubes. They work independently or in teams of two or three. They choose the appropriate cation and anion from the solubility table, find them in the available substances and mix the appropriate solutions in a test tube. They confront the effects of the reaction with the data in the solubility table, while trying to write the course of the reaction in a form of net ionic equation, after that they can try to write a complete ionic equation and finally a molecular one.

Having the formulas of cations and anions available in the solubility table, they create on this basis the salt formulas, taking into account the fact that the salt is electrically neutral, i.e. it must contain the same amount of positive and negative charges in its structure. At the same time, the ionic structure of the salt is consolidated in students' minds.

Combining the laboratory work and discussion with the analysis of the solubility table, as well as the theoretical work of creating salt formulas on this basis, writing the appropriate reaction equation in an ionic form and bringing the equation to the molecular form, has many advantages:

• Due to the variety of precipitates, both in form and colour, it is visually attractive, which strengthens the student's internal motivation to further explore the issue.

• Makes the process of learning chemistry similar to its scientific exploration.

• It forces a pupil to analyse information, and then synthesize and evaluate it, to find cause-effect relationships, which teaches scientific thinking.

• It teaches the student in a poly-sensoric way.

• Working in small groups (no more than three people) also contributes to practicing in organizing group work, collaboration and scientific discussion.

• It naturally teaches many topics at the same time:

  • constructing salt formulas

  • using the solubility table

  • salt structures

  • ionic notation of chemical equations

  • one of methods of obtaining salt

  • mastering laboratory activities

  • in addition, the types of precipitates formed

Also included within the scope of the subject “salts” are methods of making salt. However, the mere mastery of the salt preparation schemes is not enough to correctly write the course of the reaction, it is also necessary to use other parts of knowledge. For example, in order to correctly write down one of the easiest-to-write reactions of a metal with a non-metal, in addition to the concepts of metal and non-metal, the student must remember that in this reaction there is a transfer of an electron or electrons from an atom of a less electronegative to a more electronegative one and the formation of ions. The student must also remember that this way only the salts with simple anions can be obtained.

Another method of salt preparation, not much more difficult to write in molecular form than previously discussed, is the reaction of metal with acid if we only take typical examples of metals, such as magnesium, calcium or zinc, and non-oxidizing acids such as hydrochloric and sulfuric in not high concentrations. This reaction then produces salt and gaseous hydrogen. However, if taking into account the wider scope of this method and trying determine whether the reaction will actually take place and what its course will be, the student, in addition to the concepts of acid, metal, salt, chemical reaction, must skillfully use the available sources of information, among others electro-potential series of metals, since virtually most cases need to be considered individually. The student must take into account here whether the metal is active or chemically inactive, whether it reacts in the same way with oxidizing and non-oxidizing acids, whether the concentration of the acid has an influence on the resulting reaction products or whether the reaction takes place at all or not, e.g. due to passivation of the metal or other conditions. For example,

$Cu + HCl$ (diluted), room temperature → no reaction occurs

$Cu + HCl$ (diluted.), heated to a boil → no reaction occurs

$Cu + HCl$ (conc.), room temperature → no reaction occurs

$Cu + HCl$ (conc.), heated to a boil → no reaction occurs

$Cu + H_2SO_4$ (diluted), room temperature→ no reaction occurs

$Cu + H_2SO_4$ (diluted), heated to a boil → no reaction occurs

$Cu + H_2SO_4$ (conc.), room temperature → no reaction occurs

$Cu + H_2SO_4$ (conc.), heated to a boil → reaction occurs, SO_2, salt and water are formed

$Cu + HNO_3$ (diluted), room temperature → reaction occurs, NO, salt and water are formed

$Cu + HNO_3$ (conc.), room temperature → reaction occurs, NO_2, salt and water are formed

Fe + H_2SO_4 (diluted), room temperature → reaction occurs, $FeSO_4$ and H_2 are formed

Fe + H_2SO_4(conc.), room temperature → no reaction occurs

Al + HNO_3 (conc.), room temperature → no reaction occurs

Oxidizing acids (diluted and concentrated HNO3, diluted and concentrated $HClO_4$, hot concentrated H_2SO_4) react with both active and noble metals by reducing their acid residue. The corresponding oxides are the products of these reactions.

That brief analysis showed that in order to determine if the reaction of a metal with an acid will occur pupils have to make a thorough analysis of the problem, sometimes including searching through academic od scientific literature. After that a synthesis of the information is needed.

The similar problem of analysis and synthesis of information, based on previous knowledge, literature and laboratory work concerns the remaining methods of obtaining salts. These reactions require depending on the educational level general or detailed knowledge about oxides and their properties and reactions. Moreover the knowledge of hydroxides and acids is required. On one hand basic oxides can react with acidic oxides or with acids, however conditions of the reactions can vary. On the other hand acidic oxides can react with hydroxides. Hydroxides and acids can react also with amphoteric: metals, oxides and hydroxides to form salts. Each of these methods has its own limitations.

In addition to the precipitation method described above where as substrates other salts have been used and using a solubility table is useful or knowing some rules about it is required there are at least three other methods that use other salts as a substrate. One is the reaction of hydroxide with a salt, where usually other hydroxide precipitates. The second one is the reaction of salt with acid where stronger acid displaces weaker acid, sometimes leading to its decomposition. Such a situation takes place when for example carbonates are used in the reaction. Reaction of metal with the salt is the third one. In this case skill of using electro-potential series is highly recommended. The analysis of the place of metal in series allows the pupil to predict if the displacement of the metal from its salt caused by other metal will take place.

The scope of the concept salts also includes other topics and issues. All those require thorough analysis of the problem and can be learnt with scientific thinking.

Summary

The paper revealed that effective learning about salts is a very complex issue, which requires a thorough analysis of the problem and well-grounded knowledge concerning other chemistry topics. In order to gain that knowledge a systematic work is highly recommended. One of the best approaches to learning the salts and also chemistry is scientific thinking and reasoning.

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SCHEME OF THE cleverCHEMHELPER PROGRAM BASED ON BLOOM'S REVISED TAXONOMY

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Abstract

The article presents an idea for an interactive program dedicated to pupils. The program is to be an aid enabling the individualisation of the process of teaching the skills of writing chemical equations. It should be mastered by every pupil during chemical education in primary school in Poland. The complexity of the mental operations involved in writing a correct chemical reaction equation makes it difficult for pupils to write and agree chemical equations. Individual learners have difficulty writing chemical equations at various stages. One pupil has difficulty writing down the symbols of individual elements. Another pupil cannot write down the sum formula of a given chemical compound correctly. Yet another pupil has difficulty balancing the chemical reaction equation. There are many problems and little time in lessons. In Poland the group of pupils has about 28 people. Also, the small number of lessons devoted to learning chemistry means that many pupils finish their education without mastering the ability to write chemical equations. The proposed concept of the program, with the key features of the construction of the leading sentences based on the revised Bloom Taxonomy, may be a solution to this situation. Interactive program posted on the website to help the pupil write down each step of the chemical reaction equation. An important element of such a program is accessibility to pupils regardless of their parents' financial status. The difficulty in constructing a schema of such a tool is that the didactic aspects are included in the programming language. It is important that the computer program has a user-friendly interface. The program should allow the pupil to use only those hints that are necessary for him, and not force him to tediously go through the stages. The article presents the multidimensional construction of this tool called cleverCHEMHELPER.

Key words

chemistry in primary school, chemical equations, interactive computers program, cleverCHEMHELPER, scientific thinking

Background, framework and purpose

The ability to write chemical equations is essential for any chemist. It is also one of the competences that every pupil should acquire during chemistry education in a primary school in Poland. The complexity of the mental operations involved in writing a correct chemical reaction equation make it difficult for pupils to acquire this skill. Individual pupils encounter difficulties in writing chemical equations at different stages of this notation (Nodzyńska, 2009). One pupil has difficulty writing down the symbols of individual elements. Another pupil does not know how to correctly write down the sum formula of a given chemical compound. Yet another pupil has difficulty balancing the chemical reaction equation. There are many problems, and little time in lessons (Nodzyńska, 2005).

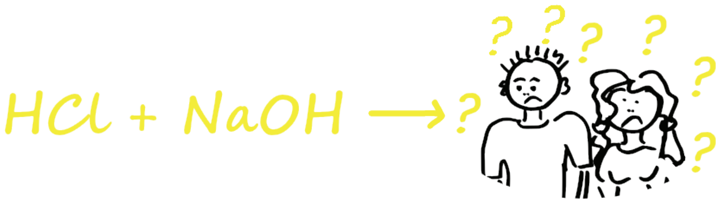

Fig. 1. Writing chemical equations often presents pupils with many challenges.

With around 28 pupils per class. A small number of lessons devoted to studying chemistry, for many of them end up not mastering the ability to write chemical equations. The solution to this situation can be a properly constructed interactive program placed on the website, helping the pupil to write down each step of the chemical reaction equation. An important element of such a program is accessibility to pupils regardless of their parents' financial status. The difficulty in constructing a schema of such a tool lies in the inclusion of didactic aspects in the programming language. It is important that the computer program has a user-friendly interface. The program should allow the pupil to use only those guidelines that are necessary for him, and not force him to go through the stages tediously.

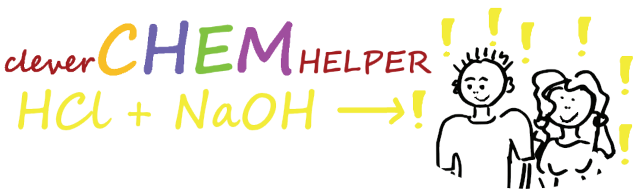

Fig. 2. cleverCHEMHELPER is an application that is to become a real help for a large group of pupils and at the same time a research tool.

This article presents some elements of the concept cleverCHEMHELPER based on Bloom's revised taxonomy. Creating tools based on Bloom's revised taxonomy is used in teaching (Tavares, Tavares 2010). In this application has developed a guiding sentence scheme for the pupil to help develop the ability to write chemical equations based on building lasting connections with the pupil's knowledge. An important aspect of the developed classification, based on Bloom's revised taxonomy, is the creation of the pupil's independent work. Work adapted to his individual pace of development (Nodzyńska, 2005). Guiding the user through elements that he cannot and does not understand. The independence of this process guarantees the ability to deal with each equation without the need for an additional person (teacher or tutor).

cleverCHEMHELPER

Fig. 3. The program is designed to shape the independence of pupils.

The scheme of the cleverCHEMHELPER:

Program cleverCHEMHELPERin the didactic sphere is based on three groups of helper sentences for the pupil based on Bloom's revised taxonomy.

Main assumptions of the didactic concept of the program cleverCHEMHELPER for learning to write chemical equations:

Three groups of hints (helper sentences for the pupil) were created for each chemical reaction equation included in the program cleverCHEMHELPER. Three levels of chemical reactions comply with the requirements of the Polish core curriculum and have been divided into three levels of difficulty:

- easy,
- medium,
- difficult.

The groups of sentences leading the pupil were defined in the same way as in Bloom's taxonomy. This key to describe groups of lead sentences is needed for the transparency of the teaching process. This allows the teacher-researcher, based on the analysis of the record of steps chosen by the pupil, to determine which spheres the pupil has a problem with. Such knowledge allows for real assistance to pupils in their process of acquiring the ability to write down chemical equations. The described three groups of auxiliary sentences for the pupil result from the spheres distinguished in Bloom's taxonomy (Bloom, Engelhart, Furst, Hill, Kratwohl, 1956):

- cognitive (knowledge) sphere. This category is intended for those pupils who do not remember the theoretical elements presented in chemistry lessons.

- affective sphere (attitudes and abilities). It is a category dedicated to those pupils who know. They remember the theory needed to solve the task, but are unable to translate it into practical activities. They are missing skills.

- psychomotor sphere (skills). It is intended for those pupils who know. They know the theory, they have skills to a certain extent, but they want to be specialists in writing chemical equations. I want to deal with unusual tasks. It is a chance to move from school interest in chemistry to being connected with it in your professional career.

Fig. 4. Human knowledge is like a network that can always be enriched by correlating new knowledge, skills, attitudes and abilities with those that he already has (Nodzyńska, 2010).

The three groups of pupil statements described above are based directly on Bloom's taxonomy. For the purposes of cleverCHEMHELPER, these are defined as the highest level black boxes. In each main box, we put helper sentences for pupils that follow the main categories for Bloom's concepts.

Technical aspects of the program cleverCHEMHELPER:

The very structure of the program in terms of programming requires solving the following technical problems:

- the user interface should be pupil-friendly and encouraging to use the website on which the program will be placed;

- the content included in the program must comply with the principles of chemistry didactics, e.g. taking into account superscripts and subscripts;

- placing a module that allows to track what decisions the pupil made while working with the application;

- structure for generating helper sentences that is tailored to the needs of a particular pupil.

Bearing in mind the above postulates, correlated with the didactic concept based on the revised Bloom taxonomy, a schematic of an application designed to learn to write chemical equations called cleverCHEMHELPER was created.

Elements of the application cleverCHEMHELPER:

1. learning to write chemical equations - the part dedicated to pupils;

Each pupil is a unique and unique personality. He has the knowledge, skills and predispositions that distinguish him, resulting in specific needs and achievements in the process of his own education. Such an individual approach in the teaching process allows each pupil to develop a sense of educational success. The need for the individualization of the teaching process has been particularly highlighted by the pandemic. Pandemic has had a major impact on changing the teaching style in most countries, but also showed the weaknesses of education. She has proved the need for continuous application of the individualization of teaching. This important didactic element motivated the development of the application cleverCHEMHELPER. Helper sentences for the pupil are adapted to their answers and needs. Their generation based on Bloom's revised taxonomy ensures the holistic development of pupils in terms of knowledge, skills, attitudes and abilities. This structure of lead sentences allows you to effectively master chemical equation writing skills early in the course of chemical learning. Work in all these dimensions provided by the program cleverCHEMHELPER allows you to permanently master the ability to write chemical equations.

2. collecting data on the course of the thought process - a part dedicated to research.

Getting to know the thought processes of contemporary pupils (Nodzyńska, 2000) - digital natives - allows you to revise the ideas teaching about how to master the ability to write and reconcile chemical equations. Obtaining data for scientific analyzes using the application cleverCHEMHELPE. allows you to determine how many authentic all mental operations are needed for a pupil to obtain this skill at a high level. Advantage cleverCHEMHELPER is that application gives a real picture based on facts. Logins containing information, which prompts were most often chosen by pupils, what is the time of working with the application, what equations of chemical reactions were most often chosen by pupils. Do elements such as gamification or praise constituting additional external motivation have real significance? Does it matter for pupils to break down chemical equations into levels of difficulty? (Jagodziński, Wolski, 2011).

3. economic availability of the program - the part that equalizes educational opportunities.

An important dimension of the program is making it available to as many pupils as possible. Regardless of their parents' financial status or place of residence. This dimension makes it possible to take into account the entire population, which should have the same access to education. It also gives pupils the opportunity to self-study in all conditions: stationary education, distance education, education in times of prosperity or education in times of economic instability.

The first window of the program - questions recognizing the user:

A pupil logging in to the application window uses his / her nickname.

When logging in for the first time, he answers short questions:

1. How are you coping with writing and reconciling chemical equations? Using the five-point Likert scale:

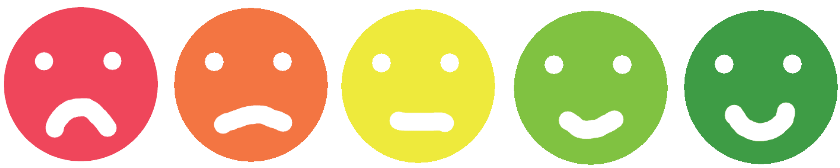

Fig. 5. The Likert scale proposed to the user.

2. Gender (single-choice closed question):

- girl

- boy

3. How old are you (enter a number)?

Every five consecutive logins on the site, a question about the pupil's well-being reappears: How are you coping with writing and reconciling chemical equations? (Reuse of the five-point Likert scale.)

The main program

The main program window contains fixed elements that the pupil has access to all the while working with the program:

1. the periodic table;

2. mini chemical tables [contain basic formulas, eg formula for density];

3. solubility tables;

4. particle calculator;

5. macro film world;

6. micro animation world (Nodzyńska, 2005).

This part allows the pupil may to see the need to expand their knowledge and improve their skills. Responsible for building internal motivation to learn. In the record of work with the program cleverCHEMHELPER includes element related to the use of individual groups of available information.

Another element in the main window of the program cleverCHEMHELPER are groups of chemical compounds to choose from for the pupil resulting from the Polish core curriculum:

1. Oxygen, hydrogen and their chemical compounds. Air.

2. Hydroxides.

3. Acids.

4. Salts.

5. Carbon and hydrogen compounds - hydrocarbons.

6. Hydrocarbon derivatives.

7. Chemical substances of biological importance.

In each group of chemicals reactions, we have three levels of difficulty for each example chemical equation: easy, medium, and hard. For each chemical reaction equation, helper sentences are prepared that correlate with the previously discussed spheres: cognitive, affective and psychomotor. For pupils which have difficulties related to a selected sphere, e.g. cognitive, introductory helper sentences were prepared, in which verbs were used to describe the learning goals assigned to this sphere. (Tříska, Čtrnáctová, 2017)

Additional personalization of the tool consists in moving between the spheres according to the needs of the pupil. This is an interesting dimension that is also worth testing.

Summary

The developed concept of the application cleverCHEMHELPER based on Bloom's taxonomy is to ensure comprehensive development of pupils. Comprehensive shaping of all spheres distinguished by Bloom and his successors allows for full anchoring of new knowledge, skills, attitudes and abilities in those developed earlier. The legitimacy of creating new tools of this type is related to the pupils developing the attitude of independent creators of their own education process. This is also justified by the change in the way people belonging to the generation of digital natives function and learn. This generation has to deal with a much greater amount of information that reaches them every day, and such a situation affects their concentration, the amount of information they remember and the precision of the skills they develop. Therefore, an important functionality of the developed tool is the collection of scientific data that may affect the more effective creation of the modern didactic process.

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DOES TEACHING CHEMISTRY EDUCATE STUDENTS' SCIENTIFIC THINKING?

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Abstract

Student research shows that chemistry is one of the less-liked school subjects. It is widely believed that this state is responsible for the level of difficulty and abstraction of chemistry. However, my recent research shows that the problem may be the inability to transfer knowledge by textbook authors (both traditional and e-textbooks).

In chemistry textbooks many types of errors were diagnosed: incorrect illustrations, names of chemical compounds incompatible with IUPAC, outdated or incorrect definitions, the use of different definitions of the same concepts even in the same lesson, the use of previously undefined concepts, too many concepts introduced in one lesson, language mess consisting in the use of colloquial terms, lack of precision and logic in sentences. The variety of these errors and their accumulation puts into question the usefulness of these textbooks in education. And the fact that they have gone through the review process positively indicates that such an imprecise and incorrect way of communicating in chemistry does not bother anyone.

A detailed analysis of the Core Curriculum and chemistry textbooks shows that very often the contents presented therein are mutually inconsistent or even contradictory. This situation not only confuses students' minds but also disturbs the learning of logical and scientific thinking.

Key words

scientific thinking, analysis of the core curriculum and textbooks of chemistry

Background, framework and purpose

Scientific thinking is the ability of people to form ideas and mental representations rationally and objectively. It begins with observations and experiences that generate research questions and hypotheses. Based on the research questions, verification methods are developed that confirm or reject the hypotheses. In life sciences, verification methods are based on experience and measurements. Therefore, it is widely believed that teaching biology, chemistry or physics develops scientific thinking in students.

As science education elements are introduced even in kindergarten, it is important that science knowledge is graduated step by step. When it comes to chemistry education it is important that the usage of models (and connected to the theoretical concepts) on subsequent stages of education complements and expands upon the models adapted on preceding levels. So that knowledge would expand (Fig. 1.).

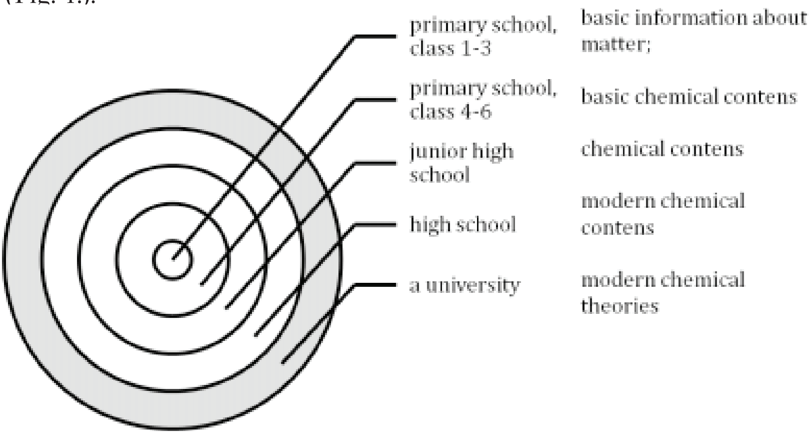

Fig. 1. Chemical knowledge to the next levels of education (in theory).

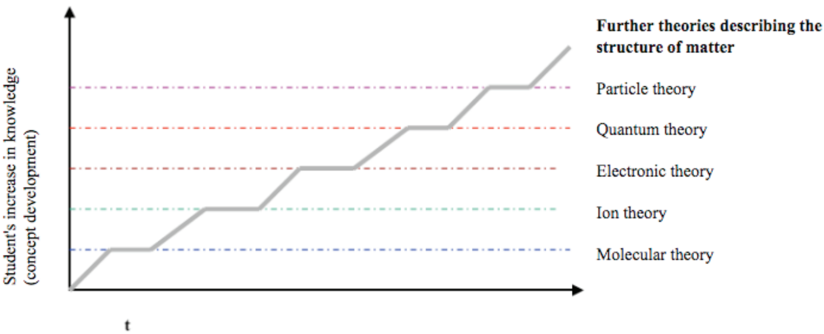

Fig.2. Chemical theories on the next levels of education (in Polish practice).

However, in Polish Education that does not happen. On each stage of education, the chemical models that are used are changed and theories. Figure 2 shows how in consecutive stages of education we change the theory of chemicals and thus used models.

When several different theoretical models are used in the educational process, learners may experience cognitive dissonance (Festinger, 1957). Cognitive dissonance is a state of unpleasant mental stress that occurs when a person perceives / feels simultaneously two or more elements, attitudes (e.g. thoughts or information) that are in conflict with each other. This situation can cause problems in education. Cognitive dissonance occurs when the student has to apply various theoretical models to solve similar problems (Lwowskij, 1989).

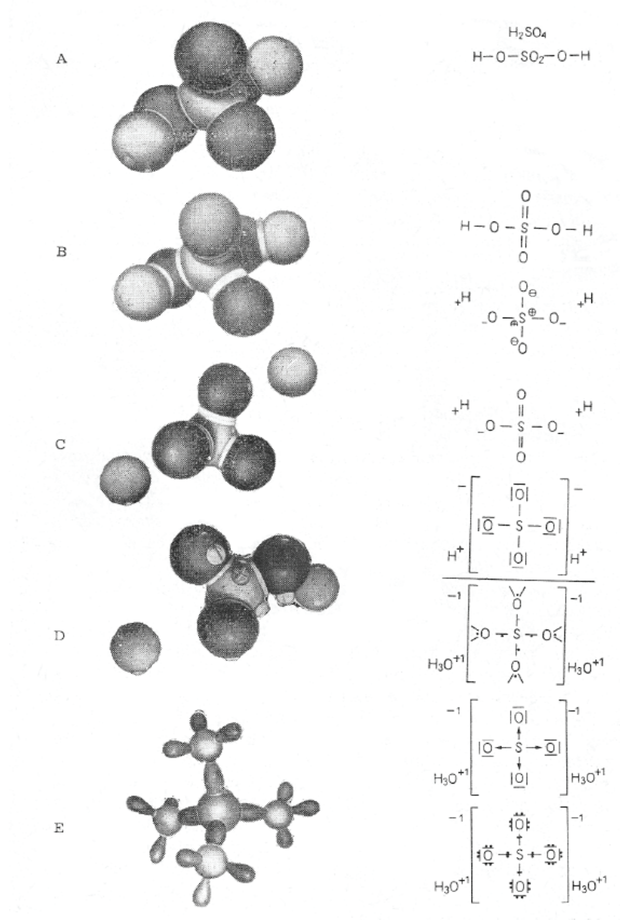

Fig. 3. Change of the sulfuric acid (VI) molecule model with the change of theory (Soczewka, 1975).

In Poland, the transition from particular theories of molecular structure to the corresponding models (on the example of a sulfuric acid molecule) is described and presented in detail by Soczewka (Soczewka, 1975). We can see the changed theory is followed by the change of the model used (Fig. 3).

Thus, during school education, students encounter several different models and theories in turn. Is this diversity a positive factor? Is there really only one theory at a given stage of education?

In teaching, this situation is particularly unfavorable and leads to disruption of the learning process, which in some situations can even cause the following unfavorable phenomena: negative transfer, generalization of the stimulus and pro- and retroactive interference. This way of education also disturbs scientific thinking.

Methods

As part of the research, an analysis of the Chemistry Core Curriculum, as well as textbooks and teaching aids for chemistry, were carried out. The following methods were used for the analysis: graph method, matrix method and logical analysis (Nodzyńska, 2015).

Results

As a result of the analysis, several types of errors disturbing the process of logical and scientific thinking were distinguished.

Undefined terms

The analysis showed that many textbooks and teaching aids introduce concepts and terms that have not been previously explained or defined. This situation most often applies to two-word terms (eg: oxidizing acids, organic acids, volatile acids, strong acids, characteristic reaction, vacuum distillates, ...). In this case, the authors believe that the term "main" has been defined and that the second word is simply an adjective familiar to students. But does the term "strong" mean the same for man and acid? By understanding the term "characteristic" in everyday life, will the student correctly define the term "characteristic reaction"? The same goes for terms that are common in everyday use - they, too, are often not defined (such as element, acid precipitation, hard minerals, passivation, octane number, non-metal…). In this case, based on imprecise, common perceptions, large misunderstandings can arise and erroneous, false knowledge may arise in the minds of students. However, sometimes even typically scientific terms appear without explanation (eg. Oxidation state, hydrates, Mohs hardness scale, ...).

It is true that the concept of non-foundationism assumes that our thinking is devoid of unshakable foundations, but introducing concepts without defining them (or even explaining them) makes it difficult for the student to create the correct mental network in his mind. And it makes it difficult, if not impossible, to find cause-effect relationships between successive concepts, which is contrary to scientific reasoning.

Obsolete theories or several different theories at once

Often in chemistry textbooks, authors use outdated scientific theories - arguing that more modern theories are too difficult at this stage of education (which, of course, is not true). This is a specificity of chemistry - in the textbooks for biology or physics, outdated theories are not presented. Sometimes in chemical education, several different theories or definitions of the same concepts are used simultaneously. We will not meet such activities in teaching biology or physics.

The structure of matter

In the Polish CC and textbooks, various theories of the structure of the atom are presented and applied at various stages of education. The first is the Bohr model of the atom, followed by the quantum model of the atom. This arrangement creates a negative transfer and blocks students' minds from assimilating the new, correct model. Additionally, the comparison of the structure of the atom to the structure of the solar system known to students before, causes a strong association and consolidation of this idea. To explain bond formation using the Bohr model of the atom, the octet theory is used. Forgetting that there is no octet theory (or we can talk about the octet rule, i.e. the striving of some elemental atoms to obtain the electron configuration closest to the noble gas in the periodic table of elements, i.e. to obtain an energetically favorable electron system). However, numerous exceptions to the octet rule are known:

- hipovalent compounds having atom (s) with an incomplete octet, e.g. carbenes or multiple boron compounds (e.g. BF_3) with six valence electrons;

- hypervalent compounds having atom (s) with more than an octet, e.g. halides of heavier elements 15 and 16 of the periodic table group, e.g. PCl_5 and SF_6,

- radicals having an odd number of valence electrons, for example, Cl•, nitric oxide(II).

It is also difficult to talk about the octet rule in the case of transition metal compounds (possibly rule 18?). Therefore, it seems that introducing a rule from which there are many exceptions and which then causes confusion in the description of chemical bonds types is unjustified. Most textbook writers do not even know when or how this rule came into existence. (The model of an atom in the form of a cube, the surface of which corresponded to the outer shell of an electron, with 0 to 8 electrons at its corners, was the basis of Lewis's theory of chemical bonding in 1802).

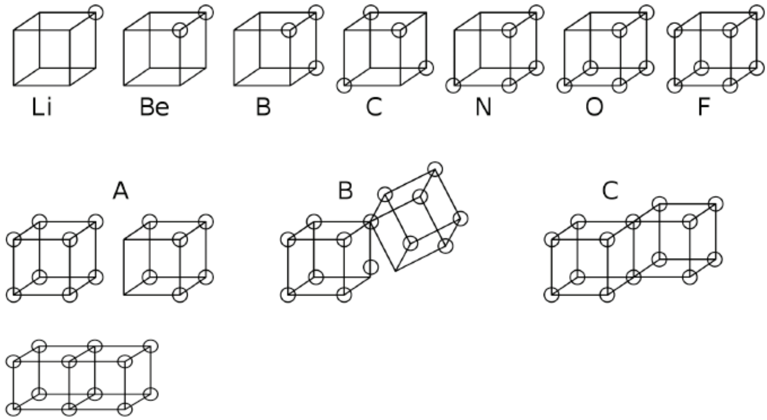

Fig. 4. Cubic models of atoms (from lithium to fluorine) and Lewis bond formation. (https://pl.wikipedia.org/wiki/Model_atomu_Lewisa).

Chemical bonds

At the beginning of teaching, chemistry textbooks introduce atomic, polarized and ionic bonds. Unfortunately, in the further part of the textbook, patterns or models of substances with ionic bonds are often drawn as if they had atomic bonds. Very often, incorrectly, the term molecule is used for substances with ionic bonds.

Another problem arising from the use of the Bohr model is the introduction of donor-acceptor bonds for inorganic compounds.

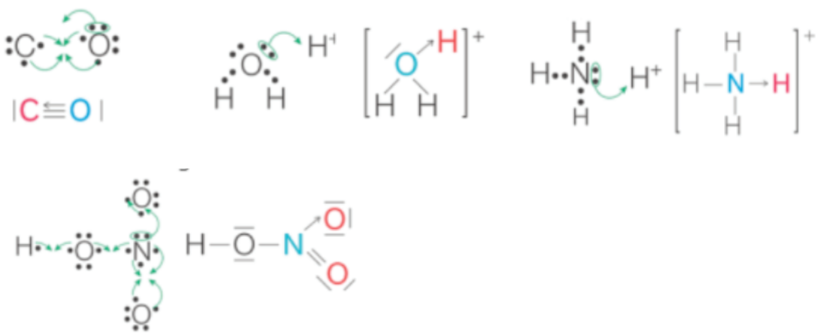

Fig. 5. Structural formulas showing donor-acceptor bond formation.

While it is logical to explain the structure of the NH_4^+ ion or the H_3O^+ ion using this bond, applying this explanation to some chemicals raises more questions than benefits. Let us look at the following structural formulas showing donor-acceptor bonds.

How to explain valence (C, O, N) when we define it as the number of bonds produced. (In CO, carbon forms 2 bonds and O 3 bonds. In H_3O^+ oxygen creates 3 bonds. In NH_4^+ nitrogen forms 4 bonds. And in HNO_3 nitrogen also forms 4 bonds.) It is impossible to explain this contradiction to the student.

And let's compare them with typical structural formulas.

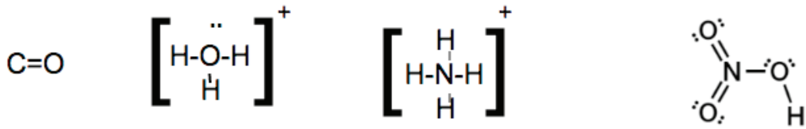

Fig. 6. Common structural formulas.

Why, when drawing a traditional structural formula, we mark the donor-acceptor bond as 1 line (ammonium and oxonium ion), once as 2 lines (nitric acid (V)) and once omitted at all (in CO)?

Thus, it seems that the introduction of donor-acceptor bonds for some inorganic compounds is not justified. It is a pity that the authors of the textbooks do not use the previously introduced quantum structure of the atom when explaining the formation of particles and their shapes.

The theory of acids and bases

In the Polish CC and textbooks, various theories of acids and bases are presented and applied at various stages of education. In primary school, the Arrhenius theory is used, and in high school, three at once: Arrhenius, Bronsted, and Lewis. In the process of chemical education, there is no reason to refer to the so-called Arrhenius theory. It is not only outdated but also scientific research shows (Paśko, Kurzawa, 2016) it causes negative transfer and generalization of the stimulus, which in turn makes it difficult for students to absorb newer, more correct theories. There is also no reason to treat students as people who are not able to understand the rather simple theory of Bronsted (students who start learning chemistry are over 13 years old, so they are already at the 4^{th} stage of Piaget's development - formal operations). Besides, numerous scientific studies have confirmed that Bronsted's theory is not more difficult than Arrhenius theory and that even elementary school students are able to understand Bronsted's theory (Nodzyńska, Paśko, 2004).

Some teachers try to justify introducing many definitions of acids and bases by the fact that the subsequent new definitions are really only extensions of previous theories (Fig. 7.). However, this is not true. The definitions sound completely different to the student, other compounds are classified as acids and bases, and we write the dissociation reaction equations differently. Definitions of terms in subsequent phases are not expanded or refined, but completely changed (Nodzyńska, 2010):

- definition of acids according to Arrhenius - acids are substances that dissociate in water into hydrogen cations (H^+) and the remaining anion (R^-);

- Bronsted definition of acids - acids are substances that can transfer protons;

- Lewis definition of acids - acids are substances that can be acceptors of a free electron pair.

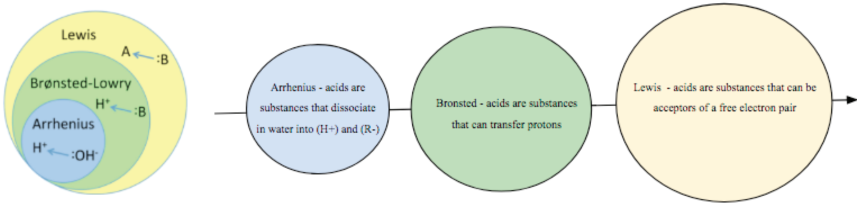

Fig.7. On the left, a drawing showing the popular belief in the expansion of next acid theories On the right is a drawing showing the real relationships between the various acid theories.

Therefore, the introduction and application of several theories of acids and bases disrupts the logical order in the student's mind and disrupts his or her reasoning process.

Additionally, in many textbooks and teaching aids, after the introduction of the Bronsted theory, the notation of H^+ instead of H_3O^+ is still used in the equations of electrolytic dissociation of acids. This creates unnecessary confusion in the minds of the students. And it makes it difficult for them to create the correct network of concepts in their minds.

A similar situation applies to the definition of the concept of 'neutralization reaction'. Very often there are different descriptions/definitions of this concept next to each other. Once this reaction is correctly defined as the result of the reaction of H_3O^+ ions and OH^- ions resulting in the formation of water. But at the same time, there is a definition that says that any reaction between acid and hydroxide that produces salt and water is a neutralization reaction. The concept thus defined leads to a misconception in the minds of students that any salt resulting from this reaction is neutral. Which of course is not true! Additionally, the simultaneous use of two different definitions must lead to misunderstanding!

Knowledge introduced in this way is easier to forget. This is because students that experience both proactive inhibition and retroactive inhibition.

Wrong definitions

Authors of textbooks and teaching aids for chemistry often try to simplify scientific knowledge so that it is understandable for students. However, this simplified knowledge cannot be wrong and it cannot create false ideas in the minds of the students.

Acids and bases

One of the most common mistakes is to define acids as substances that increase the concentration of H^+ ions in a solution. Of course, this is not true, the concentration of H_3O^+ (H^+) ions in the solution also increased by salts (derived from strong acids and weak bases).

What is worse, the authors refer to the fact that such a definition, along with an extensive commentary and justification, is given on p. 451 in the monograph "Didactic Chemistry", ed. PWN Warszawa 1990 (this book is the basis for teaching future chemistry teachers in Poland). A similar situation occurs when defining the term "base". In many teaching aids, we find the following statement: "Bases are substances that increase the concentration of OH^- ions in a solution." Which is not true because, for example, an aqueous solution of sodium nitrate(III) is alkaline, i.e. in the solution, we have more OH^- ions. This incorrect definition causes a misunderstanding of the alkalinity of ammonia. Also, in this case, the authors refer to the above-mentioned publication.

Weak bases

Sometimes there is not only a wrong definition but in the rest of the text, there are contradictory translations: "Weak bases are hydroxides, which are slightly soluble in the water (....), however, ammonia is a weak base, it is well soluble in water because in the aqueous solution of this compound (...) there is a relatively small increase in the concentration of hydrogen ions." Several problems can be diagnosed here:

1. The weak base definition is wrong because a weak base is a base that, upon dissolution in water, does not dissociate completely, so that the resulting aqueous solution contains only a small proportion of hydroxide ions and a large proportion of undissociated molecules of the base.

2. Putting hydroxides and ammonia in the same sentence may confuse students or they will think that ammonia belongs to the hydroxides.

3. This sentence may also raise the question: Does the good dissolution of

ammonia in water result from the fact that the concentration of hydrogen ions increases?

pH

In chemical education the simplified definition of pH = -log[H_3O^+] is still used. At this level of education, this is a sufficient approximation. However, in some documents, we can find the statement "The exact relationship between pH and the concentration of ions is described by the equation pH = -log[H_3O^+]" which is obviously not true. The pH of solution X in which a standard galvanic cell defined by IUPAC is immersed and for which the first electromotive force E_X has been measured is:

$$\mathrm{pH(X)} = \mathrm{pH(S)} + \frac{(E_\mathrm{S} - E_\mathrm{X})F}{RT\ln 10}$$

where:

F - Faraday constant

R - universal gas constant

T - temperature on the Kelvin scale.

ES and pH (S) - respectively the electromotive force of a standard cell immersed in a standard solution (e.g. distilled water) and the pH of this solution at a given temperature, given in the IUPAC table.

Using incorrect definitions in textbooks and teaching aids has no justification and is highly harmful. Students may feel that all knowledge given to them at school is false. The belief that science / knowledge can be false generates people who believe that the Earth is flat, vaccines are harmful … .

Noble gases

There are also numerous misconceptions about the chemical properties of noble gases. There is often information that noble gases are passive / chemically inert. This is not true according to the 'PWN' dictionary "passive" means inactive, "not participating in chemical reactions". According to the Dictionary of the Polish Language, passive means "indifferent, not showing any activity", and chemical passivity is "the inability to enter into chemical reactions, characteristic of some elements and chemical compounds." Although noble gases exist in the form of single atoms and not molecules like other gases, they also form compounds. Despite the very low reactivity of lighter helium materials, unstable helium compounds are known: the He_2 molecule (Schöllkopf, Toennies, 1994), the HeH^+ ion (Hogness, Lunn, 1925) and LiHe (Tariq, Taisan, Singh, Weinstein, 2013). It was reported to obtain the first solid helium compound, Na_2He (Dong, Oganov, Goncharov, Stavrou, at all 2017). The argon compound is also known - argon hydrofluoride, obtained at a temperature of about 40 K. Krypton and xenon form a larger number of compounds, including the stable red-orange compound, xenon hexafluoroplatinate. Radon is relatively the most reactive. There is a chemically stable compound - radon fluoride RnF_2.

However, even in the "Encyklopedia Szkolna - CHEMIA - praca zbiorowa" (Encyclopedia School - CHEMISTRY - Collective Work) there is a definition: "Noble gases are chemically inactive (...), high values of ionization energy make it possible to understand the lack of chemical activity of noble gases."

This way of defining the properties of noble gases causes further erroneous information, for example: "Each period in the periodic table of elements begins with an active metal and ends with a passive non-metal (noble gas)." It seems a good solution to say that noble gases are very slightly reactive.

Chemical individuals

At the beginning of their chemistry education, students are familiar with the definitions of atom, ion and particle. The teacher explains to them the differences between these chemical entities. It is the duty of students to know the definitions and be able to assign a given chemical individual to a given type, be able to describe their structure and differences between them and how they arise. However, later in the process of chemical education, incorrect phrases appear very often, violating the differences between atoms and ions e.g.:

"Seawater contains magnesium" - seawater contains ions, magnesium compounds;

"Magnesium is part of the chlorophyll molecule" - magnesium ions are part of the chlorophyll molecule;

"Iron is a component of haemoglobin" - iron ions are a component of haemoglobin;

"Zinc-rich foods" - foods rich in zinc compounds.

The authors' explanations that everyday practise shows that in both professional and popular science some content, e.g. concerning the distribution of elements in nature, their application or the elemental composition of chemical compounds, it is customary to use the "name of the elements", although it is known that it is o elements in the bound state since only a few elements exist in the free state, they are unacceptable. If we require precise chemical language from students, we should also use such language in textbooks and teaching aids. The student may didn't know (and he has the right) that the elements are bound because only a few elements are present in the free state. This way of creating information not only shows a lack of respect for the student, but also a lack of respect for logic and scientific precision.

The situation is similar for atoms and chemical compounds. Often in the description, concepts from the description of the micro- and macro-world are mixed. Examples of incorrect and correct wording with a commentary are shown in the table below.

Tab. 1. Incorrect and correct wording with a commentary are shown in the table below.

Incorrect	Correct wording or a commentary
“In these compounds, individual atoms ...”	“In these compounds, individual chemical entities ...” or “In these compounds, individual atoms, ions or groups of atoms ...”
“The main component of the hydrosphere is hydrogen and oxygen”	“The main component of the hydrosphere is water, the molecules of which are made of interconnected hydrogen and oxygen atoms.”
“Oxygen and silicon are components of the earth’s crust”	Oxygen and silicon do not exist in the elemental form in the earth’s crust
“Sulfur is the constituent of car tires”	Tires do not contain elemental sulfur
“... water molecules ... consist of hydrogen and oxygen atoms ...”	“... water molecules ... consist of interconnected hydrogen and oxygen atoms ...”

The authors’ translations: “every time we say that a molecule consists (or is made of) of some atoms, we mean that they are joined, not separated” seem frivolous. It is not for the students to guess what the author of the textbook meant.

Metals and their alloys

A similar situation occurs in the case of metals and their alloys. At the beginning of their chemistry education, students learn to distinguish elements from their mixtures (e.g. alloys). However, in further education, the two terms are often used interchangeably (incorrectly)

Using the name of the element aluminium when we mean its alloys (in Polish we have two different terms: the element aluminium in Polish is “glin” and its alloys are “aluminium”). A similar situation occurs when the name of the alloy is the same as the name of the element (gold, silver). In this case, the term alloy is often omitted, e.g. rings are made of gold. This is not true. You cannot make a ring of pure gold, because it is very soft.

Obsolete nomenclature, colloquial terms

In the textbooks, there are also common names of chemical compounds. Often these names are not used for a long time, e.g. bitter salt, saltpetre, caustic soda, caustic potash, bitter salt, English salt, nitrogen saltpetre, ammonium saltpetre, Chilean saltpetre, vinyl chloride,

The use of common names instead of systematic ones takes place, especially in organic chemistry. This approach makes students learn chemistry by heart. And chemistry ceases to be a science that requires logical thinking and ordering content. In the case of providing a common name (e.g. glycerol), the student must remember what formula this chemical compound has. However, if we give the student a systematic name (propane-1,2,3-triol), the student is able to create a structural formula by himself.

Therefore, all names of chemical compounds in the text of the manual should be systematic names. As second, complementary, common names can be given - as long as they are commonly used, for example, in biology or geography lessons. Adding common names, currently not commonly used, seems to me not only an unnecessary burden on students' memory but also causes information chaos and does not allow students to properly organize their knowledge. It also unteaches them to use theoretical knowledge in practice (e.g. to use the theory of the principles of naming organic compounds to name organic compounds based on their structural formula, or to draw a structural formula based on a systematic name).

Linguistic mess

There is often a linguistic mess in textbooks and teaching aids for chemistry. Often, instead of the phrase "write down and balance on the chemical reaction equation " the phrase "write the chemical reaction" appears. These sentences are not equivalent. Reaction writing may mean its verbal description, without the use of chemical formulas and stoichiometry. (The sentence "write the chemical reaction equation" without the term "balance" may cause the student to think that he or she does not need to balance the chemical reaction equation.) Sometimes there is also the phrase "This reaction can be illustrated by an equation". The course of a chemical reaction can be illustrated by a film, photo or drawing. But this reaction can be written by the chemical reaction equation. The phrase "Write a structural formula" also appears frequently. A more correct wording in Polish is "Draw a structural formula".

Notoriously, materials for students use colloquial terms instead of chemical ones, e.g .:

- sugar (food grade, i.e. sucrose) and sugar (as the name of the carbohydrate group),

- salt (table salt, i.e. sodium chloride) and salt (as the name of a family of compounds),

- alcohol (ethanol) and alcohol (as the name of a family of compounds).

In a chemistry textbook, colloquial terms (sugar, salt, alcohol) should not be used when we think of specific chemical compounds (sucrose, sodium chloride, ethanol).

Often, ambiguous terms are also used without explaining which meaning should be used this time, e.g .:

- water (as a mixture) and water (as a chemical compound),

- fossil coal ("węgiel" in Polish) and carbon as an element ("węgiel" in Polish).

Sometimes this mess is even about the writing of chemical equations. There is a lack of consistency in writing arrows one way (for irreversible reactions) or two directions (for reversible reactions). In the case of gases, arrows with the tip pointing upwards (showing that these are gases leaving the reaction medium) are ignored. Likewise, for substances which precipitate, downward arrows are ignored. The authors' explanation that adding arrows would render the reaction equations illegible seems stupid!

Lack of logic and consistency

The most common error in chemistry textbooks is inconsistency. Once a concept or theory is introduced is not applied later in this manual. For example, after introducing ionic bond - models of metal oxides, hydroxides, salts are drawn as if there is no ionic bond. After the introduction of the Bronsted theory, the H^+ ion is still written in the acid dissociation equation. After the introduction of the S_8, P_4 particles, the S, P notations are used later in this manual. After the introduction of the quantum model of the atomic structure, references to the Bohr model still appear. It is obvious that such a lack of consistency causes chaos in students' minds and prevents them from constructing the correct grid of concepts.

In many chemistry textbooks and teaching aids, to write down the formula of an aqueous ammonium solution, the formula $NH_3{\cdot}H_2O$ is used. However, it has no logical justification. After all, we do not write the aqueous HCl solution as $HCl{\cdot}H_2O$ (or as $HCl_{(aq)}$), similarly, we do not write the aqueous solution of H_2S as $H_2S{\cdot}H_2O$. To write the formula of an aqueous ammonium solution, it is sufficient to write $NH_3 + H_2O$ or $NH_{3(aq)}$. In addition, the $NH_3{\cdot}H_2O$ record may suggest to students that it is a hydrate, which is not true.

Sometimes the logic of the next sentences left much to be desired.

The next three sentences do not form a logical sequence: “The basic building blocks of the Earth are chemical elements. They form millions of various chemical compounds. Only a few elements occur in nature in a free state; these are, for example, oxygen, nitrogen, sulfur, platinum, gold, silver, copper. “ The question arises: What is the basic building block of the Earth: elements or chemical compounds?

Sometimes it is difficult to predict what the student will understand from a given sentence, for example: “At a temperature of about 20^{o}C, lead does not react with acids, with which it forms sparingly soluble salts.” This sentence generates further questions, for example: Is lead finally reacting with acids or not? At what temperature? And with acids with which it does not form soluble salts, at what temperature (or not) does it react?

Oftentimes, the entire chemistry textbook is not logically structured because concepts appear before they are defined, and concepts that were defined earlier are not used later.

Forms of conveying the content

Unfortunately, in most chemistry textbooks, ready-made information is given to students (transmission learning). There is a lack of explanation and translation of individual content (no constructivist approach). This form is more suited to a cheat sheet or a skript than to a textbook. The content once explained in the manual does not appear to explain and illustrate the next educational content. This contradicts the Latin maxim “Repetitio est mater studiorum”. Nor does such a textbook develop cause and effect thinking, which is the basis of scientific thinking.

Conclusions and implications

Scientific reasoning is often considered the most advanced form of human thinking. Therefore, an extremely important goal of education in the field of science (including chemistry) should be to equip students with tools for critical analysis of information, i.e. teaching them scientific reasoning. However, it seems that the way the content is presented in chemistry textbooks and teaching aids is inconsistent with the above assumption. Using undefined concepts, giving incorrect definitions, applying several theories (sometimes contradictory) at the same time is not conducive to ordering facts, performing logical operations and finding cause-and-effect relationships between chemical concepts. Also, the lack of precision and logic in formulating sentences, or the use of colloquial terms in textbooks is far from structured, logical scientific thinking. Providing dry facts in handbooks without explanations and without argumentation is also far from the scientific way of thinking. It seems that the majority of Polish chemistry textbooks not only do not develop scientific thinking in students, but on the contrary cause it to disappear.

Despite the fact that scientific reasoning is characteristic of scientific research and education in the field of exact, natural and technical sciences, it is also necessary in everyday life. In everyday life, we refer to scientific reasoning, e.g. by analyzing leaflets for medicines and cosmetics, food products. These days, we are bombarded with information, many of which are false. Some authors try to undermine the credibility of scientific claims (including anti-vaccination movements, denying anthropogenic climate warming, rejecting the theory of evolution). These pseudo theories are often put forward in a pseudoscientific relay race to mislead low-profile audiences.

Therefore, it seems that chemistry textbooks should be rewritten. And their guiding principle should be to develop scientific thinking in students.

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