GRANT journal
ISSN 1805-062X, 1805-0638 (online)
Vol. 13, issue 01
EUROPEAN GRANT PROJECTS | RESULTS | RESEARCH & DEVELOPMENT | SCIENCE

Interdisciplinarity of science education in Slovakia - use of mathematics in chemistry

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Grant: 2021-1-SK01-KA220-VET-000027995
Název grantu: Digitization of chemical experiments to improve quality and support the teaching of chemistry in secondary schools
Oborové zaměření: AM - Pedagogika a školství

Abstract Teaching chemical calculations appears to be a challenging and difficult job for teachers because solving chemical calculations requires students' mathematical skills. The main aim of this paper was to verify the implementation of chemical calculations in chemistry teaching by analyzing curriculum documents and comparing them with the real situation from teachers' perspectives. The results point to the need for a change in the approach to teaching chemical calculations, as pupils have indeed significant deficiencies in basic mathematical skills, they also have difficulty in identifying the problem of the task, as they are often unable to understand the technical text. Teachers should focus more on specific activating methods to facilitate and motivate pupils to solve them, such as an appropriate solution algorithm, contextual problems, problems applied to everyday life and problem-solving tasks.

Keywords: science educations, interdisciplinarity, chemical calculations, mathematics

1. THEORETICAL BACKGROUND

Teaching chemical calculations is challenging not only for students but also for teachers because solving chemical calculations requires students' mathematical skills. Most students find it difficult to connect knowledge from different subjects and to put all the information received into context. It is a subject that is abstract and there is little connection to real life in schools. Chemical calculations are a widely discussed area of chemistry in many countries (Rusek, 2022; Scott, 2012; Srougi and Miller, 2018). Several researches consider the topic of chemical calculations to be critical for several reasons: it is a link between mathematical skills and chemistry content, and students find it difficult, precisely because of the connection between mathematics and chemistry (Drummond, Selvaratnam and African, 2009; Leopold and Edgar, 2008). Also, students often find the topic unimportant even unnecessary.

The reasons for the unpopularity of chemical calculations as well as the failure to solve them can be different, it may not be only mathematical literacy or the use of mathematics in solving problems, but the problem can occur even before the actual solving of the task, when the students do not understand the submitted text or the assignment correctly and here comes the question of whether the students know how to work with the technical text, whether they can understand it correctly to be able to find the appropriate algorithm for solving the calculation? Possible explanations for the lower ability of students to solve chemical calculations may be due to the lack of students' ability to work with concepts as well as their ability to identify the problem in the task (Cepria and Salvatella, 2014; Tóthová, Rusek and Chytrý, 2021).

Reading comprehension is critical for science performance and improves the interaction between reading comprehension and the linguistic features of written text in science subjects (Wellington, J. Osborne, 2001; Cruz Neri, Guill and Retelsdorf, 2021).

Research on mathematical verbal problem solving shows that differences in achievement are not only due to differences in the level of cognitive ability of students, but that motivation also plays a role. The influence of the attractiveness of the context of a mathematical verbal problem has a positive effect on the problem solving process and, under certain conditions, can lead to an increase in students' efforts to solve them and, in some cases, to a slight increase in the success rate of problem solving (Havlíčková, 2020).

In contrast to classical (rigid) tasks, verbaltasks require text processing, comprehension and problem implementation. Only in this way can individual relationships be understood and the correct mathematical model or algorithm be used to solve the problem. And computational tasks are a special form of tasks and therefore require problem-solving skills. A considerable amount of research emphasizes problem-solving skills as an essential factor in chemistry education (Bellová, 2018). Problem-based learning (PBL) easily finds ways of solving problems that one may encounter in real-life situations (Akinoglu and Tandogan 2007). Previous research shows that science teachers often focus their explanations in the classroom on real-world problems (Bellová, 2018).

2. CHEMICAL CALCULATIONS IN SLOVAK CURRICULUM DOCUMENTS

The State Educational Programme (SEP) in Slovakia is a binding document that sets out the general objectives of education and the key competences towards which education should be directed**.** The

State Educational Programme also defines the framework content of education, dividing the content of education into seven educational areas: language and communication, mathematics and information processing, man and nature, man and society, man and values, art and culture, health and movement (SPU, 2020). According to the current SEP curriculum, the subject of chemistry belongs to the area of 'Man and Nature' together with the subjects of biology and physics.

The educational standard consists of content and performance standards. The content standard defines the core curriculum (mainly concepts) that the student should understand and be able to explain. The performance standard specifies the requirements for knowledge, competence and application of knowledge, especially in relation to everyday life and students' attitudes. In lower secondary education (primary schools), pupils have the chemical calculations included in the content standard in one thematic unit, where the concepts of substance quantity, molar mass and composition of solutions such as mass fraction and substance concentration are included. According to the performance standard, students should know these concepts and be able to use them in simple calculations (NIVAM, 2020). In upper secondary education (grammar and high schools), the topic of chemical calculations is included in several thematic units (System of substances, Calculations in chemistry, Chemical reactions, Organic substances, Thermochemistry). According to the performance standard, students should be able to calculate given quantities from simple balances and from chemical equations, while in chemical calculations they should progressively develop their thinking from the basic competences of scientific work to the integrated competences of scientific work (SPU, 2020).

In the characteristics of the educational area of Man and Nature it is stated how it is necessary to show students that the boundaries between the different disciplines of natural sciences are only formal and that the study of nature requires a multidisciplinary and interdisciplinary approach. It is also necessary to use not only theoretical but also empirical research methods, which complement the theoretical methods and are essential for comprehensive knowledge (SPU, 2020).

The basic characteristics of the educational area is the search for lawful connections between the observed properties of natural objects and phenomena that surround us in everyday life and understanding their essence, which requires an interdisciplinary approach and therefore close cooperation within the natural science subjects. The aim is not only to lead students to an understanding of the processes taking place in the real life, but also to teach them to think critically, to acquire and evaluate information.

One of the aims of the subject is for students to make good use of mathematical skills in basic chemical calculations. The hourly allowance for chemistry in the The State Educational Programme in both the first and second year of high schoolis two hours per week (66 hours per year) and in the third year one hour per week (33 hours per year).

3. MATHEMATICS IN CHEMISTRY

Once students have understood the assignment of a task, they design a procedure - an algorithm for solving it, either deductively or inductively, they often encounter another problem, and that is mathematical skills. If students do not have the right mathematical skills, it is very difficult for them to apply them in other subjects. Many students do master mathematical operations such as equations and trinomials, but only within the subject of mathematics. When they have to use these knowledge and skills in other subjects, such as chemistry, they are unable to apply them. It is probably for this reason that chemical calculations are among the most difficult subjects in chemistry.

Mathematics is widely accepted as the basis of science and technology and is a very important subject in the high school curriculum. Mathematics is also regarded as a fundamental subject for the study of other sciences. While solving chemical calculations, teachers often encounter students' deficiencies in mathematics, which, however, cannot be remedied during chemistry lessons. Students are often unable to calculate a simple example where they use basic mathematical operations such as the use of parentheses, the use of fractions, the use of percentages, the rounding of numbers, the conversion of units that they have been taught in primary school. Once students encounter more complex tasks where more mathematical operations and steps need to be used, they have considerable difficulty in solving the task.

4. RESEARCH OBJECTIVES

In this research, we addressed the didactic problem of solving computational tasks in chemistry among primary and high school students, namely: reasons for the failure of solving chemical computational tasks among students from the teachers' perspective. Based on this, the following research questions were defined:

1. ***What is the frequency of inclusion of chemical computational tasks in the classroom in primary schools compared to high schools?***
2. ***Do students have comparable difficulties with mathematics in solving chemical computational tasks in primary and high schools from teachers' perspectives?***
3. ***How do teachers activate students in chemical computational tasks?***

5. METHODS OF DATA ACQUISITION AND EVALUATION

The present research is based on qualitative and quantitative data collection methods and analytical procedures. Prior to the actual conduct of the research, an analysis of current curriculum documents was carried out focusing on the possibilities of implementing chemical calculations in chemistry teaching.

The basis of our research was to evaluate an electronic questionnaire survey among 73 teachers in Slovakia who teach at primary or high school level. The questionnaire was divided into an introductory part where we identified the respondents and a content part that focused on the implementation of chemical calculations in chemistry teaching.

From the total number of respondents, 64 females and only 9 males completed our questionnaire, this shows a percentage of 87.7% females and 12.3% males, 54.8% of the teachers were from primary school, 35.6% of the teachers were from grammar school and 9.6% of the teachers were from high school. Overall, most of the teachers have the subject of biology as a combination with chemistry. In primary school, 55% of chemistry teachers had biology as their other approbation, 27.5% of teachers had mathematics as the other approbation, and 5% of teachers had physics as the other approbation. At high school, most teachers 66.6% of the respondents indicated biology as their other approbation, 12.1% of the teachers have chemistry alone, 12.1% of the respondents have mathematics with chemistry, and 6% of the teachers have physics with chemistry.

6. RESEARCH RESULTS AND DISCUSSION

Question 1. What is the frequency of inclusion of chemical computational tasks in the classroom in primary schools compared to high schools?

In particular, we were interested in how often teachers include chemical calculations in the classroom. Figure 1 shows that more than half of primary school teachers rarely teach chemical calculations in chemistry classes, which is understandable given the required standards and recommended topics. On the positive side, not a single chemistry teacher indicated Never as their response.

Figure 1 Frequency of use of chemical calculations in chemistry lessons

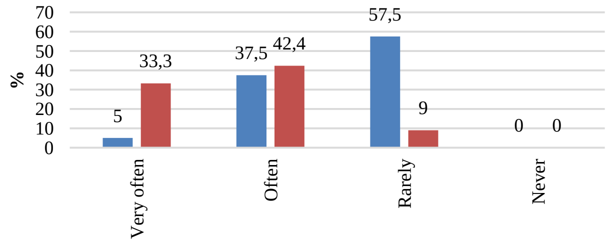
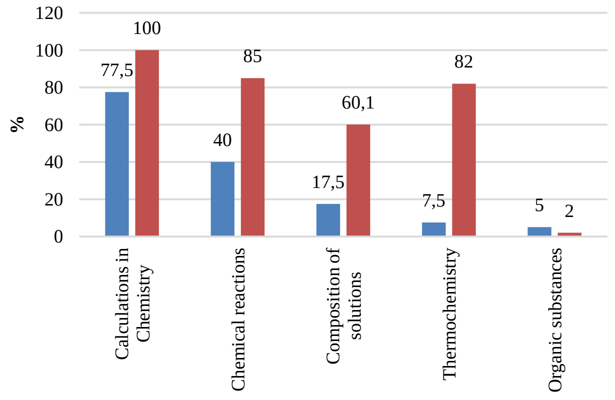
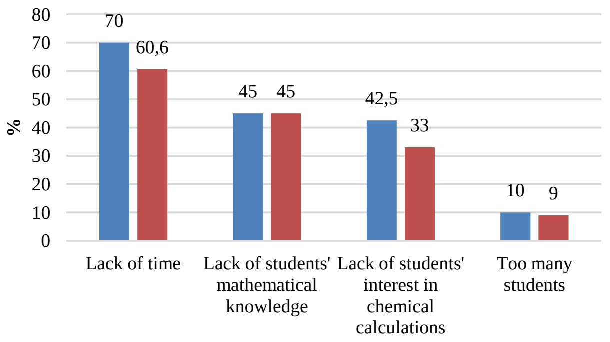


Figure 2 Overview of the use of chemical calculations in individual chemistry topics in percentages



The second question focused on the use of chemical calculations in particular chemistry topics. In this question, respondents could indicate multiple choices. Figure 2 shows that all high school teachers use calculations in the topic of Calculations in Chemistry, with the majority of high school teachers including calculations in the topics of Chemical Reactions and Thermochemistry. For primary school teachers, it should also be obvious that all teachers use chemical calculations in the compulsory content standard topic of Calculations in Chemistry, but this is not the case; on the other hand, 40% of teachers use them in Chemical Reactions. This fact raised the question of why teachers include calculations not so often in chemistry lessons, so we investigated the barriers or what reasons they have for doing so.

Figure 3 Barriers to the use of chemical calculations in chemistry



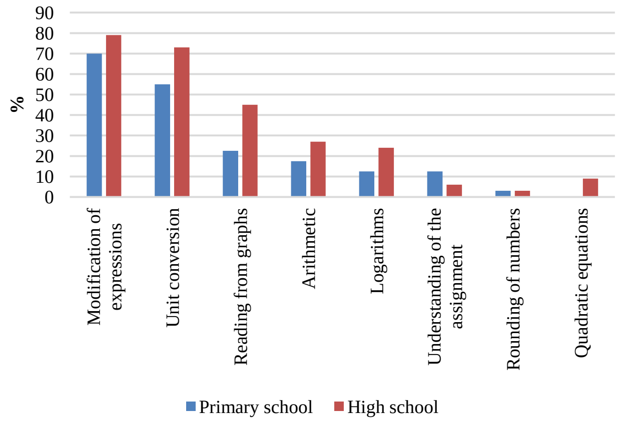
In Figure 3 we see that 60.6% of high school teachers are hindered by the lack of time to teach chemical calculations. Also a major hindrance for teachers is students' deficiencies in mathematics which accounts for 45% of the total. We were surprised that only 33 percent of high school teachers indicated students' lack of interest in chemical calculations because the subject of chemical calculations is abstract for students and one of the unpopular topics in chemistry. From the perspective of 70% of primary school teachers, lack of time is also the biggest obstacle. The reason for this may be the low allocation of chemistry lessons in primary and high school. From the graph it is clear that not only in primary schools but also in high schools students have problems with mathematics, this interested us more closely, so we asked in the next question about the specific problems of students' mathematical skills in solving chemical calculations.

Question 2. Do students have comparable difficulties with mathematics in solving chemical computational tasks in primary and high schools from teachers' perspectives?

From Figure 4, it is evident that both high and primary school students have the most difficulty in modifying expressions and converting units. Overall, when we look at those results, high school students, according to those results, have more problems with maths than primary school pupils. We can assume that this is due to the lower difficulty of chemical calculations in primary schools, where mostly simplier calculations are solved according to a predefined formula (algorithm), as well as the lower frequency in primary school classes. High school students also have relatively high difficulties with graph reading, arithmetic and logarithms.

Very remarkable is the finding that only a small proportion of respondents have difficulty understanding the assignment, 12.5% of students in primary school and only 6% of high school students. Although this competence falls more in reading literacy than in mathematical literacy, but without a correct understanding of the given task, students would find it very difficult to solve it. This is an inadequate finding in relation to pedagogical research as well as to the results of national testing (PISA), in which students have great difficulties with reading comprehension.

Figure 4 Overview of students' mathematical skills' problems in solving chemical calculations



Question 3. How do teachers activate students in chemical computational tasks?

Due to the low frequency of incorporating chemical calculations into the classroom, we were interested in what could help teachers to increase the frequency of implementing computational tasks.

Figure 5 Overview of options to help teachers incorporate chemical calculations

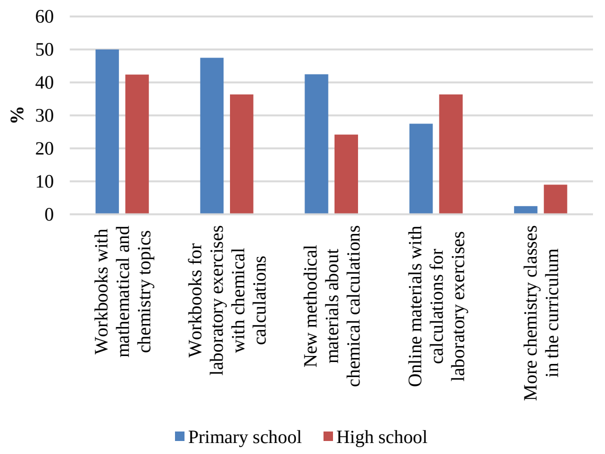


Figure 5 shows that 42.4% of high school chemistry teachers identified Workbooks with mathematical and chemistry topics as an improvement in the teaching of chemical calculations. The answer Workbooks for laboratory exercises with chemical calculations and Online materials with calculations for laboratory exercises was ticked by 36.4% of high school chemistry teachers. 9% of high school chemistry teachers responded in the open question, where they suggested More chemistry classes in the curriculum as another option. In the view of 50% of primary school teachers, Workbooks with mathematical and chemistry topics would be the best option to improve the teaching of chemistry calculations. The other responses were less than 50%.

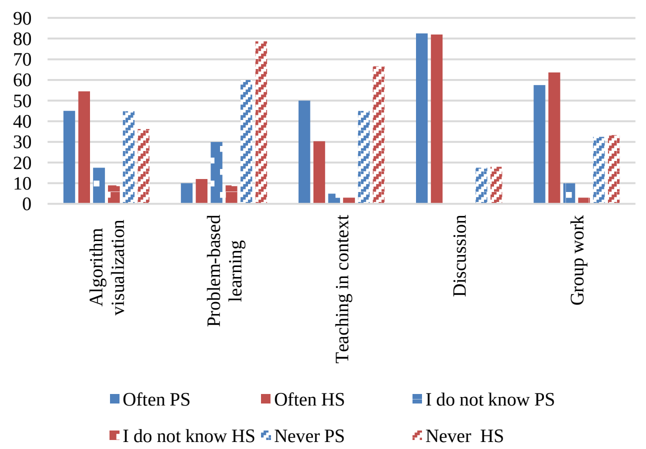
Since teachers mainly lack various materials that would facilitate or motivate them to include calculations in teaching, we asked how they approach solving computational tasks in the classroom, what methods, procedures, methodological turns they use in their practice. In terms of keeping students' attention, it is more effective when methodological turns are included in the classroom within different topics, which means moving from one method to another, combining different types of methods to motivate students and at the same time keep their attention.

In the literature, we find different approaches to the management of chemistry problem solving. For example, Rusek et al. (2016) recommend a classification of tasks focused on chemical calculations. The authors propose three levels of chemical calculations-based tasks according to the operation that the student has to perform to solve the task. The existence of such a classification is justified as a guideline for students, for whom we want to make the work easier. However, the question is whether such a classification of tasks does not lead to mere drill. Learning certain patterns of problem solving may indeed simplify the work, but on the other hand it dampens the need for students to think about specific problems.

Maciejowska (2009) argues that students can approach any computational, task in at least two ways: either problem-based or algorithmic methid. Very simplistically speaking, the problem-based method requires posing a hypothesis and verifying it, for the algorithmic one - to find in memory an algorithm that would suit the conditions of the problem and to use it. In fact, due to their specificity, these methods differ: the problem-based method is mainly applied when there is no clear-cut solution and in education when developing so-called higher-order cognitive skills or integrated scientific skills, while the algorithmic method can be solved mechanically using a learned model (Toth, 2001).

Maciejowska (2009) recommends three different suggestions (visualizing the algorithm, teamwork with students, and adding context to the exercises) that could help teachers educate their students in solving mathematical analysis tasks in chemistry. Each teacher can choose the method they wish to follow and which will suit their students.

Figure 6 Activating methods - methodological turns in computational tasks - Primary School versus (PS)High School (HS)



For a practical display, we used a three-level Likert scale in the question so that we could directly compare the results of primary (PS) and high school (HS) teachers in one graph (primary schools are always in blue and high schools in red, only the pattern differs). We gave teachers a variety of options and from the responses we found that they use discussion the most in both primary and high schools, with almost half of the teachers using group work, which are very similar methods due to their positive impact in getting students to work together. When working in groups, students find it easier to communicate, explain problems in more accessible language, and are less stressed when working with their classmates. More than half of teachers (54.5%) use algorithm visualization in high school and almost half (45%) in primary school. The prescribed solving algorithm is particularly suitable for the introductory examples in the exposure part of the lesson, where students learn the solution procedures for typical school tasks, which are specific transfer tasks, and this is a good prerequisite for further solving more complex non-specific transfer tasks (e.g., problem-based tasks). The algorithm can also be used in the fixation phase of the lesson, where the teacher calculates one example and students solve the next example using the algorithm, first solving typical school tasks and then solving more complex tasks independently (Bellová, 2010; Chiu, 2005). This method of computation can be solved individually, as well as in pairs or larger groups. Teachers make the least use of problem-based learning, which is logical because research also suggests that problem-based learning (PBL) is very challenging for teachers in terms of preparation, implementation and evaluation (Bellová, 2018).

To increase the effectiveness of the teacher's work in the development of students' abilities is to use the long-known principle of combining theory with practice in a somewhat specific form. This is called 'teaching in context'. According to our results, teaching in context is applied by 50% of teachers in primary schools and 30.3% in high schools. While in the context of "pure chemistry" no one questions the need to use examples from everyday life, teachers' views on solving problems with calculations are different. On the one hand, having an interesting context for the problem increases motivation and therefore the effectiveness of the work, but on the other hand, it happens that some students feel that the task is rather complicated and they cannot find out what it is really about. Therefore, in each exercise it should be stated what the required calculations are to be made for, what is the connection with everyday life, the connection with a particular environment, with some interesting thing that would attract, motivate the students.

Teachers should also focus more on reading comprehension. The most common reading comprehension method that can be used very effectively, especially in science teaching, is active reading comprehension, which is one of the methods that can be used in different variations in every lesson. The most important specialist text for students is the textbook, as it contains basic information in the field of the relevant scientific discipline, but also graphically differentiated extension material supported by a variety of illustrations - pictures, photographs, diagrams, tables. It is very important for the teacher to teach students to work with the textbook, which is usually the students' first specialist text, as early as in primary school. Students often read a specialist text superficially, do not think about its content, cannot 'distinguish' what is essential and important in the text, and cannot abstract and interpret the text in their own words. The predominant way in which students perceive and try to memorise parts of a technical text is 'visual', thus missing the essential facts, which leads to mechanical learning and misunderstanding of the essence of the subject matter or the assignment of the example. This may be one of the reasons for the very poor use of problem-based tasks in both primary (60%) and high schools (78.7%).

7. CONCLUSION

The results point to a significant need to change the approach to teaching chemical calculations not only from the teachers' point of view but also from the students' point of view. The obstacles faced by students include the ability to identify the problem in the task, to understand the concepts of calculation and to use the mathematical apparatus correctly. We see the need for interdisciplinarity in education because mathematical literacy and science literacy are interconnected, interrelated and influence each other. In this way, teachers should also see chemical calculations as a complex problem and approach the preparation and implementation of lessons focusing on calculation exercises with this in mind.

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