Research Article https://doi.org/10.12973/eu-jer.11.3.1781

European Journal of Educational Research
Volume 11, Issue 3, 1781 - 1796.
ISSN: 2165-8714
https://www.eu-jer.com/

Using Algebraic Manipulations and Analogical Transformations to Problem-Solving of Contextual Chemistry Problems

Eda Vula
University of Prishtina 'Hasan Prishtina', KOSOVO

Fatlume Berisha*
University of Prishtina 'Hasan Prishtina', KOSOVO

Received: February 21, 2022 ▪ Revised: May 8, 2022 ▪ Accepted: June 21, 2022

Abstract: Algebraic knowledge transfer is considered an important skill in problem-solving. Using algebraic knowledge transfer, students can connect concepts using common procedural similarities. This quasi-experimental study investigates the influence of algebraic knowledge in solving problems in a chemistry context by using analogical transformations. The impact of structured steps that students need to take during the process of solving stoichiometric problems was explicitly analyzed. A total of 108 eighth-grade students participated in the study. Of the overall number of students, half of them were included in the experimental classes, whereas the other half were part of the control classes. Before and after the intervention, contextual problems were administered twice to all the student participants. The study results indicate that the students of the experimental classes exposed to structured steps in solving algebraic problems and the procedural transformations scored better results in solving problems in mathematics for chemistry compared to their peers who did not receive such instruction. Nevertheless, the result shows that although the intervention was carried out in mathematics classes, its effect was more significant on students' achievements in chemistry. The findings and their practical implications are discussed at the end of the study.

Keywords: *Algebraic manipulation, analogical transformations, contextual chemistry problems, mathematics, problem-solving.*

To cite this article: Vula, E., & Berisha, F. (2022). Using algebraic manipulations and analogical transformations to problem-solving of contextual chemistry problems. *European Journal of Educational Research*, *11*(3), 1781-1796. https://doi.org/10.12973/eu-jer.11.3.1781

Introduction

Enabling people to become successful problem-solvers is one of the priorities of all those who believe that the foundation of every society is active and responsible participation of educated and intelligent citizens in decision-making, regardless of their career orientation (Zoller, 1987). Hence, as in many countries worldwide, problem-solving has an essential place in textbooks and state evaluations, in Kosovo it also has an important place in the Pre-university Education Curriculum (Ministry of Education, Science and Technology [MEST], 2016a). Problem-solving represents one of the key goals of mathematical education and natural sciences since it enables the development of understanding and critical and creative thinking (MEST, 2016b). Moreover, it represents a facilitation process of learning and developing students' cognitive abilities during the learning process (Caproro et al., 2012; Hickendorff, 2013). For these reasons, many researchers and educators have paid particular attention precisely to the factors that influence the necessary abilities and skills that students need to become successful problem solvers and active participants in decision-making (Capraro & Joffrin, 2006; Jonassen, 2003; Monroe & Orme, 2002; Zoller, 1987).

Despite the importance of the inclusion of these problems in mathematics and natural sciences, the studies have shown that there are gaps between the cognitive field that comprises the application of conceptual knowledge and procedural knowledge in solving them (Bunce et al., 1991; Lythcott, 1990; Niaz, 1995; Sumfleth, 1988). These studies emphasize that students often do not understand the concepts of mathematics and/or chemistry, especially when they are included in contextual problems (Raviolo et al., 2021). The students face difficulty in comprehending the tasks' content and applying conceptual knowledge in problem-solving, or they fail to use procedures to accomplish successful solutions (Lee et al., 1996; Vula et al., 2017). On the other hand, if students do not acquire specific cognitive skills or strategies such as the skills of comprehending the contextual problems, analogical argumentation, or the ability to relate contexts, which are frequently neglected in our schools, according to Lee et al. (1996), acquisition of knowledge does not guarantee successful problems solving

* **Corresponding author:**
Fatlume Berisha, University of Prishtina' Hasan Prishtina', Faculty of Education, Kosovo. ✉ fatlume.berisha@uni-pr.edu

Problem-Solving

Problem-solving refers to "an individual's capacity to use cognitive processes to resolve real, cross-disciplinary situations where the solution path is not immediately obvious" (Organisation for Economic Co-operation and Development [OECD], 2004, p. 156). It offers opportunities for students to develop a broader and deeper understanding of reason and make connections between mathematics, other subjects, and everyday life (Kolar & Hodnik, 2021). As an important skill, problem-solving and the methods for solving them have been discussed by many researchers (Hodnik Čadež & Manfreda Kolar, 2015; Novick & Holyoak, 1991; Polya, 1957; Schoenfield, 1985; Vula et al., 2017). Therefore, based on this importance, it should be integrated into all subjects because these integrations, especially the coherence between math and science, are significantly related to problem-solving competence (Scherer & Beckmann, 2014).

The process of contextual problem solving that integrates mathematics and sciences requires students to use linguistic and contextual understanding, organize the data, identify the missing information, and then apply the calculations. This process engages students in being prepared to identify the unknown in the structure of algebraic expressions, explaining and supporting their judgments during all the stages of the problem-solving process (Fuchs et al., 2008; Pape & Smith, 2002).

For solving contextual problems, content knowledge and the ability to relate the reading with the concept of mathematics and science are required. Korpershoek et al. (2014) have shown that students' reading comprehension ability and problem-solving skills in mathematics are the key factors for students' achievement in natural sciences. Although the need to distinguish and combine the contents and strategies from different fields poses a challenging situation for students, Beigie (2008) says these experiences encourage cognitive abilities for higher-order thinking in students and lead to a deeper understanding and better acquisition of the content.

In addition, the research in the field of education in mathematics and natural sciences by Gulacar (2007), has shown that students are unsuccessful in solving contextual problems, mainly because of fragmented knowledge in sciences and mathematics into unrelated procedural parts. Hence, according to Beigie (2008), student engagement in solving problems should explore procedural decision-making to build a solution plan and make connections between integrated concepts and separate procedures instead of routine-based execution of previously learned algorithms.

It is noteworthy that the first framework for problem-solving was introduced by Polya (1957) through the following four steps: *comprehending the problem, planning the solution, implementing the solution plan, and checking and analyzing the solution.* Later on, Lee and Fensham (1996) modified Polya's steps and identified seven distinct processes in solving problems: (1) reading and comprehension of the problem as a whole, its reformulation or simplification using symbols or diagrams to visualize the problem to enable understanding; (2) translation of parts of the problem into statements that have their meaning; (3) setting the main purpose or sub-purposes; (4) selection of information that they consider of importance obtained in the three first processes; (5) recalling the facts and the rules; (6) achieving the purposes and/or sub-purposes from clearly stated and implied connections of the processes 4 and 5; and (7) checking the paths of the solution and the answers. According to Beigie (2008), the second step is a key ingredient in the problem-solving experience, distinguishing a problem from an exercise whose solution path is known.

Researchers generally agree that acquiring cognitive strategies and their systematic and adequate use by students is rather difficult. In many cases, teaching treats and practices solving a significant number of problems by focusing instructions and reflections mainly on sequences of steps of the solution, neglecting the importance of conceptual and contextual knowledge and cognitive strategies in the execution of solutions successfully. Some teachers demand students to solve tasks that orient them to reproduce previously learned facts. In contrast, some teachers instruct their students toward problem-solving, which is required to explore and comprehend concepts, processes, and relationships (Beigie, 2008). The latter is known as information consisting of two or more represented subjects mentally linked through particular connections mentioned in Hallett et al. (2010) work. In addition, in their study, BouJaoude and Barakat (2003) have cited numerous research on strategies that students use during problem-solving in chemistry, particularly the relationship between conceptual and procedural understanding of chemistry during this process. They have shown that the approaches to problem-solving may be algorithmic when following a sequence of actions, algorithms, rules, or calculating abilities is required, and the conceptually based approach whereby the solution of the problem is in the function of the competency of sustainable knowledge.

Solving Analogical Problems

When we encounter a new problem, we refer to similar problems we have treated earlier. Thus, in most cases, to deal with homework assignment tasks in mathematics or natural sciences, students apply abstract algebraic principles involved in solving the tasks in class, using the same structure, rules, and formulas. This approach is known as analogical problem solving and includes transferring knowledge from one situation to another. According to Wong et al. (2017), analogical problem solving comprises three separate processes: recalling learned (source) problems and their solutions, extracting the basic principle of the solution, and applying this information to solving new (targeted) problems. This strategy that makes use of a known problem (the base – the analog) to solve a new problem (the objective – the problem) is known as *analogical transfer* (Reeves & Weisberg, 1994). Analogies enable the new material, especially the abstract concepts, to adapt to students' previous knowledge, enabling them to develop a more profound understanding of the concept. An analogical transfer is rather important in teaching problem solving since it allows students to code the information during the retrieval from memory regarding the problems they have encountered earlier and relate them to the topics in different fields, based on the understanding of common and similar structures (Ngu & Yeung, 2012; Novick & Holyoak, 1991). According to Novick and Holyoak (1991), the schemes facilitate solving analogical problems since they serve as a framework for problem-solving in all fields and often help students understand abstract concepts (Polya, 1957). Moreover, according to Glynn (1989), when analogies are used as teaching tools, six steps should be followed: 1. presentation of the concept; 2. presentation of the analogical concept (a concept with which students must have been acquainted through previous experience; 3. identification of respective features between targeted and analogical concepts; 4. explicit description of similarities between the targeted and analogical concepts; presentation of the endpoint of analogy; and 6. final presentation regarding the targeted concept based on the previous steps.

Furthermore, considering the significant number of common characteristics of problems in mathematics and natural sciences, particularly in chemistry, what functions in solving problems in mathematics, according to Ngu and Yeung (2012), may also function in the field of chemistry. Therefore, many instructors use analogies to solve problems presented in science texts using algebraic manipulations (proportion, ratios, equation, systems). Through algebra, the relations between different concepts within a field or different fields become appropriate based on understanding common structural similarities (Bush & Krap, 2013; Ngu & Yeung, 2012). However, many researchers report that solving algebra problems is a challenge for lower high school students (Bush & Krap, 2013; Capraro & Joffrin, 2006). This may be because of students' lack of abilities and skills to recognize a similar problem in a wide range of contexts and apply prior knowledge learned about different types of problems.

Similarly, Bunce et al. (1991) have reported that students struggle to solve mathematical dependent problems in chemistry. The majority of contextual problems assigned in the subject of chemistry, and especially in the field of stoichiometry, contain at least one mathematical manipulation of algebraic expressions required for solving the problem. This type of contextual chemistry problem, in most cases, involves the use of mathematical analogy to salving the problem. Students with solid mathematical understanding can quickly establish connections and transfer their knowledge and skills to different disciplines. Hence, continuous attempts are made to motivate students to transfer learned algebra manipulations and expressions to solving problems in a new context (Sun-Lin & Chiou, 2019).

Bush and Krap (2013) also point out that transferring algebraic manipulations and expressions is essential in solving new problems. It enables students to apply their knowledge to construct an understanding of a new concept. Furthermore, through the transfer of algebraic manipulations and expressions, students can make adequate connections between different concepts within a field by using common procedural similarities between problems (Bush & Krap, 2013; Ngu & Yeung, 2012).

Problem-Solving in Chemistry

Problem-solving characterizes mathematics and natural sciences, and chemistry in particular, regardless of whether they work in stoichiometry, theory, analysis, or characterization of compounds. Nevertheless, Bodner and Herron (2002) have shown that in most cases, successful students in the subject of chemistry have developed their problem-solving skills of solving contextual chemistry problems by transferring those skills from mathematics. They emphasize that chemistry teachers need to engage more in supporting students to use the analogy to transfer their problem-solving skills in chemistry.

Sunday et al. (2019) define stoichiometry as the quantitative study of the mass-mole number relationship, chemical formulae, and reactions. Stoichiometry involves the mole concepts and the balancing of chemical equations analyzing the relationship between the number of reactants and products. Stoichiometry determining the amount of the substance in a reaction consists of mathematical procedures and understanding it requires problem-solving and high-level thinking skills. Cook and Cook (2005) define problem-solving as applying previously learned rules to a new situation to find a solution.

Additionally, successful problem-solving is based on proper algorithms, memorized rules, and much more (St Clair-Thompson et al., 2012; Swanson & Fung, 2016); first and foremost, it requires integrating knowledge of different curriculum areas and deep analysis of conceptual understanding (Gulacar, et al., 2019). Schmidt (1997) and Carlson (2022) point out that learning in stoichiometry is difficult, but using algebraic knowledge and appropriate teaching strategies enables significant problem-solving.

As a result, mastery of the skills of a successful problem-solver produces a solid base for exceptional performance in various scientific disciplines and the subject of chemistry. Considering that stoichiometry involves calculations of masses of products and reactants obtained during the chemical reactions, essential attention should be dedicated to developing students' problem-solving skills if such skills are not already established through mathematics. Stoichiometry occupies the central position in the subject of chemistry, whereas the problems that are treated there are of a larger scale of complexity since it is concerned not only with the quantitative but also with the qualitative understanding of a variety of types of chemistry problems (Bopegedera, 2019; BouJaoude & Barakat, 2003; Carlson, 2022). On the other hand, its abstract nature is related to the complexity of execution of calculations that require the understanding of the concept of mole, the construction and balancing of chemical equations, algebraic abilities, and interpretation of the solution of word problems, as well as procedural steps that lead to the accurate answer (Chiu et al., 2022; Okanlawon, 2010).

Studies indicate that insufficient or erroneous conceptual knowledge hinders solving problems in stoichiometry (Carlson, 2022; Chiu et al., 2022; Harmon, 1993; Niaz, 1995). However, the inaccurate use of algebraic manipulations (algorithms procedures) is the key factor in the inaccurate solving of stoichiometric problems (Chiu et al., 2022; Huddle & Pillay, 1996; Lythcott, 1990; Nakhleh, 1993; Sawrey, 1990; Staver & Lumpe, 1995; Tullberg et al., 1994). Hence, to overcome the gaps in solving problems in chemistry, importance should be placed on reciprocal relations in the cognitive processes between reading, mathematics, and science and conceptual and procedural knowledge. Theoretical models and teaching strategies for problem-solving, proposed by many researchers, are based mainly on cognitive structures as means that enable linking reading with operational systems of thinking to increase 'students' achievement level (Capraro & Joffrin, 2006; Chiu et al., 2022; Mevarech et al., 2010; Ngu & Yeung, 2012; Vula et al., 2017). On the other hand, analogical reasoning, as a powerful mechanism in utilizing previous experience, planning, and solving problems (Carbonell, 1983, p. 137; Chiu et al., 2022), is often facilitated by the use of supporting signals to attract students' attention make the structure of problems more transparent. As a result, the transfer of knowledge from one situation to another is facilitated (Lee et al., 2017; Ngu & Phan, 2020).

Considering that Kosovar students' results in the Program for International Student Assessment (PISA) showed that there is a serious lack in students' problem-solving skills (OECD, 2018) in the context of language, science, and mathematics, in the present study problem-solving in mathematics and chemistry is analyzed. Therefore, considering the common characteristics between algebraic and stoichiometric problems, special attention should be dedicated to utilizing algebraic procedures for solving problems in stoichiometry. The present research analyzed the impact of algebraic knowledge manipulations and expressions in solving problems in a chemistry context. The study will aim to answer the following research question:

Does an algebraic manipulations and analogic transformation have an impact on problem solving of contextual chemistry problems?

Hence, it investigated whether the provision of guided practices in solving problems in mathematics and those in the subject of chemistry would enhance students' achievement. The analysis focused on whether teachers' interventions in structuring the actions of solving problems influenced students' achievement. The research has highlighted the importance of including teaching and learning strategies based on cognitive processes and analogical transformations. Hence, the research design took into account mainly understanding the algebraic word problem and the transformation of problem-solving procedures in solving problems with chemistry context.

Methodology

Research Design

This study is an empirical study that examines if students' algebraic manipulation and analogical transformation impact their achievement in chemistry contextual problem-solving. Research is based on quasi experiment design (Cresswell, 2003) that aids researchers and educators to understand better how to facilitate learning experiences among students in a daily educational context.

Research Participants

A total of 123 students of the age range varying from 12 years to 14 years old were included in the research. The students who participated in the study were from four eighth-grade classes selected randomly from two urban primary and lower high schools in Prishtina municipality. The test results of 15 students who did not sit either the pre-test or the post-test were not considered.

From the overall number of students (N=108), 56 students (51.85%) were included in two experimental classes, in which intervention strategies (instructions for problem-solving) were used. In comparison, 52 students (48.15%) partook in the control classes, where they executed the tasks without specific instruction, relying exclusively on the teacher's teaching methods and respective textbooks. To increase the sample size, two experimental and two control classes were chosen randomly. In addition, there was an even number of male and female students in the experimental group. In the control group of 52 students, 29 (55,76%) participants were females, and 23 (44.23%) were male students.

Active participants in the study were two teachers in the experimental classes: one of mathematics and the other of chemistry, who were given specific instructions on "modus-operandi", or the manner of intervention, to be conducted in the interval between the execution of tasks for the first time and their realization after the intervention. Considering that the same curriculum is implemented in the entire country (Kosovo), the same textbooks approved by MEST are used, and the same qualifications are required for teachers, the selected sample is representative of Kosovo students.

Instruments

Several problems that integrate algebraic principles and stoichiometric concepts were compiled to measure the impact of analogical transfer as a strategy for solving algebraic problems. These problems aimed to impact the students' skills in solving problems in chemistry by utilizing analogies and their knowledge in solving algebraic problems.

The pre-test and the post-test comprised ten mathematical problems containing equations with one unknown, tasks related to percentages and ratios, and tasks for transforming the measuring units. Some of these contents have been studied in the seventh grade; however, it is necessary to review them. Such mathematical problems were needed to be adapted to the problems with chemistry context, in which at least one mathematical manipulation is required to find the solution.

Apart from the mathematical problems, the pre-test and post-test consisted of 6- problems from chemistry. The chemistry problems were stoichiometry related, such as understanding the mole, mole percentage, concept of mole, and mass of reactants and products of the reactions. As a branch of chemistry, stoichiometry studies the relationship between the relative amounts of chemical elements involved in a process or generating a product, usually expressed as a ratio of whole integers. In the curriculum area of natural sciences, the eighth-grade chemistry aims at the accomplishment of the learning outcomes for the stoichiometry concept, as follows: *calculate the number of moles from the given mass and reversely, calculate the participation of the elements of the compound in mass or in percentage based on the percentage of constituent elements, calculate the quantity of the reactants and the products of the reaction using the mole*. Some of the pre-test and post-test tasks in mathematics and chemistry are included in textbooks.

All students completed the tasks in a booklet using pen and paper, which the researchers and the teachers led. The tests were delivered twice for 45 minutes each during the same week, the first time in mathematics and the next time in chemistry. The scoring system is used to assess completed mathematical word problems and problems in a chemistry context. Both testing stages (pre-and post-test) were as follows: 2 points for an entirely correct task, 1 point if the procedure or the result was correct, and 0 points if the process of solving the problem failed utterly. Each researcher individually assigned scores, ensuring the reliability is the overall trustworthiness. The researcher's agreement was 94 %. The Cronbach was found to be 0.67 for pre-test and 0.86 post-test.

Procedure

The researchers also prepared the guidelines related to the steps of the activity for solving word problems in mathematics and chemistry. The intervention methodology between the two tests was based on the strategies of word problem solving, including the problem-solving steps (Polya, 1957). To understand the problem, as the first step in solving problems in mathematics, the bar model method (Baysal & Sevinc, 2021) was used, which helps students use their understanding of percentages and ratios in solving problems. On the other hand, analogical transformations of this knowledge enabled students to use various mathematical manipulations required to solve chemistry word problems. The basis for solving the problems of molarity, the transference of algebraic problem-solving in the sciences curriculum, was taken (Ngu, 2016).

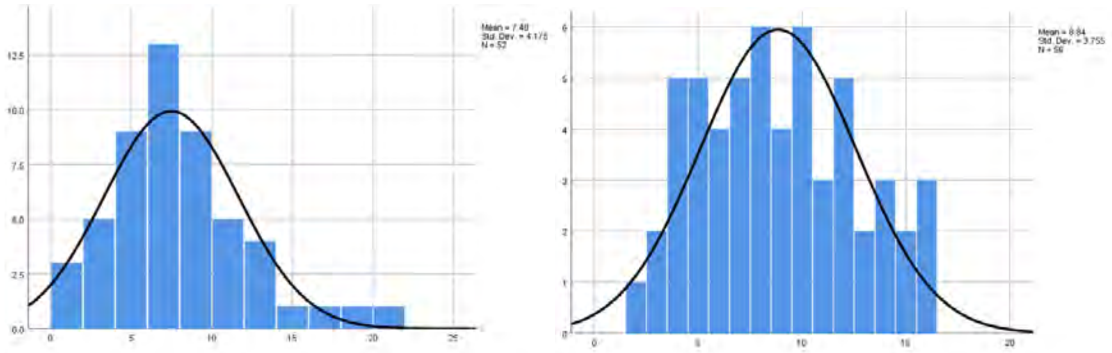
After administering the pre-test with experimental and control group students, the teachers of experimental classes cooperated. The mathematics teacher "trains" the students to utilize the required algebraic apparatus to solve problems with chemistry context. Both teachers in experimental classes had the opportunity to review the content of the topics included in this research and, at the same time, to practice solving word problems following Polya's steps: understanding the problem, planning the solution, implementing the solution plan, and checking and analyzing the solution. Considering that the first step, understanding the problem, is paramount in solving problems, the teachers were instructed to use bar models to present the data in mathematical problems using algebraic manipulations, similarly with chemistry context problems (see Appendix A).

Data analyses

Descriptive statistics (means and standard deviations) for all the variables were calculated. The t-test was used to analyze the differences among pre-test scores in the experimental and control groups in mathematics and chemistry subjects.

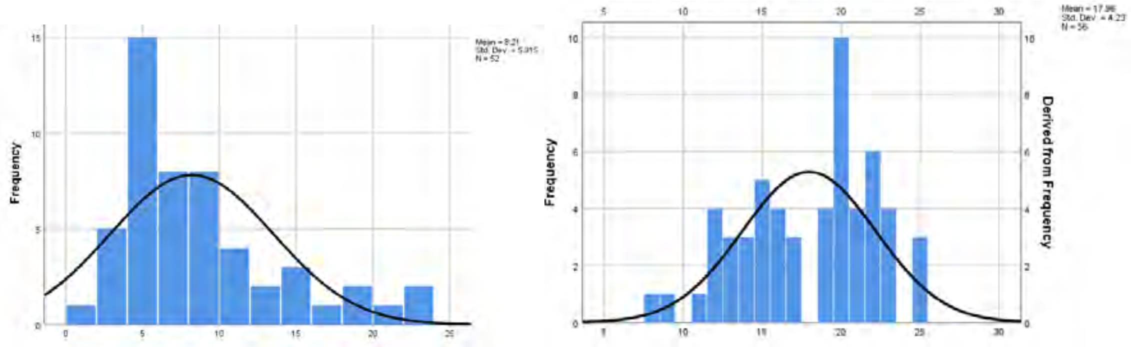
To answer the research question, a follow-up one-way multiple analysis of covariance MANCOVA was employed to find statistical differences between groups based on students' mean scores in post-tests of mathematics and chemistry classes and pre-test means scores as covariates. All statistical analyses were performed using the SPSS version 26.0. The statistical significance level was set at $p < .05$.

On figure 1 and figure 2, the distribution of variables is presented. As can be observed, the distribution of variables in the pre-test and the post-test does not differ from the normal distribution in both experimental and control groups.



Control Group Experiment Group

Figure 1. The Distribution of Variables in the Pre-Test in Control and Experimental Group



Control Group Experiment Group

Figure 2. Distribution of Variables in the Post-Test in Experimental and Control Group

Results

Presented in Table 1 is the analysis of the mean scores and standard deviation of the students' mathematics achievement in both experimental and control groups. Students in the experimental group had a mean score of 5.20 with a standard deviation of 2.84. Students in the control group had a mean score of 4.29 with a standard deviation of 2.63. The t-test yielded a score of 1.721 with 106 degrees of freedom, and the differences were not statistically significant.

Table 2 shows the mean scores and standard deviation of the students' achievement in the chemistry. Students in the experimental group had a mean score of 3.64 with a standard deviation of 2.26. Students in the control group had a mean score of 3.19 with a standard deviation of 2.28. The t-test yielded a score of 1.105 with 106 degrees of freedom; the differences were not statistically significant. Hence, it can be concluded that there is no significant difference between the control and experimental groups in both mathematics achievement and chemistry achievement tests.

Table 1. Pre-test Analyses of Differences in Mathematics Achievement Between the Two Groups

	N	Mean	Std. deviation	df	t value	p-value
Experimental	56	5.20	2.84	106	1.721	.088
Control	52	4.29	2.63			

Table 2. Pre-test Analyses of Differences in Chemistry Achievement Between the Two Groups

	N	Mean	Std. deviation	df	t value	p-value
Experimental	56	3.64	2.26	106	1.105	.272
Control	52	3.19	2.28			

The result after the intervention showed better students' achievements. Table 3 showed the mean scores and standard deviation of the student's achievement in the post-test in mathematics. Whereas table 4 shows the results for students' achievement in the chemistry post-test.

Table 3. Post-test Analyses of Differences in Mathematics Achievement Between the Two Groups

	N	Mean	Std. deviation	df	t value	p-value

Experimental	56	10.27	3.57	106	7.647	.000
Control	52	5.19	3.31			

Table 4. Post-test Analyses of Differences in Chemistry Achievement Between the Two Groups

	N	Mean	Std. deviation	df	t value	p-value
Experimental	56	7.70	1.82	106	11.196	.000
Control	52	3.02	2.49			

Moreover, a one-way multiple analysis of covariance (MANCOVA) was used to indicate if the differences in average student scores in pre-and post-test for each group of subjects were significant (Table 5).

Table 5. Multivariate Test Comparing Pre- and Post-test for Mathematics and Chemistry Groups

	Value	F	df	Error df	Sig.	Partial eta squared	Observed power
Pillai's trace	.585	72.485	2	103	P<.05	.585	1.000

The results indicated significant main effects for intervention on dependent variables (Pillai's Trace =.585, $F(2, 103) = 72.485$, $p < .05$) (Table 5).

We find a significant effect in post-test for math and post-test for chemistry (Table 6). The intervention explains the effect of 35.9 % math post-test scores after intervention and an effective contribution of 54.4% for chemistry post-test scores.

Table 6. Results from the Test of Between-Subject Effects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power
Corrected Model	M post-test	1027.672[a]	3	342.557	38.474	.000	.526	115.421	1.000
	Ch posttest	667.980[b]	3	222.660	55.045	.000	.614	165.135	1.000
Intercept	M posttest	357.881	1	357.881	40.195	.000	.279	40.195	1.000
	Ch posttest	278.410	1	278.410	68.827	.000	.398	68.827	1.000
M pretest	M posttest	215.371	1	215.371	24.189	.000	.189	24.189	.998
	Ch posttest	58.020	1	58.020	14.344	.000	.121	14.344	.963
Ch pretest	M posttest	31.047	1	31.047	3.487	.065	.032	3.487	.456
	Ch posttest	3.263	1	3.263	.807	.371	.008	.807	.144
Intervention	M posttest	519.004	1	519.004	58.291	.000	.359	58.291	1.000
	Ch posttest	501.384	1	501.384	123.95	.000	.544	123.950	1.000
Error	M posttest	925.986	104	8.904					
	Ch posttest	420.687	104	4.045					
Total	M post-test	8565.000	108						
	Ch posttest	4290.000	108						
Corrected Total	M posttest	1953.657	107						
	Ch posttest	1088.667	107						

a. R Squared = .526 (Adjusted R Squared = .512)
b. R Squared = .614 (Adjusted R Squared = .602)
c. Computed using alpha = .05

Discussion

This study aimed to investigate the effect of solving problems in a chemistry context by utilizing mathematical knowledge and analogical transformation of that knowledge. For a month the experimental group received algebraic problem-solving based instructions and analogical transformation of mathematical knowledge to solve problems with chemistry context. Evidence from results has shown a significant difference in performance between the experimental classes students and their peers taught with the conventional lecture method, the control group. Furthermore, students taught problem-solving procedures performed significantly better than those who did not receive the instruction of the kind.

The result shows that although the intervention was carried out in mathematics classes, its effect was more significant on students' achievements in the subject of chemistry. It can be justified that students solved algebraic problems with the chemistry context, even in mathematics class. So, the focus was greater on tasks from chemistry. This conclusion is supported by previous studies that indicate that effective teaching based on analogical transformations enhances students' ability to solve word problems (Ngu & Phan, 2020; Sunday et al., 2019; Ngu & Yeung, 2012) in whatever context

In their study Raviolo et al. (2021) had concluded that students have no difficulty with proportional reasoning but rather with how to apply it to chemistry, while in our study, the intervention had enabled students to enhance their mathematical skills in this chemistry course, and they tackled chemistry algorithmic problems with sound reasoning and processing skills. In the problem example in Figure 3, part, whole, and percent proportions are needed. In the post-test (Figure 3), student number 16 used an analogy of algebraic manipulations to solve the chemistry context problem.

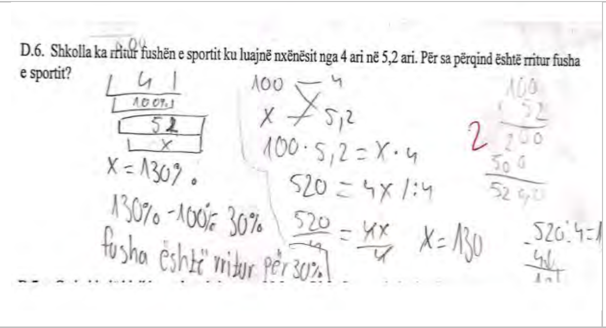
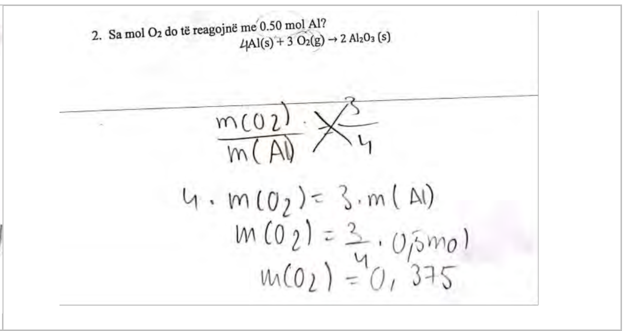
	
Translation of the problem: The school has increased the sports field where students play from 4 Acres to 5.2 Acres. By what percentage has the field of sports increased?	*Translation of the problem:* How many moles of O_2 will react with .50 mol Al?

Figure 3. The Post-Test Problems Examples Using Part, Whole, and Proportion from Mathematics and Chemistry Solved by Student Number 16, the Experimental Group

Student number 54, in the first step, uses the bar model to understand the problem (Figure 4). Further in solving the problem, student 54 uses part, whole, and percent proportion.

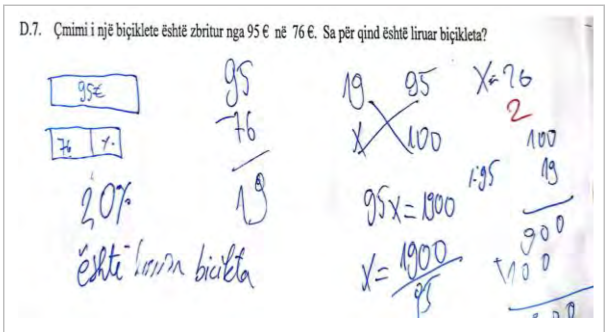
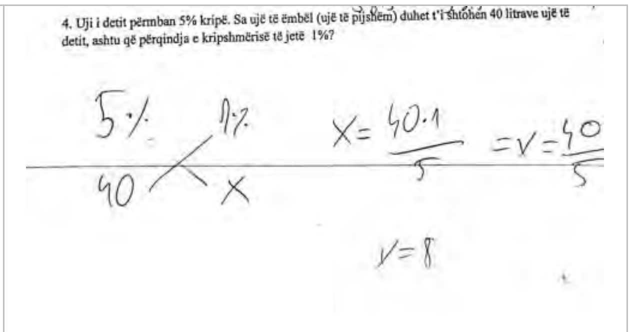
	
Translation of the problem: The price of a bicycle has been reduced from 95 € to 76 €. What percentage is the bike released?	*Translation of the problem:* Seawater contains 5% salt. So how much freshwater (drinking water) should be added to 40 liters of seawater, so the salinity percentage is 1%?

Figure 4. The Post-Test Problems Examples Using Part, Whole, and Proportion from Mathematics and Chemistry Solved by Student Number 54, the Experimental Group

In the problem with the chemistry context (Figure 4), the students used the proportion to solve the problem. Besides that, the student got the correct answer, and the teachers should pay close attention to step 4 of Polio's steps (presentation of the solution and interpretation). However, the students solved the problem correctly yet did not explain the solution's context and understanding and lacked the performance of the problem. Therefore, teachers must encourage students to perform the proper calculations, interpret the answer, and justify it (Chiu et al., 2022). Students have generally used the standard way for solving proportions, using cross multiplication.

In the post-test examples, numbers 16 and 54 represented above, students used bar models (or sketches) to understand the problem (the first step for problem-solving), which has influenced the results, especially in mathematics.

In the following example, Figure 5, student 74 from the control group solved the chemistry problem very well using chemistry procedural knowledge and memorization of formulas and procedures). However, the same student in mathematics was not successful in solving a similar problem, probably due to not understanding the problem's first step. As a result, student number 74, in the problem below (Figure 5), did not set up the problem reports correctly and made errors in calculations.

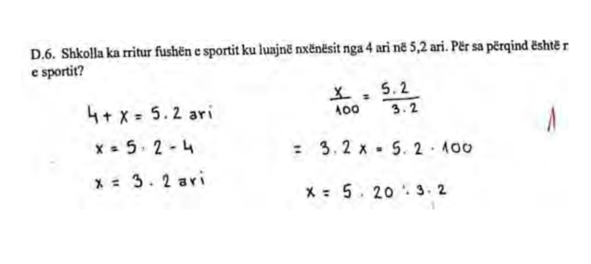
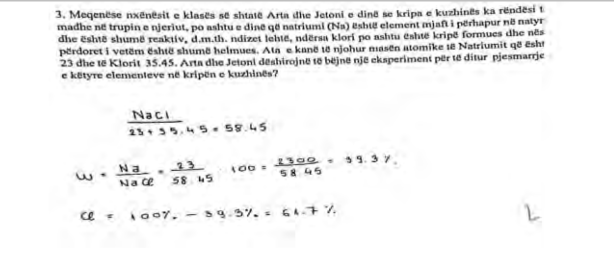
	
Translation of the problem: The school has increased the sports field where students play from 4 Acres to 5.2 Acres. By what percentage has the field of sports increased?	*Translation of the problem:* The seventh-grade students Arta and Jeton know that table salt is essential in the human body, and they also know that sodium (Na) is a widespread element in nature and very reactive, i.e., it ignites easily. At the same time, chlorine is also a forming salt and, if used alone, is highly toxic. They know the atomic mass of sodium, which is 23, and chlorine 35.45. Arta and Jetoni want to experiment to see these elements' participation (percentage) in table salt?

Figure 5. The Post-Test Problems Examples from Mathematics and Chemistry Solved by Student Number 74, the Control Group

The mathematics teachers should collaborate closely with other science teachers and integrate algebraic manipulations knowledge of mathematics tasks to different contexts (in our case, chemistry context). Moreover, the students who possess mathematical knowledge will find mathematics helpful in solving problems in other contexts from various fields much more effortless (Chiu et al., 2022).

A determinant factor for improving the results in solving word problems in chemistry was the problem's context and basic algebra knowledge. Similar to BouJaoude and Barakat (2003) study, students performed better in problems that could be solved by applying the algorithmic strategies, whereas, in problems that required conceptual understanding of chemistry concepts and were "non-routine" problems, the results were shallow. This result can be justified because 'students' knowledge regarding science and mathematics is fragmented into unrelated procedural parts (Gulacar, 2007; Raviolo et al., 2021). Furthermore, Wong et al. (2017) showed that students found it challenging to transform their mathematical knowledge to problem-solving tasks in a chemistry context. A larger scale of analogy in solving procedures was required.

Reading comprehension influences the accuracy of analogical methods in problem-solving tasks in mathematics and chemistry, representing the first step towards successful problem-solving. In this research, the relation of reading comprehension of word problems was not studied, but as it is elaborated in the study of Korpershoek et al. (2014), the cognitive abilities of students (comprehension of the text of the problem) are the precondition for the development of metacognitive abilities (planning of the solution). Consequently, high importance during the intervention was placed particularly on this process, which was reflected in the post-test result.

It is noteworthy that in the test with mathematical problems the results were higher since the contexts of the problems (particularly of those with the content of percentages) were better known to students and applicable in daily life. Meanwhile, problems in chemistry are seen as more complex and more difficult, perhaps because students did not have any experience with tasks of this nature. In chemistry, especially stoichiometry, problems solved in class and those presented in textbooks require memorizing procedures and rules to complete the tasks. This explains the study of Raviolo et al. (2021), which revealed that half of their first-year university students do not have a solid conceptual understanding of stoichiometry concepts. Consequently, similar to the study of Bodner and Herron (2002), in our study, students who demonstrated higher results in the subject of chemistry were particularly those who used skills acquired in mathematics.

Chiu et al. (2022) revealed that students who have experience with solving problems of any sort would be able to use more effective strategies to solve problems from other subjects, even when they don't have all the information, they need to solve them. Similar to Chiu et al. (2022) the student examples 16 (Figure 3) and 54 (Figures 4) shown above were able to employ the analogy of algebraic manipulations and procedural transformations to problem-solving contextual chemistry problems.

From our results, it can be stated that some students can use algebraic manipulations in problems with a mathematical context; however, they face difficulties applying it to problems with context in chemistry or general science. This is because in classes where mathematics instruction is delivered classically, it is considered essentially contextless, independent, and abstract. Meanwhile, chemistry, on the other hand, is abstract and conceptual, but most of the contextual problems are related to everyday life. This means that physical objects are unobservable, but the variables that describe those objects have physical meaning and units. Hence, if students acquire mathematical abilities but cannot transfer that knowledge to other contexts, such as chemistry, those abilities are not helpful.

Conclusion

The research indicated that mathematics and chemistry context tasks were challenging for eighth-grade students, despite the intervention that focused on problem-solving, using algebraic manipulations, metacognitive strategies, and analogical transformations. Students are frequently confused by the cumulative nature of chemistry, which causes a narrowing of students' thinking. In general, they consider only the concepts closely related to the chemistry found in textbooks and often superficially discussed in class. This approach leads students to incomplete solutions to problems or the impossibility of solving problems in everyday life. Since solving problems in stoichiometry depend significantly on students' problem-solving skills requiring deep algebra knowledge, they frequently encounter difficulty in solving them. Consequently, this research is of particular importance in the development of integrated education in sciences, as well as in the development of analogical transformations of knowledge skills, as the key factor that affects the development of capacities for applying knowledge in new situations and provision of creative solutions to new problems (Wong et al., 2017). This study and subsequent ones will contribute to developing these and future findings in the hope of incorporating them into curricula and textbooks at every educational level (Gulacar et al., 2019).

The present study also offers the opportunity for the professional development of mathematics and chemistry teachers at all education levels. The collaboration of mathematics and chemistry teachers enables students to solve problems from both areas. However, further studies supporting students by instructing them how to reinterpret mathematics in acquiring chemistry are necessary. Furthermore, there are many cases when students come to the subject of chemistry with insufficient knowledge of mathematics; hence, attention should be focused on the kind of experiences in mathematics that students bring.

Statistical analysis showed that engaging students to understand and then apply algebraic knowledge for conceptual problem-solving in a chemistry context had an effect. However, future studies must further analyze the strategies used by students to identify other gaps and take the other actions.

Most in-service teachers have limited experience in the treatment of context in their teaching. Consequently, special attention should be paid to planning professional development programs and implementing the instructions that directly serve the inclusion of contexts in teaching and greater collaboration of mathematics and other sciences teachers. In addition, these programs would also benefit the faculties of education to reflect the need to integrate mathematics with natural sciences in teacher training programs. Hence, the teaching strategies utilized in this research can also be used by other teachers, aiming to enhance analogical transformations skills of algebraic manipulation and knowledge in solving word problems in other subjects such as physics, biology, or geography.

Recommendations

In this study, we see that the needed cohesive synergy between mathematics and other subjects is substantial, linking the development of problem-solving skills to curriculum and school organization qualities to building an education system that contributes to socio-economic competencies. Using algebraic and procedural transformation strategies to solve contextual chemistry problems helps eliminate the struggles of applying proportional and conceptual thinking in chemistry. Mathematics must complement and reinforce conceptual chemistry comprehension. Stoichiometry learning is made easier while simplifying the characteristics of algebraic manipulations and procedural transformations. The convergence of mathematics and chemistry and other subjects, if widely implemented, will help in-service and prospective teacher professionals overcome one of the most common traditional hurdles of their careers, cross-curriculum integration, and STEM education instruction.

Lastly, teaching chemistry is often thought to be content-specific. Explaining and discussing problem-solving procedures in several different techniques and highlighting that not every answer can be found the same way could inspire perseverance skills in chemistry students. Based on the findings of this study, other research-based pedagogical recommendations that will aid in the effectiveness of student learning in school settings while using mathematics in chemistry can be explored and developed. Building conceptual understanding not only for contextual chemistry problem solving but also for other chemistry topics will help students correct their misunderstandings about chemistry and develop an appreciation and preference for a more in-depth understanding of chemistry rather than shallow learning.

Limitations

According to the teachers of both experimental and control groups, a significant influence on the results of this study is due to the pandemic situation with COVID 19 that resulted in students facing a great number of absences in attendance and reduced teaching schedules. This situation posed a challenge for this study, especially for implementing the intervention.

Acknowledgments

The author would like to thank the mathematics and chemistry teachers and their students who participated in the study.

Funding

The study was supported by the Ministry of Education, Science, and Technology of Kosovo.

Authorship Contribution Statement

The author's contribution to the manuscript is equally shared, starting from conceiving and designing the research, data collection, data analysis, the study's presentation, and the paper's writing.

References

Baysal, E., & Sevinc, S. (2021). The role of the Singapore bar model in reducing students' errors on algebra word problems. *International Journal of Mathematical Education in Science and Technology*, *53*(2), 289-310. https://doi.org/10.1080/0020739X.2021.1944683

Beigie, D. (2008). Integrating content to create problem-solving opportunities. *Mathematics Teaching in the Middle School, 13*(6), 352-360. https://doi.org/10.5951/MTMS.13.6.0352

Bodner, G. M., & Herron, D. J. (2002). Problem-solving in chemistry. In J. K. Gilbert, O. De Jong, R. Justi, D. F. Treagust, & J. H. Van Driel, *Chemical education: Research-based practice.* Kluwer Academic Publishers.

Bopegedera, A. M. R. P. (2019). Preventing mole concepts and stoichiometry from becoming "Gatekeepers" in first year chemistry courses. In S. Kradtap Hartwell, & T. Gupta, *Enhancing retention in introductory chemistry courses: Teaching practices and assessments* (Vol. 1330, pp. 121-136). American Chemical Society. https://doi.org/10.1021/bk-2019-1330.ch008

BouJaoude, S., & Barakat, H. (2003). Students' problem solving strategies in stoichiometry and their relationships to conceptual understanding and learning approaches. *Electronic Journal for Research in Science & Mathematics Education, 7*(3), 1-42. https://bit.ly/3xNdSno

Bunce, D. M., Gabel, D. L., & Samuel, J. V. (1991). Enhancing chemistry problem solving achievement using problem categorization. *Journal of Research in Science Teaching, 28*(6), 505-521. https://doi.org/10.1002/tea.3660280605

Bush, S. B., & Krap, K. S. (2013). Prerequisite algebra skills and associated misconceptions of middle grade students: A review. *The Journal of Mathematical Review, 32*(3), 613-632. https://doi.org/10.1016/j.jmathb.2013.07.002

Capraro, M. M., & Joffrin, H. (2006). Algebraic equations: Can middle school students meaningfully translate from words to mathematical symbols? *Reading Psychology, 27*(2), 147-164. https://doi.org/10.1080/02702710600642467

Caproro, M. R., Caproro, M. M., & Rupley, H. W. (2012). Reading-enhanced word problem solving: A theoretical model. *European Journal of Psychology of Education, 27*(1), 91-114. https://doi.org/10.1007/s10212-011-0068-3

Carbonell, J. G. (1983). Learning by analogy: Formulating and generalizing plans from past experience. In R. S. Michalski, J. G. Carbonell, & T. M. Mitchell (Eds.), *Machine learning. Symbolic computation.* Springer. https://doi.org/10.1016/B978-0-08-051054-5.50009-1

Carlson, E. (2022). Improving student success in stoichiometry via the scale factor method. *Journal of Chemical Education, 99*(5), 1863-1867. https://doi.org/10.1021/acs.jchemed.1c01155

Chiu, B., Randles, C., & Irby, S. (2022). Analyzing student problem-solving with MAtCH. *Frontiers in Education, 6*, 769042. https://doi.org/10.3389/feduc.2021.769042

Cook, E., & Cook, R. L. (2005). Cross-proportions: A conceptual method for developing quantitative problem-solving skills. *Journal of Chemical Education*, *82*(8), 1187-1189. https://doi.org/10.1021/ed082p1187

Cresswell, J. W. (2003). *Research design: Qualitative, quantitative, and mixed methods approach* (2nd ed.). Sage Publications, Inc.

Fuchs, L. S., Fuchs, D., Stuebing, K., Fletcher, J. M., Hamlett, C. L., & Lambert, W. (2008). Problem solving and computational skill: Are they shared or distinct aspects of mathematical cognition? *Journal of Educational Psychology, 100*(1), 30-47. https://doi.org/10.1037/0022-0663.100.1.30

Glynn, S. M. (1989). The teaching with analogies (TWA) model: Explaining concepts in expository text. In K. D. Myth (Ed.), *Children's comprehension of narrative and ex-pository text: Research into practice* (pp. 185-204). International Reading Association.

Gulacar, O. (2007). *An invstigation of successful and unsuccessful students' problem solving in stoichiomethry.* Western Michigan University. https://scholarworks.wmich.edu/dissertations

Gulacar, O., Tan, A., Cox, C. T., Bloomquist, J., Jimmy, O., & Cao, N. (2019). Analyzing characteristics of experts in the context of stoichiometric problem-solving. *Education Sciences, 9*(3), 219-230. https://doi.org/10.3390/educsci9030219

Hallett, D., Nunes, T., & Bryant, P. (2010). Individual differences in conceptual and procedural knowledge when learning fractions. *Journal of Educational Psychology, 102*(2), 395-406. https://doi.org/10.1037/a0017486

Harmon, M. (1993). *The role of strategies and knowledge in problem solving: A review of the literature* [Paper presentation]. ERIC. https://files.eric.ed.gov/fulltext/ED366640.pdf

Hickendorff, M. (2013). The Language Factor in elementary mathematics assessments: Computational skills and applied problem solving in a multidimensional IRT framework. *Applied Measurement in Education, 26*, 253-275. https://doi.org/10.1080/08957347.2013.824451

Hodnik Čadež, T., & Manfreda Kolar, V. (2015). Comparison of types of generalizations and problem-solving schemas used to solve a mathematical problem. *Educational Studies in Mathematics, 89*(2), 283-306. https://doi.org/10.1007/s10649-015-9598-y

Huddle, P. A., & Pillay, A. E. (1996). An in-depth study of misconceptions in stoichiometry and chemical equilibrium at a South African university. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 33*(1), 65-77. https://doi.org/10.1002/(SICI)1098-2736(199601)33:1<65::AID-TEA4>3.0.CO;2-N

Jonassen, H. D. (2003). Designing research - based instruction for story problems. *Educational Psychology Review, 15*(3), 267-296. https://doi.org/10.1023/A:1024648217919

Kolar, V. M., & Hodnik, T. (2021). Mathematical literacy from the perspective of solving contextual problems. *European Journal of Educational Research, 10*(1), 467-483. https://doi.org/10.12973/eu-jer.10.1.467

Korpershoek, H., Kuyper, H., & van der Werf, G. (2014). The relation between students' math and reading ability and their mathematics, physics, and chemistry examination grades in secondary education. *International Journal of Science and Mathematics Education, 13*(5), 1013-1037. https://doi.org/10.1007/s10763-014-9534-0

Lee, H. S., Betts, S., & Anderson, J. R. (2017). Embellishing problem-solving examples with deep structure information facilitates transfer. *The Journal of Experimental Education, 85*(2), 309-333. https://doi.org/10.1080/00220973.2016.1180277

Lee, K. L., & Fensham, P. (1996). General strategy for solving high school electrochemistry problems. *International Journal of Science Education, 18*(5), 543-555. https://doi.org/10.1080/0950069960180504

Lee, K. L., Goh, N. K., Chia, L. S., & Chin, C. (1996). Cognitive variables in problem solving in chemistry: A revisited study. *Science Education, 80*(6), 691-710. https://doi.org/10.1002/(SICI)1098-237X(199611)80:6<691::AID-SCE4>3.0.CO;2-E

Lythcott, J. (1990). Problem solving and requisite knowledge of chemistry. *Journal of Chemical Education, 67*(3), 248-252. https://doi.org/10.1021/ed067p248

Mevarech, Z. R., Terkieltaub, S., Vinberger, T., & Nevet, V. (2010). The effects of meta-cognitive instruction on third and sixth graders solving word problems. *ZDM Mathematics Education, 42*(2), 195-203. https://doi.org/10.1007/s11858-010-0244-y

Ministry of Education, Science, and Technology. (2016a). *Korniza Kurrikulare e Arsimit Parauniversitar të Republikës së Kosovës (e rishikuar)* [Curriculum Framework of Pre-University Education of the Republic of Kosovo (revised)]. Retrieved May 15, 2019, from Ministria e Arsimit, Shkencës dhe Teknologjisë. https://bit.ly/3zOuqhl

Ministry of Education, Science, and Technology. (2016b). *Kurrikula Bërthamë e arsimit të mesëm të ulët të Kosovës (Klasa VI, VII, VIII dhe IX) (e rishikuar)* [Core Curriculum of Kosovo Lower Secondary Education (Grades VI, VII, VIII and IX) (revised)]. Retrieved May 15, 2019, from Ministria e Arsimit, Shkencës dhe Teknologjisë. https://bit.ly/3O9veSe

Monroe, E. E., & Orme, M. P. (2002). Developing mathematical vocabulary. *Preventing School Failure, 46*(3), 139-142. https://doi.org/10.1080/10459880209603359

Nakhleh, M. B. (1993). Are our students conceptual thinkers or algorithmic problem solvers? Identifying conceptual students in general chemistry. *Journal of Chemical Education, 70*(1), 52-55. https://doi.org/10.1021/ed070p52

Ngu, B. H. (2016). Number and algebra. In G. Hine, R. Reaburn, J. Anderson, L. Galligan, C. Carmichael, M. Cavanagh, B. Ngu, B. White, *Teaching secondary mathematics.* Cambridge University Press. https://doi.org/10.1017/CBO9781316442814.010

Ngu, B. H., & Phan, H. P. (2020). Learning to solve trigonometry problems that involve algebraic transformation skills via learning by analogy and learning by comparison. *Frontiers in Psychology, 11*, 2590. https://doi.org/10.3389/fpsyg.2020.558773

Ngu, B. H., & Yeung, A. S. (2012). Fostering analogical transfer: The multiple components approach to algebra word problem solving in a chemistry context. *Contemporary Educational Psychology, 37*(1), 14-32. https://doi.org/10.1016/j.cedpsych.2011.09.001

Niaz, M. (1995). Relationship between student performance on conceptual and computational problems of chemical equilibrium. *International Journal of Science Education, 17*(3), 343-355. https://doi.org/10.1080/0950069950170306

Novick, L. R., & Holyoak, K. J. (1991). Mathematical problem solving by analogy. *Journal of Experimental Psychology Learning Memory and Cognition, 17*(3), 398-415. https://doi.org/10.1037/0278-7393.17.3.398

Okanlawon, A. E. (2010). Teaching reaction stoichiometry: Exploring and acknowledging Nigerian chemistry teachers' pedagogical content knowledge. *Cypriot Journal of Educational Sciences, 5*(2), 107-129. https://www.oalib.com/paper/2751848

Organisation for Economic Co-operation and Development. (2004). *Problem solving for tomorrow's world.* https://bit.ly/3zVDpx9

Organisation for Economic Co-operation and Development. (2018). *PISA 2015 Results in focus.* https://bit.ly/3tLV5rm

Pape, S. J., & Smith, C. (2002). Self-regulating mathematics skills. *Theory Into Practice, 41*(2), 93-101. https://doi.org/10.1207/s15430421tip4102_5

Polya, G. (1957). *How to solve it: A new aspect of mathematical method* (2nd ed.). Princeton University Press.

Raviolo, A., Farré, A. S., & Schroh, N. T. (2021). Students' understanding of molar concentration. *Chemistry Education Research and Practice*, 22(2), 486-497. https://doi.org/10.1039/D0RP00344A

Reeves, L., & Weisberg, R. W. (1994). The role of content and abstract information in analogical transfer. *Psychological Bulletin, 115*(3), 381-400. https://doi.org/10.1037/0033-2909.115.3.381

Sawrey, B. A. (1990). Concept learning versus problem solving: Revisited. *Journal of Chemical Education, 67*(3), 253-254. https://doi.org/10.1021/ed067p253

Scherer, R., & Beckmann, J. F. (2014). The acquisition of problem solving competence: Evidence from 41 countries that math and science education matters. *Large-scale Assessments in Education, 2*(1), 1-22. https://doi.org/10.1186/s40536-014-0010-7

Schmidt, H. J. (1997). An alternate path to stoichiometric problem solving. *Research in Science Education, 27*(2), 237-249. https://doi.org/10.1007/BF02461319

Schoenfield, A. H. (1985). *Mathematical problem solving.* Academic Press, Inc.

St Clair-Thompson, H., Overton, T., & Bugler, M. (2012). Mental capacity and working memory in chemistry: Algorithmic versus open-ended problem solving. *Chemistry Education Research and Practice*, *13*(4), 484-489. https://doi.org/10.1039/C2RP20084H

Staver, J. R., & Lumpe, A. T. (1995). Two investigations of students' understanding of the mole concept and its use in problem solving. *Journal of Research in Science Teaching, 32*(2), 177-193. https://doi.org/10.1002/tea.3660320207

Sumfleth, E. (1988). Knowledge of terms and problem-solving in chemistry. *International Journal of Science Education, 10*(1), 45-60. https://doi.org/10.1080/0950069880100105

Sunday, E., Ibemenji, K. A., & Alamina, J. I. (2019). Effect of problem-solving teaching technique on students' stoichiometry academic performance in senior secondary school chemistry in Nigeria. *Asian Journal of Advanced Research and Reports, 4*(3), 1-11. https://doi.org/10.9734/ajarr/2019/v4i330110

Sun-Lin, H. Z., & Chiou, G. F. (2019). Effects of gamified comparison on sixth graders' algebra word problem solving and learning attitude. *Educational Technology & Society, 22*(1), 120-130. https://bit.ly/39DTPj7

Swanson, H. L., & Fung, W. (2016). Working memory components and problem-solving accuracy: Are there multiple pathways? *Journal of Educational Psychology*, *108*(8), 1153-1168. https://doi.org/10.1037/edu0000116

Tullberg, A., Stromdahl, H., & Lybeck, L. (1994). Students' conceptions of 1 mol and educators' conceptions of how they teach 'the mole'. *International Journal of Science Education, 16*(2), 145-156. https://doi.org/10.1080/0950069940160204

Vula, E., Avdyli, R., Berisha, V., Saqipi, B., & Elezi, S. (2017). The impact of metacognitive strategies and self-regulation processes of solving math word problems. *International Electronic Journal of Elementary Education, 10*(1), 49-59. https://doi.org/10.26822/iejee.2017131886

Wong, S. S., Ng, G. J., Tempel, T., & Lim, S. W. (2017). Retrieval practice enhances analogical problem solving. *The Journal of Experimental Education, 87*(1), 128-138. https://doi.org/10.1080/00220973.2017.1409185

Zoller, U. (1987). The fostering of question-asking capability: A meaningful aspect of problem-solving in chemistry. *Journal of Chemical Education, 64*(6), 510-513. https://doi.org/10.1021/ed064p510

Appendix

Examples:

1. *You just got a fruit dehydrator for your birthday and can't wait to try it! You are interested to see how much water an apricot has. You weigh the apricots before putting them in the dehydrator and see that it weighs 27g. When you remove it from the dehydrator, it weighs only 3.3g. How much water (in grams) was in apricots? Calculate in percentage (%) the composition of water in apricots? it is required to use the algebraic solution of the problem according to the steps:*

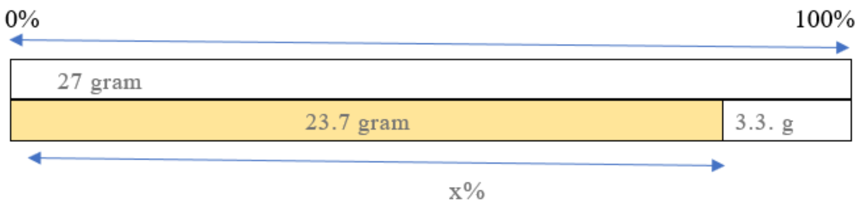
   Step 1: What is unknown? What is the data? Analyze the data. Look for visible patterns or structures. Draw the sketch. Present the notes appropriately.

   The apricot initially weighed 27g.

   After dehydration weighed 3.3g.

   Using this data on apricots' weight, we need to find the amount of water.

   See sketch



   Step 2: Do you have knowledge of the statements and concepts you need to use?

   It is necessary to find the difference in weight of apricot after leaving the dehydrator compared to the weight it had before placing in it.

   1. That difference represents the amount of water in (grams)

   2. We must calculate what percentage of the total apricot represents the amount of water found above.

   3. Write an equation:

   From the figure, we see that the ratio is valid: 27: 23.7 = 100: x

   Step 3. Look for quick calculation methods and methods

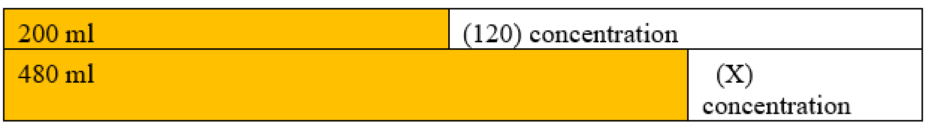
   x = (23.7 · 100) /27=87.7

   Step 4. Apricot contains 87.7% water. Justify the solution. Does it make sense? Is the answer, right? Argue the answers. Can you use the result or the way to solve it or any other problem?

   So analogous transfer is likely to occur if students can successfully design the connecting elements between a source example (in our case, find x from the ratio 27: 23.7 = 100: x) and a context-targeted problem (from chemistry).

2. *Assume that we have a glass of sugar solution (lactose C12H22O22 200ml) with a concentration of 120g / dm3. To prepare a solution in a larger glass (480ml) we obtain another concentration of the solution. What concentration have we gained?*

   Step 1: Understand the problem: Look for visible patterns or structures. Draw the sketch. Present the notes appropriately.



Step 2: Present the equation. From the figure, we see that:

200 · 120 = 480 · x

Step 3: Solve the algebraic equation. Find out if you made mistakes in calculations or accuracy in mathematical content. Then, clearly define the units of measurement.

$x = \frac{24000\ mlg/\text{dm3}}{480\ ml}$ = 50g/dm^3

Step 4. The concentration per glass (480 ml) is 50 g / dm3. Justify the solution.

3. *Ammonia is a colorless gas composed of nitrogen and hydrogen. It is extremely soluble in water and is used as a fertilizer, coolant, disinfectant, and nitric acid production. What is the maximum mass (in grams) of ammonia, NH_3, that can be obtained from 5.0 grams of H_2 and 30 grams of N_2? The balanced equation is:*

$3\ H_2\ (g) + N_2\ (g) \rightarrow 2\ NH_3\ (g)$

Step 1. What is given?

5.0 grams of H_2

30.0 grams N_2

The quantities of the two reactants are given. Only one determines the amount of product, namely the limiting reactant. Therefore, we need to find the limiting reactant.

First, we convert the mass of the reactants to the mole of the reactants.

5 g H_2 $(\frac{1\ mol\ \text{H2}}{2.016\ g\ \text{H2}})$ = 2.5 mol H_2

30 g N_2 $(\frac{1\ mol\ \text{N2}}{28.02\ g\ \text{N2}})$ = 1.07 mol N_2

Step 2. What is required to be found?

gram NH_3

We ask ourselves, how many moles of N_2 do we need to react with 2.5 moles of H_2?

2.5 mol H_2 $(\frac{1\ mol\ \text{N2}}{2\ mol\ \text{H2}})$ = 0.83 mol N_2

It follows from the above that we have sufficient quantities of N_2 and that H_2 is the limiting reactant.

Step 3. Use the map

Mole te $H_2 \rightarrow$ mole $NH_3 \rightarrow$ gram NH_3

Step 4. Set the problem so that the units are canceled

2.5 mol H_2 x$(\frac{2\ mole\ \text{NH3}}{3\ mol\ \text{H2}})$ $(\frac{17.03\ g\ \text{NH3}}{1\ mol\ \text{NH3}})$

Step 5. Do the arithmetic

$\frac{2.5\ x\ 2\ x17.03}{3}$ g NH_3 = 28 g NH_3