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HOW PRIMARY STUDENTS UNDERSTAND THE CONCEPTS OF MIXTURES AND SOLUTIONS

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Abstract: A key and persistent challenge in early science education is effectively transforming complex scientific concepts into didactic material. To meet the demands of modern teaching, practitioners and researchers are constantly developing and adapting effective science teaching models. Accordingly, selected chemical content was taught through pilot projects using the Inquiry-Based Science Education approach. The study assessed how the designed Inquiry-Based Teaching Model affected students' knowledge quality. This innovative teaching model applies STEAM+X educational framework to guide students through inquiry, dialogue, critical thinking and experiential learning, thereby contributing to the development of their persistence in problem solving, collaborative skills and unique creative abilities. The goal of this research was to check whether it is possible, and if so, how to teach concepts of mixtures and solutions in the 4th grade of elementary school through the particulate nature of matter. The research was conducted at one elementary school in Serbia on a total sample of 21 students. The obtained results show that students accomplished better achievements on the post-test compared to the pre-test, which, along with the observed high motivation of students to learn through inquiry, confirmed the effectiveness of the created and applied teaching model. The implemented IBTM facilitated a comprehensive understanding of mixture and solution properties, accurate classification of examples, improved comprehension of separation procedures, and enhanced knowledge of substance solubility in water. However, categorizing the properties of mixtures and solutions based on similarities and differences proved challenging for students at this age, irrespective of the teaching model. Given the promising potential of the obtained data, this study provides valuable insights for the future application of these or modified models across varied teaching content, with larger samples, and over longer time frames.
Keywords: *initial science education, STEAM+X teaching approach, mixtures and solutions.*
Field: Social sciences

1. INTRODUCTION

The essence of Inquiry-Based Science Education (IBSE), or simply Inquiry, is that children, through the active pursuit of compelling questions and problems, construct their own understanding and refine their learning strategies. The cognitive and procedural skills developed through inquiry-based learning directly correspond to those utilized in scientific investigation, thus enabling children to effectively interpret the scientific dimensions of their natural and constructed environment (Harlen, 2014).

STEAM education has become a highly influential educational movement. Its emphasis on integrating science, technology, engineering, arts, and mathematics reflects a modern approach to learning. (Singh, 2021). The pedagogical intent of STEAM is to move away from isolated disciplinary perspectives, and therefore to foster a holistic approach to problem-solving. (Kim & Park, 2012; Li et al., 2020). This novel STEAM + X pedagogical design merges STEAM with architecture, culture, and history, creating learning experiences that concurrently advance language proficiency for both teachers and students, irrespective of their disciplinary backgrounds (Bedewy & Lavicza, 2023). According to Miralimovna (2022), effective teacher discourse in STEAM activities promotes the scientific method. This necessitates teachers designing research activities that encourage "thinking aloud" and the use of STEAM terminology, such as observe, investigate, predict, and conduct experiments.

The abstract nature of atomic concepts, coupled with insufficient practical activities in teaching, significantly hinders students' comprehension of the particulate nature of matter. This abstractness stems from the fact that particle arrangement and behavior are not directly observable at the macroscopic level (Riaz, 2004). Findings reveal a persistent challenge for students of all ages in understanding the scientifically accepted particulate model of matter, which describes matter as composed of discrete, perpetually moving particles separated by space. This particulate model is a prerequisite for a robust understanding of dissolution mechanisms (Nakhleh, 1992).

The challenge of teaching science lies in addressing and modifying students' intuitive, but often scientifically incorrect, explanations of phenomena (Theobald & Brod, 2021). Research on misconceptions

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typically focuses on three key areas: identification through diagnostic testing, investigation of causes, and remediation strategies. Diagnostic and remediation approaches are the most frequently explored areas (Resbiantoro et al. 2022).

A study by Cañada et al. (2017) that included the 5th grade students has shown to which extent it is important to encourage the understanding of how components build more complex substances (mixtures and solutions). Besides an observation of the differences between mixtures and solutions, the authors emphasized the importance of simultaneous adoption of two concepts: the building of complex substances and the existence of small, invisible particles dissolved in solvents. Furthermore, Lofgren & Hellden (2008) indicated the importance of an early introduction of scientific ideas about chemical and physical changes of substance into the teaching process (the change in the colour of fallen leaves, the process of burning a candle and the condensation of water vapour), since it contributes to the gradual development and establishment of students' knowledge. In light of the foregoing, it would be useful to form an inventory of preconceptions at the initial school learning about natural phenomena, and in accordance with it, to design the teaching models that would prevent the 'recycling' of wrong beliefs in following years.

Synthesizing findings from previous investigations, this study developed and implemented a novel IBTM. This model, which integrates the particulate nature of matter, a concept currently outside the Republic of Serbia's curriculum, was piloted to assess its effectiveness in teaching mixtures and solutions. The present study addressed the following research questions:

1. What is the impact of the inquiry-based teaching model (IBTM) on the knowledge acquisition of 4th-grade primary school students regarding mixtures and solutions?

2. To what degree does the IBTM enhance students' conceptual understanding of mixtures and solutions through the lens of the particulate nature of matter?

2. MATERIALS AND METHODS

In this study, 21 fourth-grade students (13 girls, 8 boys) from Elementary School 'Nikola Vukićević' (NV) in Sombor, Serbia, participated in an intervention utilizing an inquiry-based teaching model (IBTM) specifically designed for the instruction of mixtures and solutions. The subsequent analysis examined the impact of this intervention on student knowledge development.

Student prior knowledge of mixtures and solutions was assessed using a pre-test, while a post-test evaluated the IBTM's impact on knowledge acquisition and conceptual understanding. Both tests comprised 12 questions, designed to measure six cognitive levels (recognition/remembering, understanding, application, analysis, evaluation, and creation) aligned with the revised Bloom's taxonomy (Anderson et al., 2001). This structure allowed for a detailed examination of student preconceptions, misconceptions, and post-intervention knowledge quality. Questions were weighted, with scores ranging from one point for recognition/remembering to five points for evaluation and creation, yielding a maximum test score of 40. Students completed the tests within a 45-minute class period. Table 1 provides an overview of the pre-test and post-test questions regarding mixtures and solutions.

Table 1. Requirements in the questions on the pre-test and post-test about mixtures and solutions

Question N°	Requests in pre-test	Requests in post-test
1.	Define the mixture.	Circle the mixtures within provided items.
2.	Circle the mixtures within provided items.	Determine whether the offered photos are a mixture or a solution.
3.	Enter the numbers 1, 2, 3 and 4 to display the correct order of mixture preparation and separation of its components (sieving).	Complete the sentences with the provided words or sets of words to make correct statements.
4.	Connect the offered statement with the corresponding illustration (separation of the mixture's components).	Enter the numbers 1, 2, 3 and 4 to display the correct order of mixture preparation and separation of its components (filtration).
5.	Suggest the ingredients and procedure used to make lemonade.	Describe and draw the process of sweet chocolate milk preparation.
6.	Suggest how to separate the components of the mixture (fruit salad) shown in the photos and explain your choice.	Based on the illustrations (different arrangement and density of particles) determine the state of matter.
7.	Sort the given statements about mixtures and solutions according to similarities and differences.	Based on the photo of the mixture (soup), suggest how to separate the solid components from the liquid ones and explain the answer (squeezing).
8.	Classify the provided terms depending on whether they are a mixture or a solution.	Sort the provided mixtures depending on whether their components are in a solid or liquid state.
9.	Based on the photos of the mixture (soil and water/clear juice), evaluate and explain which of them can be separated by squeezing.	Explain why a plastic bottle filled with air can be compressed more easily than one filled with water or sand.
10.	Sort the provided materials according to their solubility (dissolves/does not dissolve) in water and explain your choice.	A mixture or solution should be made from the provided components and sorted into the appropriate column in the table.
11.	Using the provided components, formulate and classify mixtures in a solid state, mixtures in a liquid state, considering easy separation and dissolution of the components.	Describe and draw the procedures for separating the components of the mixture obtained by mixing all provided materials.
12.	Using the provided materials (a hotplate, pot, food coloring, water and a spoon), designe and illustrate an experiment proving that the temperature of a liquid affects the rate of dissolution.	Create two meals (a mixture in liquid and a mixture in solid state) and one drink (solution). List the components, describe the process and illustrate it.

Source: Authors research

The sequences within this IBTM were: Differentiation between mixtures and solutions, Mixtures in solid, liquid and gaseous states, Separation of a mixture's constituents, Materials are made of tiny particles (particulate nature of matter), and Mixtures are everywhere around us. Within innovative model sequences, the students, applying the scientific method, defined their research questions, posed hypotheses, performed experiments, and wrote down observations and conclusions. In addition, the students used drawings to show the procedures of the experiments, as well as, the observed physical and chemical changes in substances. The peculiarity of this IBTM was reflected in its close connection with the student's daily life, such as nutrition. Additionally, the home experiments were upgraded with very useful skills: comprehension of the laboratory findings (blood test) and understanding of the percentage of milk ingredients printed on the packaging. The data collected from the achievement tests were analyzed using descriptive statistical methods. Additionally, student responses to individual test items were classified into three categories: correct, incomplete, and incorrect or unanswered.

3. RESULTS

The first task in the study was to create a pre-test, used to check students' prior knowledge and to identify misconceptions, and the obtained data was later used to create appropriate IBTM. After the implementation of innovative teaching models, its effects on student achievements were verified via a post-test. Table 2 shows the basic statistical parameters of the pre-test and post-test on mixtures and solutions.

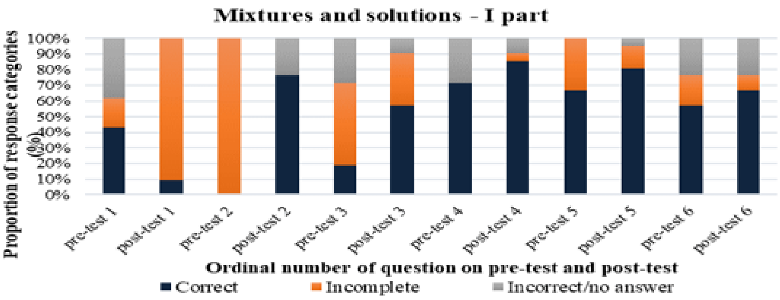
Table 2. Basic statistical parameters of the results achieved by the experimental (E) group of students on the pre-test and post-test on mixtures and solutions.

Descriptive statistics	Parameter values	
	Pre-test	Post-test
M	19.80	25.59
SE	1.46	.97
Mdn	21.10	26.60
SD	6.72	8.23
MIn	8.30	10.50
Max	31.20	36.90
SKEW	-.24	-.51
KURT	-.99	-.71

Source: Authors research

The results of the pre-test on mixtures and solutions (W = .96, p = .47), as well as the post-test (W = .93, p = .15), displayed normal distribution, as determined by the Shapiro-Wilk test. Data in Table 2 proved that after applying the IBTM, students were more successful and obtained better scores on the post-test (M = 25.59, SE = .97) in comparison to the pre-test (M = 19.80, SE = 1.46). Likewise, the results of both tests were shifted towards the higher achievements, as shown by the asymmetry coefficients (SKEW1 = -.24 and SKEW2 = -.51) and evenly distributed across the distribution curve (KURT1 = -.99 and KURT2 = -.71). Figure 1 shows the distribution of pre-test and post-test results for the first six questions within the three answer categories: correct, incomplete and incorrect/no answer.

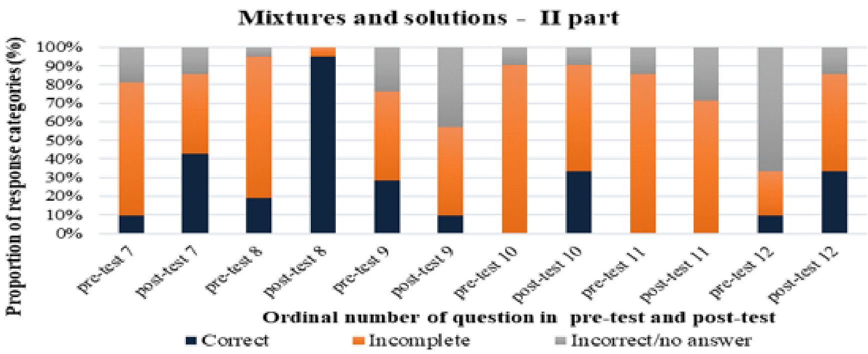
Figure 1. Proportion of response categories for the cognitive levels of recognition, understanding and application on the pre-test and post-test on mixtures and solutions



Source: Authors research

Comparing the results achieved on both tests on mixtures and solutions at the lower cognitive levels (Fig 1), it was noticed that regarding the pre-test students were more successful only in the first question, while considering the post-test they had better achievements in all other questions. The distribution of students' achievements on the pre-test and post-test on mixtures and solutions from the seventh to the twelfth question is shown in Figure 2.

Figure 2. Proportion of response categories for the cognitive levels of analysis, evaluation and creation on the pre-test and post-test on mixtures and solutions



Source: Authors research

According to the data in Figure 2, students performed better on the two remaining questions (6th and 9th) on the pre-test on mixtures and solutions, but they were more effective in answering the seventh, eighth, tenth and twelfth questions at the higher cognitive levels in the post-test.

4. DISCUSSION

The pre-test and post-test results from the IBTM implementation, as well as an analysis of student performance on individual questions, are presented in the subsequent sections.

An analysis of the 1st pre-test question revealed that about 40% of the students were able to correctly define mixtures. This was also confirmed by data obtained on the third question of the post-test, since about 55% of the students were able to complete the sentences about the properties of mixtures and solutions. However, only 10% of the students successfully identified the examples of mixtures on the post-test (1st question). When this result was compared to the 2nd question of the pre-test, which was of the same type (examples of the mixtures), only slight improvement was observed after the model application. This leads to the conclusion that regardless of the comprehension of the properties of a mixture, there is always an example that seems to be confusing for the students. Data obtained on the 2nd question of the post-test exhibited that about 75% of the students successfully distinguished between a mixture and a solution, likewise for the 4th pre-test question (about 70%), what is probably an outcome of the examples' illustrations. Regarding the steps within the procedure of the mixtures' components separation (sieving – pre-test, filtering – post-test), it was proven that students' independent research activities during the IBTM led to significantly better results achieved on the post-test (20% correct answer to the 3rd question of the pre-test and 86% correct to the 4th post-test question). Interestingly, very solid prior knowledge of the students (around 70% gave correct answers to the 5th question of the pre-test) was only slightly improved by the application of the teaching model (about 80% correct answers to the 5th question of the post-test), demonstrating the importance of learning from everyday experience (lemonade and chocolate milk making at home), as previously described (Na, J. & Song, J., 2014). Although almost 60% of the students successfully described the correct procedure for separating the ingredients of the fruit salad (6th question of the pre-test), only 30% were able to describe the filtering of the soil and water mixture (9th question of the pre-test). However, due to the application of IBTM, most of the students were able to correctly answer a similar question on the post-test (question 7) and describe the appropriate procedure for separating the ingredients of the soup (over 80% of students did it correctly or partially correctly). It is obvious that the procedures of the mixture separation with all the components in a solid state were more understandable to the students than the separation of components being in two different states (liquid and solid). Bearing in mind that the children learned about the particulate structure of the substance for the first time during IBTM, the data obtained on the 6th post-test question (about 65% correct and about 10% partially correct answers), demonstrated that at that age they were capable of understanding the mentioned concept. In addition, the results achieved for question 9 of the post-test, where almost 60% of the students correctly or partially correctly explained the difference in the compressibility of air, water or sand, also speak in support of this claim, since they obviously had to keep in mind the arrangement of particles in the mentioned substances. The request to classify the statements that describe the similarities and differences of mixtures and solutions (question 7 of the pre-test), was proved to be very difficult for many students (only 10% of correct answers), which has already been confirmed as a challenging request for students of younger school age (Allen, 2010: 111-113). The analysis of the obtained results regarding the 8th question in both tests revealed that after the application of IBTM, many of the students' doubts about the classification of the particular solutions and mixtures were resolved. As expected, everyday experience and previous school learning contributed to the fact that students easily recognized water-soluble and water-insoluble materials (10th question of the pre-test), but at the same time they were not able to justify their answers. In contrast, on a similar post-test question (question 10), over 30% of them managed to give a completely correct answer, demonstrating the positive effects of IBTM. Although at first glance it seems unexpected that the achievements on the 11th post-test question were slightly diminished in comparison to the same question of the pre-test, it should be taken into account that the question was more complex. The question implied knowledge of all procedures for the mixture's components separation, as well as the ability to describe them, which is a common problem for students of this age (Bianchi et al., 2021). The results of the 12th question of the post-test (33% correct and around 52% partially correct answers) indicated the importance and high value of the IBTM application. Namely, despite the high demands (no examples were offered), a significant proportion of students was able to independently design, describe and illustrate examples of meals and drinks made of ingredients in liquid and solid state.

5. CONCLUSION

An investigation was undertaken to enhance initial natural science instruction, focusing on the chemical concepts of mixtures and solutions and their interpretation through the particulate nature of matter. STEAM + X activities, delivered via an inquiry-based teaching model (IBTM) employing experiential learning, were implemented. Purpose-designed knowledge tests were used to assess the impact of the IBTM on the achievement of 4th-grade elementary school students.

Students, most likely, acquired prior knowledge about the methods for mixtures' preparation through everyday experiences, while IBTM contributed to a better understanding of the procedures for the separation of components in the mixtures, which was mostly unknown before. However, there are still difficulties with the mixture separation when the components are present in different states of matter. Despite the understanding of the properties of mixtures and solutions, as well as the correct classification of the particular examples, the results of the post-test revealed that some examples can always create confusion for the students. On the other hand, the applied IBTM contributed to a better comprehension of the substances' solubility in water. Sorting the properties of studied entities (mixtures and solutions) according to similarities and differences, regardless of the applied model, was too demanding for this student's age, especially in the case when the STEAM+X model was applied only once.

While the IBTM enhanced students' phenomenological understanding of the selected content, it did not fully facilitate interpretation through the particulate nature of matter. This limitation may be attributed to the single application of the model. Additionally, the limited sample size necessitates caution in generalizing the findings. Nonetheless, this study provides valuable preliminary data for future investigations, suggesting the promising potential of implementing similar or modified models on a larger scale and for a longer period of time.

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