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Оригинални научни рад

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Possibilities and Challenges in Early Science Education: Exploring Heat and Sound

Summary: *Selected physics contents (heat and sound) were taught through two pilot projects employing Inquiry-Based Science Education (IBSE) within a STEAM+X educational framework. This research investigated whether, and to what extent, primary school students can effectively interpret natural phenomena through the particulate nature of matter using Inquiry-Based Teaching Models (IBTMs). This quasi-experimental study with parallel groups involved 62 3rd and 4th grade students from two primary schools in Serbia. Students of both groups, experimental (E) and control (C), showed better results on the post-test compared to the pre-test, with the difference in achievement being more pronounced in the E group. The analysis of post-test achievement disparities between students from both groups revealed a statistically significant difference favouring the E group, thereby validating the efficacy of the implemented innovative teaching models on the content related to thermal and sound phenomena.*

Keywords: *initial science education, inquiry, STEAM+X approach, heat, sound.*

Introduction

Inquiry-based science education (IBSE), or simply *inquiry,* draws inspiration from Dewey (1938), who emphasized learning through experience: doing and reflecting. It regained prominence in the 1990s with the U.S. National Science Education Standards (National Research Council, 1996) and is now a recommended approach for developing students' scientific knowledge, skills, and motivation (Strat et al., 2022). In IBSE, students are presented with opportunities to observe and question natural phenomena. They are then challenged to develop and justify their own theories, drawing conclusions from experimental data through independent practice. These learning situations are designed to be open-ended, fostering exploration and avoiding the pursuit of a single 'right' answer (Hat-

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tie, 2009). Shymansky et al. (1990) found inquiry-based teaching to have a greater impact on students' process skills than on content knowledge. This effect was the strongest in primary school and diminished as students progressed through the educational system. In integrated STEM (Science, Technology, Engineering and Math) learning, *inquiry* is viewed holistically as a fluid and iterative process where outcomes are tentative, rather than absolute. This fluidity is reflected in the non-deterministic nature of *inquiry*, allowing students to employ various approaches such as *scientific inquiry*, *engineering design* or other relevant methods to achieve solutions (Tan et al., 2023).

STEAM (Science, Technology, Engineering, Arts and Math) education has been one of the most impressive educational movements in recent years (Singh, 2021). Within this teaching strategy, one tries to overcome seeing the world from the perspective of one's scientific discipline, and therefore in STEAM practices, problems are solved holistically (Kim & Park, 2012; Li et al., 2020). The novel STEAM + X approach connects STEAM with architecture, culture and history (Bedewy & Lavicza, 2023), whereby all created activities simultaneously contribute to the improvement of the language competencies of teachers and students, regardless of the scientific field or discipline. According to Miralimovna (2022), the language (speech) used by teachers during STEAM activities is aimed at the application of the scientific method, which involves directed observation, questioning, prediction, experimentation, and discussion. In other words, it is important for teachers to shape the teaching process so that during research activities they include thinking aloud, i.e., the use of STEAM terms, such as: *observe, investigate, predict, conduct experiments*, etc.

Interpretation of natural phenomena through the particulate nature of matter in science education

Terms describing the structure of a substance are studied within the natural sciences during the second cycle of primary education (chemistry and physics), though additionally children acquire informal knowledge about atoms and molecules from the media and everyday life (Donovan & Venville, 2012; Haeusler & Donovan, 2020). Although they understand that matter is made up of discrete particles, they are unable to apply this knowledge in order to explain natural phenomena. In the natural sciences, many concepts involve phenomena that can be observed at the macroscopic level, but can be fully explained only at the microscopic level. Therefore, it is essential to provide students with ample opportunities to connect these levels of understanding (Milanović-Nahod et al., 2003). Introducing concepts about the particulate structure of matter into the teaching process is a challenge, both for students and for teachers. In most educational systems, the interpretation of the natural phenomena in the classroom is phenomenological and on a macroscopic level. Only a small number of countries in the world apply the basics of the atomic-molecular theory at younger school age: Sweden from the 4th grade, Norway in the 5th grade, Turkey in the 6th grade and the USA in the 5th grade, where the Next Generation Standards incorporate simplified particle theory into the 5th grade curriculum (Baji & Haeusler, 2021). Bearing in mind that the students of the younger school age are cognitively unprepared to adopt the idea of the particulate structure of matter (Haeusler & Donovan, 2020), teachers create teaching models that 'bypass' the interpretation of natural phenomena from a microscopic aspect. Is it necessary, effective, and cognitively justified to introduce terms that describe a particulate structure of matter, such as a molecule, the size of molecules, and the space between them, the movement, speed and energy of molecules, in the classroom? It is one of the questions for both practitioners and researchers. The answer could be one of the 10 selected and formulated Great Scientific Ideas:

> 'All matter in the Universe is made of very small particles.
> Atoms are the building blocks of all matter, living and non-living. The behaviour and arrangement of the atoms explains the properties of different materials. In chemical reactions atoms are rearranged to form new substances. Each atom has a nucleus containing neutrons and protons, surrounded by electrons. The opposite electric charges of protons and electrons attract each other, keeping atoms together and accounting for the formation of some compounds.' (Harlen, 2015, p. 15)

This scientific idea can be seen as an expected teaching outcome at the end of primary education, regardless of the time the concepts about the particulate nature of matter are introduced into the teaching process. Ozmen (2011) pointed out to the difficulties that students have when learning the content about the particulate nature of matter, mentioning the following reasons: the concepts of atomic-molecular theory are often abstract to students, words from their everyday speech are used with a different meaning during classes, as well as an impossible visualization of the process at the microscopic level. The stated reasons hinder the correct formation of the concepts about the particulate nature of matter, as well as the understanding of natural phenomena, resulting in the creation of a large number of diverse misconceptions. Hatzinikita at al. (2005) claimed that if students are not aware of the existence of discontinuity and variability of substance, later they may adopt certain scientific concepts incorrectly. Furthermore, in the absence of any knowledge about the particulate nature of matter, students copy the macroscopic properties they understand to the microscopic level (Allen, 2011). Delaying the adoption of teaching content about the structure of matter until the older grades of primary school is challenged by Haeusler and Donovan (2020), whose research showed that the fourth-graders in Australian schools can form mental representations of complex scientific concepts, such as Bohr's model of the atom.

Misconceptions about heat and sound

A significant cognitive disparity often separates the requirements of formal scientific disciplines and the abilities of students (Milanović-Nahod et al., 2003). This is particularly evident in the pre-school phase, where children's thought processes are largely driven by intuition, anchored in spontaneous and pseudo-conceptual understandings (Vygotsky, 1986). Some complex scientific phenomena, such as temperature and heat, are most often adopted by students intuitively, and the concepts formed in this way are not scientifically correct, commonly referred to as misconceptions (Erickson, 1979). Utilising simple physical experiments, within the 'Predict-Observe-Explain' (POE) method, Fitzallen et al. (2016) studied the understanding of the concepts of heat and particle motion in 7- and 8-year-old students. Although the children offered a wide range of proposals to interpret the structure of substances and thermal changes, they still stuck to the idea of heat as an independent entity found only in heated bodies, which was also confirmed in a similar research in Serbia (Balać et al., 2022). Schönborn et al. (2014) used the POE method to examine the possibility of the knowledge improvement among 12- and 13-year-old students about thermal conduction, using infrared (IR) camera technology, which made the conduction process 'visible'. Taking the photo of the contact between the student's finger and the metal, as well as the finger and a piece of wood, a thermographic record was made and used to show the process of heat conduction. The results of the research showed that the applied model contributed to the students' motivation to learn about thermal phenomena, but did not significantly affect the process of conceptual change among students.

Sozen & Bolat (2011) studied the false beliefs of the second-graders about sound propagation. Although the children understood that sound propagation is related to the flickering (vibration) of a particle in the environment, their drawings displayed beliefs that these particles also move translationally from the source to the receiver of the sound. When it comes to sound phenomena and sound properties, Nurjani et al. (2020) revealed that the misconceptions, observed during the analysis of the results obtained on the four-level diagnostic test of knowledge, as well as the interviews conducted with the fifth-grade students, were caused by inadequate teaching approaches. In addition, they emphasized the low degree of retention of the previously acquired knowledge by students.

The highest level of spontaneous thought characteristic of a preschool child age, the pseudoconcept level, does not constitute an adequate psychological basis for the acquisition and mastery of the school content, which should be organized as systems of scientific concepts. Ivić argues that these disparities, coupled with the distinct nature of the two types of knowledge (spontaneous versus conceptual), and the inherent tension between them, must be maintained and respected (Ivić et al., 1997, as cited in Petrović, 2006). Instruction must avoid the error of reducing the learning of scientific concepts to merely expanding and enriching the child's everyday experience. Instead, the design of the schooling process must recognize the specific logico-psychological nature of scientific concepts, while simultaneously aiming a step ahead of the child's current developmental capabilities. In this process, children's spontaneous concepts should serve to provide concrete content for scientific concepts, which are exclusively abstract thought forms. During the initial years of primary schooling, the cognitive functions defining conceptual thinking reside within the zone of proximal development of the child's individual mental organization. The progression of these functions and the advancement to a higher intellectual level are facilitated by teacher-student collaboration (Vygotsky, 1999, as cited in Petrović, 2006). These theoretical foundations, coupled with the results of the studies on the possibility of forming the concepts about the particulate structure of matter at an early school age through modern teaching approaches, substantiate the authors' expectations and justify the stated research aim.

In the educational system of Serbia, the revision of misconceptions about the particulate nature of matter is mainly carried out in the higher grades of primary school (7th and 8th grade) as a part of chemistry classes (Rodić et al., 2020). However, the mechanisms of the emergence of students' misconceptions and solutions to overcome them are completely neglected in younger school age (from 1st to 4th grades).

All the presented findings of the previous research on students' interpretation of thermal and sound phenomena through particulate nature of matter gave guidelines for the creation of the STEAM + X teaching approach, which was implemented in the form of two inquiry-based teaching models (IBTM). We developed these models with a novel approach, interpreting phenomena and processes through the particulate nature of matter, a concept currently outside the Republic of Serbia's curriculum. This study sought to answer the following research questions:

(1) How does the knowledge achievement of third- and fourth- grade primary school students regarding heat and sound change after exposure to the two IBTM?

(2) To what extent do the IBTM contribute to improved understanding of the selected content from the perspective of the particulate nature of matter.

This study aimed to investigate how effectively elementary school students can adopt heat and sound phenomena through the particulate nature of matter using Inquiry-Based Teaching Models (IBTMs) within a STEAM+X framework.

Materials and methods

Participants

The investigation was carried out in two primary schools in Sombor, Serbia: 'Ivo Lola Ribar' (ILR) and 'Avram Mrazović' (AM), on a total sample of 62 students (28 girls and 34 boys). Forty students attended the 3rd, while 22 of them attended the 4th grade. The research was conducted in accordance with appropriate ethical principles, with all respondents being informed about the research and voluntarily accepting participation with parental consent. The first IBTM on thermal phenomena was applied in the ILR primary school in one 4th grade class, where half of the class consisted of the experimental (E) group, and the other half, was the control (C) group, where the Traditional Teaching Model (TTM) was applied. The experiment with parallel groups was implemented during the Covid-19 pandemic, when each class of this school was divided into two groups that attended classes separately. The second IBTM about sound was realized in the AM school with third-grade students, and one class served as an E and the other as a C group of students. The effect of these teaching models on the quality of students' knowledge was assessed after their implementation.

Instrument - Achievement tests

To examine the students' prior knowledge about heat and sound, the pre-tests were created (Cronbach's alpha coefficient: heat $\alpha = .57$; sound $\alpha = .46$), while the impact of IBTM and TTM on the quality of knowledge and the conceptual understanding was examined using the post-tests (heat $\alpha = .74$; sound $\alpha = .76$). The tests contained 12 questions with 6 levels of achievement – recognition/remembering, understanding, application, analysis, evaluation and creation, in accordance with the revised Bloom's taxonomy (Anderson et al., 2001). The distribution of the points by cognitive levels of the questions in the knowledge tests ranged from one, for the lowest level of achievement, to five for the highest levels - the levels of evaluation and creation. The maximum number of points on the tests was 40, and the students solved the tests during one school lesson (45 min).

Research design - Description of the intervention

The idea was that the students in the experimental (E) groups within IBTM carry out research activities at the classes of Nature and Society, i.e., study natural phenomena, processes, and objects from the point of view of various scientific disciplines (natural and social), with the application of graphics - art and language - speaking skills. In IBTM, the following student activities were employed: implementation of the scientific method, the research of natural phenomena through experimentation ('Hands-on' activities), participation in the game, modelling, etc. During the implementation of the IBTM group work was applied, whereby teachers through all stages strengthened the development and improvement of the students' language competencies, such as understanding of a text by reading, group reporting on the research results, as well as discussions at the class level. The students of the control (C) groups adopted the same teaching contents through the TTM, which is still the most present approach in our teaching practice. Students studied heat and sound phenomena within both models (IBTM and TTM) during the same period of time.

The IBTM and TTM on thermal phenomena consisted of the five following sequences: *States of matter, Particulate nature of matter, Temperature, Heat, and Conduction of heat*. Within all IBTM sequences, the students applying the scientific method, defined their research questions, posed hypotheses, performed experiments, and wrote down observations and conclusions. For example, in the second sequence of IBTM, the students modelled the particle structures of a body in a solid state by using balls of plasticine and toothpicks, and graphically presented the arrangement of the particles in three states (solid, liquid, and gaseous). In addition, the students used drawings to show the procedures of the experiments, as well as the observed physical and chemical changes in substances. During the third sequence of IBTM, one of the activities was 'Hands-on', which involved creating a thermometer model from suitable accessories and materials.

IBTM and TTM on sound and properties of sound was applied through the following four sequences: *Basic principles of inquiry learning, Sources and properties of sound, Sound propagation and echo, and Making posters - sound concept maps*. The STEAM + X approach was applied, with emphasis on engineering creative-design skills, as well as 'Hands-on' activities such as: construction of telephone models from plastic cups and strings, creation of musical instruments - guitars, castanets, metallophone and Pan flutes from appropriate accessories.

Data Collection

In both IBTMs and TTMs descriptive statistical method was used to process the data collected from the achievement tests. The differences in student performance on the pretest and posttest in the E and K groups were evaluated for both models. The students' achievements on individual tasks were additionally analysed, using the following answers classification into three groups: correct, incomplete and incorrect or no answer.

Results

The first task in pilot studies was to create a pre-test used to check students' prior knowledge and to identify misconceptions. The obtained data were later used to create an appropriate IBTM. After the implementation of the innovative teaching models, its effects on student achievement were verified *via* a post-test.

Results of the pilot research on thermal phenomena

The results obtained on thermal phenomena pre-test displayed a normal distribution for achievement in both groups of students, E (W=.93, p=.43) as well as C (W=.89, p=.14), which was determined by Shapiro-Wilk test. The Table 1 shows the basic statistical parameters of the results for both groups.

Table 1. Basic statistical parameters of the results achieved by E and C groups on the pre-test on thermal phenomena

Descriptive statistics	Parameter values	
	E group	C group
M	14.65	14.20
SE	1.84	2.50
Mdn	13.50	11
SD	6.13	8.30
MIn	7.50	3.75
Max	26.50	26.50
SKEW	.59	.22
KURT	-.55	-1.81

Based on the results shown in Table 1 it can be seen that the achievements of the students in E (M=14.65, SE=1.84) and C groups (M=14.20, SE=2.50) were very similar, indicating the uniformity of the groups in the quasi-experiment. The differences in the achievements of the students from both groups (E and C) on the pretest and posttest regarding thermal phenomena were evaluated. Since neither group's accomplishments on the pretest had a normal distribution, the Mann-Whitney U test was used to compare them. The pretest results showed no statistically significant difference between the groups (p=.718), indicating that the pedagogical experiment was uniform. However, the condition of normality of distribution was met on the posttest, so the t-test was used to compare the groups. According to Levene's Test of Equality of Variance (p=.976), the groups were homogeneous. Further analysis revealed a statistically significant difference between the groups on the posttest in favour of the E group (t-test results, t(20)=3.43, p=.003). The experimental component has a significant impact on students' understanding of thermal processes, as indicated by the numerical value of eta squared (ηp^2=.4).

Figure 1 shows the proportion (in percentages) of the response categories (correct, incomplete, and incorrect/no answers) of students' groups E and C for the cognitive levels of recognition, understanding, and application on the pre-test (the first six questions, i.e. for the first three cognitive levels).

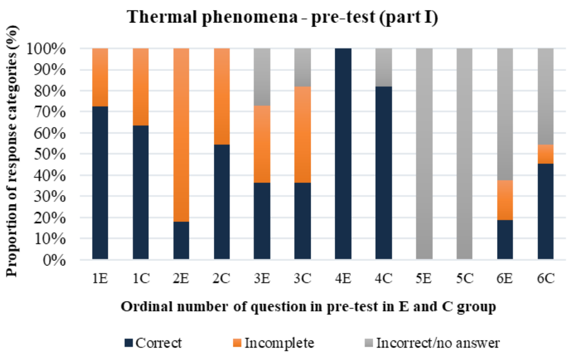

Figure 1. Proportion of response categories for E and C groups of students for the cognitive levels of recognition, understanding, and application on the pre-test on thermal phenomena

The proportion of the response categories, as illustrated in Figure 1, indicates that the achievements of the experimental (E) and control (C) student groups on the pre-test regarding thermal phenomena are highly comparable in the third and fifth questions. A minor difference favoring the E group is observable in the first and fourth questions, whereas in the second and sixth questions, the C-group students attained superior results compared to their E-group counterparts. Apart from the high achievement of the students in the fourth question, a large proportion of partially correct or incorrect/no answer can be observed in other questions, while not a single student gave a particularly or completely correct answer to the fifth question. Figure 2 displays the students' achievement based on the proportion of the response categories across the following three cognitive levels: analysis, evaluation, and creation. Comparable results were observed for all questions, with only minor differences in the response categories. The exception is question number 7, where none of the students in the E group gave a completely correct answer, while in the C group there were about 45% of such answers.

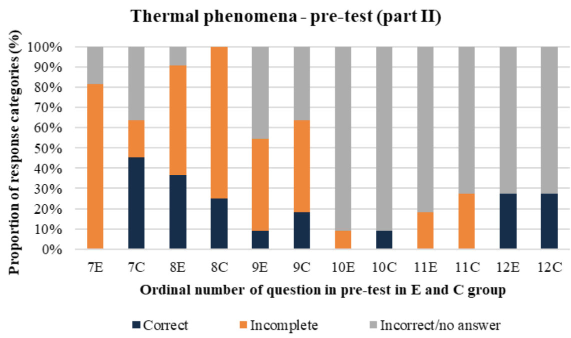

Figure 2. Proportion of response categories for E and C groups of students for the cognitive levels of analysis, evaluation, and creation on the pre-test on thermal phenomena

After the IBTM implementation, the students took a post-test that checked the impact of the applied model on their achievements, as well as a deeper conceptual understanding of thermal phenomena. The Table 2 shows the basic statistical parameters of the post-test for both groups of students, and it was observed that students of the E group (M=24.04, SE=2.18) achieved better results compared to the C group of students (M=13.79, SE=2.04).

Table 2. Basic statistical parameters of the results achieved by E and C groups on the post-test on thermal phenomena

Descriptive statistics	Parameter values	
	E group	C group
M	24.04	13.79
SE	2.18	2.04
Mdn	25.50	16.25
SD	7.23	6.76
MIn	13.75	3.25
Max	36.99	21.50
SKEW	.03	-.44
KURT	-.83	-1.34

Similarly, to the pre-test, the Shapiro-Wilk test determined the normal distribution of the results, for both the E (W=.95, p=.75) and C (W=.90, p=.21) groups. Achievements of the both groups of students for the first three cognitive levels on the post-test on thermal phenomena are shown in Figure 3.

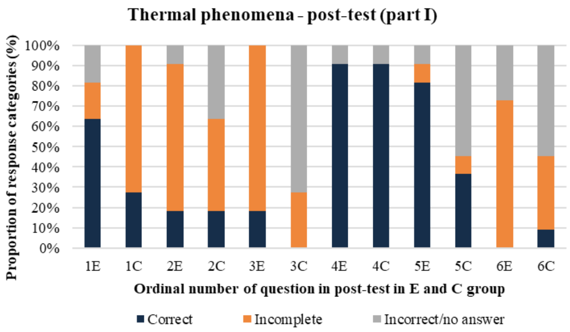

Figure 3. Proportion of response categories for E and C groups of students for the cognitive levels of recognition, understanding and application on the post-test on thermal phenomena

The observed proportion of the response categories for E and C groups of students on the post-test on thermal phenomena (Figure 3) pointed out that the E group of students was more successful regarding the first, second, third, fifth, and sixth question, while in the fourth question, identical accomplishments were achieved in both groups.

Student achievements on the post-test at the higher cognitive levels (analysis, evaluation and creation) are shown in Figure 4.

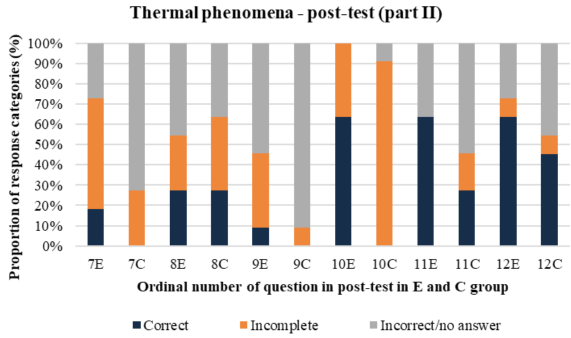

Figure 4. Proportion of response categories for E and C groups of students for the cognitive levels of analysis, evaluation and creation on the post-test on thermal phenomena

The proportion of the response categories for E and C groups of students (Figure 4) shows that students from the E group were more successful in solving the seventh, ninth, tenth, eleventh and twelfth question compared to those in the C group, while their achievements regarding the eighth question were almost equal.

Results of the pilot research on sound phenomena

The Shapiro – Wilk test confirmed a normal distribution of the results on the pre-test on sound phenomena in E and C groups of students (W=.96, p=.50; W=.97, p=.92; respectively). Table 3 shows the basic statistical parameters of the results obtained from both groups. These achievements were approximately equal in E (M=16.08, SE=1.29) and C group (M=15.47, SE=1.49), indicating uniformity of their prior knowledge of the mentioned teaching content.

Table 3. Basic statistical parameters of the results achieved by E and C groups on the pre-test on sound phenomena

Descriptive statistics	Parameter values	
	E group	C group
M	16.08	15.47
SE	1.29	1.49
Mdn	15.00	15.75
SD	5.80	6.67
MIn	6.00	2.00
Max	28.00	27.50
SKEW	.39	-.16
KURT	-.57	-.07

The differences between the achievements on the pretest and the posttest on sound phenomena of the students (E and K groups) were tested as well. Based on Levene's test on equality of variance, it can be seen that the groups were homogeneous (p=.759). The results of the t-test (t(38)=.31, p=.759) confirmed that there were no statistically significant differences between the groups on the pretest. Since the posttest did not meet the assumption of normality, the Mann-Whitney U test was used to compare the groups. With a substantial impact from the experimental factor (r =.7), it was found that the groups differed significantly (p=.000) in favour of the E group.

The proportion of correct, incomplete, and incorrect/no answer on the pre-test on sound phenomena for the first six questions is shown in Figure 5. Certain uniformity of prior knowledge of both groups was observed for the first, second and fifth question, while a slight advantage of E group when compared to C group was observed for the third, fourth, and sixth question.

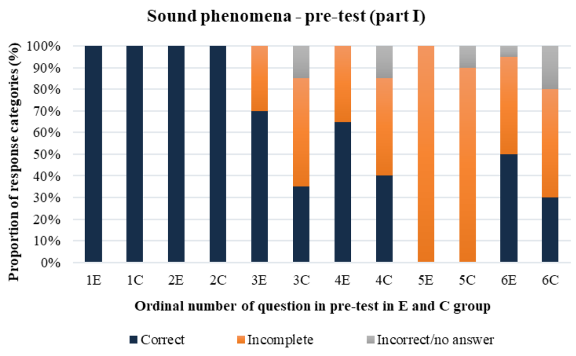

Figure 5. Proportion of response categories for E and C groups of students for the cognitive levels of recognition, understanding and application on the pre-test on sound phenomena

Figure 6 displays the students' achievement for the following three cognitive levels - analysis, evaluation and creation on the pre-test on sound phenomena.

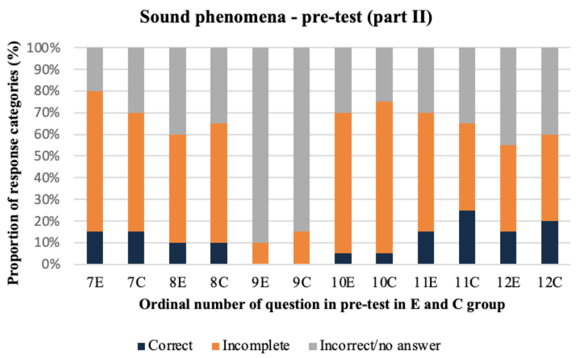

Figure 6. Proportion of response categories for E and C groups of students for the cognitive levels of analysis, evaluation and creation on the pre-test on sound phenomena

As presented in Figure 6, students' prior knowledge about sound phenomena on the pre-test was approximately equal in both groups at higher levels of achievements.

The Shapiro - Wilk (Shapiro - Wilk) test determined normal distribution of the results obtained on the post-test on sound phenomena in both groups of students, E (W=.94, p=.31) and C (W=.96, p=.61). The basic statistical parameters of the post-test for E and C groups of students are shown in Table 4. This data revealed that after the implementation of the innovative IBTM on sound phenomena, the students of E group (M=29.97, SE=1.19) were more successful than those in C group (M=16.55, SE=1.68).

Table 4. Basic statistical parameters of the results achieved by E and C groups on the post-test on sound phenomena

Descriptive statistics	Parameter values	
	E group	C group
M	29.97	16.55
SE	1.19	1.68
Mdn	29.50	16.00
SD	5.21	7.54
MIn	19.50	4.00
Max	38.00	33.00
SKEW	-.22	.44
KURT	-.27	.13

The achievements of the students of both groups (E and C) in the categories of correct, incomplete and incorrect/no answers to the first six questions of the post-test on sound phenomena are shown in Figure 7. Both groups of students answered completely correctly the questions from the level of recognition. Additionally, regarding the third question, approximately equal achievements were observed in both groups, while none of the students answered the fourth question correctly. Finally, the proportion of response categories for the experimental (E) and control (C) student groups regarding the fifth and sixth questions (Figure 7), demonstrates that the E-group students achieved greater success than their C-group counterparts.

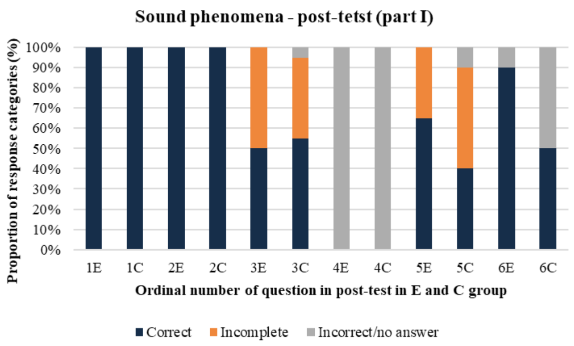

Figure 7. Proportion of response categories for E and C groups of students for the cognitive levels of recognition, understanding and application on the post-test on sound phenomena

Figure 8 displays the students' achievements for the higher cognitive levels on the post-test on sound phenomena.

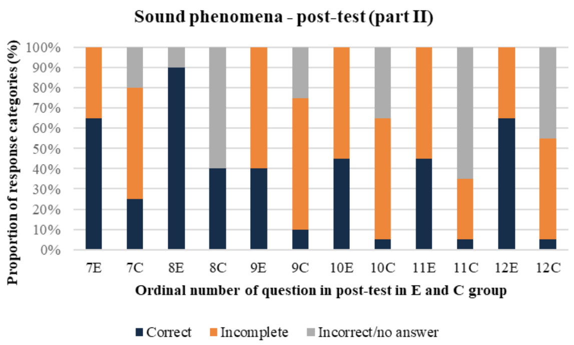

Figure 8. Proportion of response categories for E and C groups of students for the cognitive levels of analysis, evaluation and creation on the post-test on sound phenomena

The observed proportion of response categories for the experimental (E) and control (C) student groups (Figure 8), across all questions from the seventh through the twelfth, on the post-test on sound phenomena, indicated that the E-group students achieved better results compared to their C-group counterparts.

Discussion

The obtained pre-test and post-test results for two applied IBTMs and TTMs, along with an analysis of student achievements in the context of each individual question are discussed in the following subsections.

Discussion of the students' achievements on thermal phenomena

The results obtained for the 1st question in the pre-test on thermal phenomena showed that the majority of students in both, E and C group (75% and 65%, respectively) were able to recognize and distinguish materials in the liquid state, as opposed to the other two states of matter. When it comes to the natural sources of heat (question 2), most of the students in C group gave correct (55%) or incomplete answers (45%), while in E group only one-fifth marked all the natural sources of heat. The stages of the transformation process of turning ice into water vapour (3rd question) were fully understood by one-third of the students in both groups, while one-third partially understood this process, and one-third did not give the correct answer or did not answer the question. All students of the group E and four fifths of the group C (4th question) were able to connect the mercury level in the thermometer with the weather conditions shown in the illustrations (summer - sun and sunshade; winter - cloud and snow). The results obtained in both groups for the question 5 confirmed the widespread misconception (Tiberghien, 1994; Lee, 2014) that woollen fabric warms bodies or objects, i.e., melts the ice. More than half of the students in E group and slightly less in C group were not able to evaluate either the material that should be used to make the handle of the teapot or explain their choice (6th question). In addition, around 80% of the students in E group and slightly more than 60% in C group were able to correctly recognize the appearance of the power line wires in summer and winter (question 7), but none of the E group students offered an explanation for it, while less than 50% of the C group students did it successfully. When it comes to the 8th question, almost 40% of the students in E group and about 25% in C group could completely correctly associate certain properties of water with its state of matter (*has the shape of the vessel where it is placed, spreads easily, spills easily,* and *has a constant shape*), while other students had certain difficulties in solving this question. About 60% of the students of both groups understood that the balloon with the candle will go up after being released from the hand (question 9), but only 10% in the E group and approximately 20% in the C group could explain this occurrence. A significant majority of the students of both groups (question 10) did not understand the behaviour (expansion) of one gaseous substance in another (perfume in the air), which was also observed in a previous study (Oyehaug & Holt, 2013). Only a fifth of the students in E group and almost a third in C were able to partially describe the process of a thermometer model construction (question 11) from the provided materials (*plastic bottle, transparent straw, alcohol and food colouring*). Slightly less than 30% of the students in both groups were able to propose a sufficient number of actions that can alleviate or slow down the global warming (question 12), while the other students did not even try to give their suggestions.

Surprisingly, on the post-test question 1, the students of both groups had worse results than on the pre-test (C group even significantly worse - about 30%), indicating that after the application of the teaching models, they had more difficulties in recognizing the material in the liquid, than in a solid state. A possible explanation of such results could be related to the way the questions were asked. Namely, in the pre-test, the students recognized the states of mater based on illustrations, while in the post-test on the basis of a text, pointing out to the well-known fact that students have a problem understanding the written tasks (Duke & Block, 2012). The results of the 2nd question were also unexpected, since in both groups only a fifth of the students correctly completed the sentences defining what a thermometer is, and at what temperatures water evaporates. This means that regardless of the applied model (innovative - IBTM or traditional - TTM), the largest number of students did not overcome the misconception related to the difference between the concepts of temperature and heat, what is in line with previous studies (Brook et al., 1984; Carlton, 2000). Moreover, they did not overcome the misconception that water evaporates only when boiling, as confirmed by other authors (Durmus & Bayraktar, 2010). The difference in achievement depending on the applied model became evident from the level of understanding (3rd question). The results regarding this question on the post-test were unexpectedly worse compared to the pre-test in both groups. However, the observed difficulties in the changes of the state of matter for substances such as chocolate, vinegar, and margarine indicated that, for the majority of students, the most understandable was phase transitions of water, which is supported by a better result on the pre-test, since it contained only the question related to water. The influence of heat on solubility (question 4) was equally well accepted in both groups (90% of correct answers), and it should be emphasized that in both models experiments included food colouring dissolving in hot and cold water (E group – individual hands-on experiments, C group – demonstration experiments). On the one hand, the results obtained on the question related to the knowledge of thermal conductivity of materials (question 5) demonstrated the difference in the effects of the applied models, in favour of IBTM; while on the other hand, a comparison with the pre-test confirmed the importance of the application of experiments in sciences education. Data analysis of the sixth question (graphic representation of the process of mixing two different liquid substances from the aspect of particulate nature of matter) revealed a slight difference between the two models, again in favour of IBTM. Although such interpretation was applied in both models, the results showed (absence of correct answer in E group and small proportion of correct answers in C group) that a single application was insufficient for the successful adoption of this concept.

At higher cognitive levels, the better achievements of the students in E group were even more prominent compared to the differences at the first three cognitive levels. At IBTM, special attention was paid to overcoming the misconception that clothing warms the human body as well as to understanding the correct concept that clothing preserves (insulates) body heat. Therefore, the scores of the E group students on the 7th question were better than their peers from the C group. The student achievements on question 8 (analysis of numerical data with comprehension of metals' phase transitions - melting and solidification) were equal in both groups. Further, although cooling one liquid (hot coffee) with another liquid (cold milk) is a part of everyday experience (question 9) it was demonstrated that most children (especially those in C group) did not acquire the ability to correctly explain the cooling process. In IBTM, special attention was paid to the transfer of heat from one solid body to another with special emphasis on the direction (from a hotter to a colder body). Thus, data obtained on the 10th question, which tested the understanding of this concept, exhibited a dramatic difference between the E and C groups, in favour of E group (E group 60% correct answers, C group – 0%). Finally, when it comes to the tasks at the level of creation, over 60% of the E group students solved the questions 11 and 12 completely accurately, since they suggested the correct way how to make a thermos cup from the given material, or a creative way how to reuse an old T-shirt. In the C group, the questions 11 and 12 were solved by 30% and 45% of students, respectively. Comparing the results of these two questions on the pre-test and post-test, it was concluded that IBTM enlarged the ability in majority of students to think creatively and solve problems successfully.

Discussion of the students' achievement on sound phenomena

An analysis of the 1st and 2nd pre-test questions on the sound phenomena revealed that the majority of the students in both groups were able to recognize sound sources, and distinguish between those that produce soft and loud sounds. Between 50% and 70% of the students in the E group, and between 30% and 40% of those in the C group knew that: sound intensity decreases when passing through solid material obstacles (question 4), sound intensity (girl's voice) decreases with distance (question 6), and that the boys, even though they are surrounded by walls, will hear each other (question 3). Most of the students in both groups did not fully understand how the pitch ('higher' or 'lower' sound) depends on the length of the air column in the tubes of Pan's flute (question 5). In comparison to the results obtained for the first three cognitive levels on the pre-test, at the higher cognitive levels (analysis, evaluation, and creation) the results were worse. When it comes to understanding sound propagation through water and air, various combinations of source and receiver positions caused difficulties to a greater or lesser extent (questions 7, 8, and 10), which is in line with a previous study (Eshach, H. & Schwartz, J. L., 2006). About 15% of the students in both groups understood that, if they are under the surface of the water, they can still hear the sound from the air (question 7). Moreover, only 10% of them comprehended the opposite situation, i.e., that the sound that originated under the surface of the water will be heard in the air (question 8). However, the most difficult situation (with only 5% of correct answers) was when both, the source and receiver (child and phone), were under the surface of the water (question 10). A very small percentage of students in both groups (E group - 10%, C group 15%) had prior knowledge about the fact that sound does not spread in a vacuum, while none of them was able to explain why the sounds (orchestra) cannot be heard on the Moon (airless space) (question 9), what had been observed previously (Eshach at al., 2017). As anticipated, and regarding the first question at the creation level (question 11), a significant number of children in both groups were able to guess that the beans in the tin box would make a sound. However, the request to give another example created difficulties for them. It was encouraging that some students were able to fully (E group – 15%, C group - 20%) or partially (about 40% in both groups) explain the process of the flicker transmission (caused by the impact of the wooden spoon on the glass), through different environments (glass, air, balloon) and the consequent movement of the body (rice grains).

The results obtained on the post-test on sound phenomenon demonstrated that both applied models (IBTM and TTM) had an equal impact on the first two cognitive levels (recognition and understanding), while the differences were observed/ more pronounced with the increase in cognitive levels. Taking into account the results of the pre-test (students recognized sound sources and distinguished between loud and soft sounds), the result of the post-test was expected and confirmed the understanding of these concepts (questions 1 and 2). Partially correct answers to the 3rd question (propagation of sound through air, water and solid materials) have shown that students have a hard time overcoming the misconception that sound propagates not only through gases (air), but also through materials in other two states of matter. The students in both groups were unable to explain, using their own words, propagation of sound through some mediums (question 4). This could stem from an insufficient comprehension of the phenomenon in question, as well as limited language skills. On the pre-test, the students only partially understood that the pitch depends on the height of the fluid column (air or water), while all the students in E group gave correct or partially correct answers on the post-test (question 5), confirming that IBTM contributed to a better understanding of this concept. Likewise, the concept that encompasses reduction of sound intensity if there are obstacles in its propagation (question 6), as well as the concept that sound does not propagate through a vacuum (question 8), were more comprehensible to the students in the E group. The results achieved on question 7, requesting to indicate the order of the illustrated stages of the sound propagation process from the source (guitar) to the receiver (ear), once again confirmed the positive effects of the applied IBTM. The data obtained for questions 9 and 10 showed that the students in both groups understood that the intensity of the sound transmitted through the string is higher if it is taut, but a significantly larger number of the students in E group, when compared to C group, were able to explain it. At the highest cognitive level (questions 11 and 12), students in the E group achieved better results compared to the C group, which indicated that the applied IBTM contributed to the development of functional knowledge, i.e. the ability to independently propose and illustrate noise protection measures.

Conclusion

In order to improve initial science education, two pilot studies were carried out on selected physical (heat and sound phenomena) contents interpreted through the particulate nature of matter. STEAM+X approach were carried out through experiential learning within IBTM and traditional approach in TTM. The quasi-experimental study with parallel groups (E and C) were carried out. Purposefully designed knowledge tests were used to examine the influence of the created IBTM and TTM on the achievements of 3rd and 4th grade primary school students on the mentioned contents.

Checking the students' prior knowledge about thermal phenomena demonstrated that they distinguished individual states of matter, successfully connected the level of mercury in the thermometer (i.e. temperature) with typical illustrations of weather conditions, as well as that they were able to recognize the appearance of power line wires under winter and summer conditions. On the other hand, a number of problems were identified, and some of them are: recognition of natural sources of heat, proper comprehension of the stages of the process of turning ice into water vapour, distinction of the properties of substances in different states of aggregation, with special emphasis on the gaseous state, as well as the presence of misconceptions about thermal insulation properties of wool and other materials. Even after the application of IBTM on thermal phenomena, there is still a misidentification of the concepts of heat and temperature, indicating the deep rootedness of the observed misconception (Sözbilir, 2003). Moreover, the understanding of phase transitions is satisfactory only when it comes to water. Nevertheless, the applied model improved the phenomenological understanding of thermal conductivity and the process of mixing substances at different temperatures, but not from the aspect of their particulate structure or through the interpretation of numerical data. The innovative teaching model improved students' understanding of the thermal insulation properties of materials and improved the ability to creatively solve problems (making a thermocup and proposing measures to save heat energy in the household).

According to the results obtained on the pretest, it was obvious that even before the application of the IBTM, the students recognized sound sources very well, distinguished between quiet and loud sounds and understood that the intensity of sound decreases with distance, and when passing through solid obstacles. However, they did not know the concept of sound propagation through different mediums, especially through those in solid and liquid state (Veith, 2023). Processes such as transmission of sound by the flickering of particles in the medium, as well as the impossibility of sound propagation in a vacuum, were partially known to the students, but they were unable to explain the causes of these phenomena. The application of IBTM confirmed previous knowledge about some concepts (sound source, loud/quiet, decrease of intensity with distance from the source) and, at the same time, contributed to a better understanding of others, such as the reduction of sound intensity when passing through obstacles and the absence of sound in a vacuum. Moreover, IBTM enabled a deeper understanding of the stages of sound propagation from the source to the receiver, the connection between the height of the air or water column and the pitch generated in them, and contributed to the development of creativity in proposing activities that reduce the harmful impact of noise on people. The mistaken belief that sound does not travel through water and solid bodies persisted among some students even after the application of IBTM, what was also observed in a previous research (Mazens & Lautrey, 2003).

IBTM contributed to the improvement of the existing phenomenological understanding of selected teaching contents, but did not sufficiently enable students to interpret phenomena and processes from the particulate nature of matter. This, however, could be explained by the insufficient, a single application of the particular teaching models. The effectiveness of the applied models, with the emphases on the independent students' research activities, once again has confirmed the importance of the experiments' application in teaching, what is in line with the principle of obviousness in science education.

The lack of students' ability to understand the text and to justify their choices or claims, as well as to explain procedures and processes were the key problems observed during the analysis of students' achievements on the tests that were not overcome by the short-term application of the models. This may be attributed to an insufficient concept comprehension and /or underdeveloped language literacy. Differentiation and classification of the properties of entities, phenomena or processes, according to the similarities and differences, remained a supreme difficulty for students aged 9 and 10. Similarly, the highest cognitive level (level of creation), i.e. the procedures of designing activities or experiments, as well as creating models from the particular materials, persisted unattainable for a large number of students even after the application of IBTM.

Both IBTM and TTM were implemented in a short period of time (4 to 5 weeks), which was obviously insufficient for developing higher cognitive abilities of students, or certain skills such as creativity. In addition, the research for each of the two teaching models was conducted on a small sample, and it lacked proper statistical evidence for matching the groups based on prior knowledge. Therefore, this study brings enlightenment for the application of the same or modified models in the future, on a larger scale, regarding both the sample and the length of time, since the obtained data hold promising potential.

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МОГУЋНОСТИ И ИЗАЗОВИ У РАНОМ ПРИРОДНО-НАУЧНОМ ОБРАЗОВАЊУ: ИСТРАЖИВАЊЕ ТОПЛОТЕ И ЗВУКА

Одабрани садржаји физике (топлота и звук) обрађени су кроз два пилот-пројекта који су реализовани путем истраживачке наставе (енг. Inquiry-Based Science Education – IBSE) у оквиру STEAM+X образовног приступа. Истраживањем се проверавало да ли и у којој мери ученици разредне наставе могу ефикасно да тумаче природне феномене путем честичне структуре супстанце применом истраживачки обликованих наставних модела (ИОНМ). Ови иновативни модели наставе воде ученике кроз истраживачке активности, дијалог, критичко размишљање и искуствено учење, доприносећи тако развоју њихове упорности у решавању проблема, сарадничких вештина и јединствених креативних способности. Квазиексперимент са паралелним групама (експериментална – ИОНМ и контролна – ТНМ (традиционални наставни модел)) обухватао је 62 ученика трећег и четвртог разреда из две основне школе у Сомбору (Србија). Претест је креиран за проверу претходног знања ученика о топлоти и звуку, а утицај ИОНМ И ТНМ на квалитет знања и дубље концептуално разумевање је проверен помоћу посттеста. Тестови су садржали по 12 питања на 6 нивоа постигнућа у складу са ревидираном Блумовом таксономијом.

ИОНМ о топлотним појавама се састојао од следећих 5 секвенци: Агрегатна стања супстанце, Честична структура супстанце, Температура, Топлота и Провођење топлоте. ИОНМ о звуку и својствима звука реализован је кроз следеће четири секвенце: Основни принципи истраживачког учења, Извори и особине звука, Простирање звука и ехо и Израда постера – мапе појмова о звуку. У оквиру свих секвенци оба модела ученици су, примењујући научни метод, дефинисали своја истраживачка питања, постављали хипотезе, експериментисали, записивали запажања и закључке. Током реализације иновативних наставних модела примењен је групни облик рада, при чему су наставници кроз све етапе оснаживали развој и унапређење ученичких језичких компетенција, попут разумевања прочитаног текста, извештавања група о резултатима истраживања, као и кроз дискусије на нивоу одељења. Ученици контролних група усвајали су исте наставне садржаје путем ТНМ, који је још увек најзаступљенији у нашој наставној пракси.

Након примене ИОНМ о топлотним појавама и даље је присутно погрешно поистовећивање појмова топлоте и температуре, што говори о дубокој укорењености уочене мисконцепције, а разумевање фазних прелаза је задовољавајуће само када је реч о води. Примењеним моделом побољшано је феноменолошко разумевање топлотне проводљивости и процеса мешања супстанци различитих температура, али не и разумевање са аспекта њихове честичне структуре или на основу тумачења нумеричких података. Иновативни наставни модел је побољшао ученичко разумевање термоизолационих својстава материја-

ла и унапредио способност за креативно решавање проблема (израда термошоље и предлагање мера уштеде топлотне енергије у домаћинству).

Примењени ИОНМ о звучним појавама потврдио је претходна знања о неким концептима (извор звука, гласно/тихо, опадање интензитета са удаљавањем од извора) и истовремено допринео бољем разумевању других, као што је смањење интензитета звука при преласку кроз препреке и одсуство звука у безваздушном простору. Такође, ИОНМ је омогућио дубље разумевање етапа преношења звука од извора до пријемника, повезаност висине стуба ваздуха или воде са висином звука који настаје у њима, и допринео развоју креативности при предлагању активности којима се смањује штетни утицај буке на људе.

У спроведеном педагошком експерименту ученици обе групе (Е и К) показали су боље резултате на посттесту у поређењу са претестом, с тим да је разлика у постигнућима код ученика Е групе израженија. Тестирањем разлика постигнућа ученика обе групе на посттесту о топлотним и звучним појавама утврђено је постојање статистички значајне разлике у корист Е групе. Величина утицаја експерименталног фактора је у оба случаја велика, што потврђује ефикасност примењених иновативних модела наставе на садржајима о топлотним, као и о звучним феноменима. Сходно томе, ово истраживање пружа смернице за будућу примену истих или сличних модела у већем обиму, у смислу величине узорка и дужине трајања пројекта, с обзиром на то да су добијени резултати обећавајући.

Кључне речи: *почетно природно-научно образовање, истраживачки обликована настава, STEAM+X приступ, топлота, звук*