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COMPARING PRE-SERVICE PRIMARY SCHOOL TEACHERS' AND LOWER-SECONDARY LEARNERS' UNDERSTANDING THE PARTICULATE NATURE OF MATTER

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Abstract. *Cross-age studies have suggested that although children's notions of scientific phenomena change moderately with increasing age, certain misconceptions persist from preschool to a higher educational level. The purpose of this study was to diagnose the prevalence of selected misconceptions about the particulate nature of matter among pre-service primary school teachers and to compare the findings with the results of lower-secondary learners. The participants in the study were 197 pre-service primary school teachers and 170 ninth graders. The multiple-choice diagnostic test was developed to collect data. In the analysis of the test results, the paired difference test and Pearson's chi-square independence test for the contingency table were used. Frequency analysis was performed for individual questions in the test and percentages were calculated. The results obtained with primary school teacher trainees demonstrate the existence of a number of misconceptions similar to those observed with ninth graders; some misconceptions were observed to even be present significantly more frequently among pre-service primary school teachers. This study confirmed that age maturity and mere knowledge of scientific concepts such as atoms, molecules, etc. do not have to be sufficient to allow students to better understand the particulate nature of matter.*

Keywords: *lower-secondary learners, misconceptions, multiple-choice diagnostic test, particulate nature of matter, pre-service primary school teachers*

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Introduction

The atomic hypothesis, i.e., that all things are composed of atoms that are constantly moving and attract each other when they are a certain distance from each other and repel when they are close together, is undoubtedly one of the most important scientific findings at present. Atomism therefore holds an important position in science curriculum worldwide. The particulate nature of matter (PNM) is considered a threshold concept in science education (Karataş et al., 2013; Park & Light, 2009) and the conceptual understanding of PNM plays a fundamental role in science learning, as the particle model of matter serves as the basis for understanding the states of matter, phase changes, and properties of substances (Haidar & Abraham, 1991; Snir et al., 2003).

A great deal of research has been conducted on the understanding of PNM by students (e.g., De Vos & Verdonk, 1996; Driver et al., 2003; Gabel et al., 1987; Griffiths & Preston, 1992; Harrison & Treagust, 1996; Krnel et al., 1998; Liu & Lesniak, 2005; Novick & Nussbaum, 1978, 1981; Özmen et al., 2002; Özmen, 2011; Pella & Carey, 1967; Renström et al., 1990; Stepans, 2003) and numerous misconceptions (that is, conceptions which differ from those accepted by the scientific community) have been identified at various educational levels. A particular misconception is considered significant if it was observed in at least 10% of the study group (Tan et al., 2002; Chu et al., 2009). One of the most widespread are, for example, animism, that is, the idea that atoms are alive (Griffiths & Preston, 1992; Harrison & Treagust, 1996; Palečková et al., 1997; Taber & Abdo, 2013); the idea of matter as continuous, that is, there is no empty space between particles or that the space between the atoms is filled with some matter (Boz, 2006; Harrison & Treagust, 1996; Novick & Nussbaum, 1981; Özmen, 2011; Tatar, 2011; Valanides, 2000); and the assignment macroscopic properties of substances to the atoms or molecules that compose the substance (Ben-Zvi et al., 1986; Harrison & Treagust, 1996; Lee et al., 1993).

Cross-age studies (Ayas et al., 2010; Boz, 2006; Liu & Lesniak, 2005, 2006; Novick & Nussbaum, 1981; Westbrook & Marek, 1991) have suggested that although children's notions of scientific phenomena change moderately with increasing age, certain misconceptions persist from preschool to higher educational level and some cognitive difficulties are not overcome by many older subjects, for example, difficulty in conceiving a vacuum. The cross-

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age study by Novick and Nussbaum (1981, p. 7) involving apart from pupils in a primary, lower-secondary, and upper-secondary school, university non-science majors has indicated a reluctance to think of the space between particles as completely empty (20% at the primary and lower-secondary levels and increasing to only 37% at the upper-secondary and university levels).

Research with Pre-service Primary School Teachers

Some established studies (e.g., Aydeniz et al., 2017; De Jong et al., 2005; Kiray, 2016; Mumba et al., 2014; Unver & Arabacioglu, 2015) have shown that pre-service science teachers have a great number of misconceptions in the topic of PNM, which could potentially perpetuate the belief of these misconceptions in the future generations of students taught by these teachers. The Valanides study (2000) has focused on the conceptions of primary school teacher trainees related to aspects of dissolving and the effects of filtering or heating solutions. The results of his study have shown that the majority of the pre-service teachers had a limited conceptual understanding of PNM, for example, the existence of an empty space within matter (Valanides, 2000, p. 259). Tatar's study (2011) has aimed to determine misconceptions among pre-service primary school teachers about the differences between solid, liquid, and gaseous states of matter. The participants of this study stated that the particles of solids cannot move, there is no space between the particles of solids, and solids are completely made up of particles, but liquids and gases are not completely made up of particles (contain other things).

Education Context of the Study

The education system in the Czech Republic includes pre-primary education (aged 3 to 6), primary education (aged 6 to 11), lower-secondary education (aged 11 to 15), upper-secondary (aged 15 to 19), and tertiary education (university). Integrated science is a compulsory subject in primary education, and when students come to the lower-secondary school, chemistry, physics, and biology are compulsory subjects.

Pre-service primary school teachers, who teach children ages 6-11 years, are usually prepared for their profession in faculties of education in 5-year master's degree programs. To a greater or lesser extent, they are introduced to a knowledge of natural science, mostly within the mandatory science courses taken in their programme areas, such as the subject of Integrated Scientific Basics. These courses are then usually followed by didactically oriented disciplines, sometimes supplemented by various practical natural scientific lessons, in which students become acquainted with simple experiments.

The period of early primary education can be considered very important, if not crucial, in terms of encouraging an interest in natural sciences. At this age, children love to watch and explore things and think about the correct explanation of various phenomena. Thus, children's curiosity can be very well used for motivation, as well as to build a positive attitude toward the natural sciences. Teachers play a particularly significant role in this process, as they can provide children with suitable topics to think about and experiment with and may also lead their learners to formulate correct ideas about how the world around them works.

According to a strategic document of the Ministry of Education, Youth and Sports (2021) entitled the Framework Educational Program for Elementary Education, knowledge about matters and their properties are included within the teaching of elementary natural science in the educational area Man and His World, specifically in the thematic area Diversity of Nature. For primary learners, however, atoms and molecules are not yet introduced as particulates of matter (Podroužek, 2003). Children typically encounter these concepts no earlier than 6th grade. Pella and Carey (1967), however, demonstrated that children can already grasp the main concepts of atomic theory (that is, matter is composed of particles that are moving) at an early school age. In addition, it can never be ruled out that more curious learners will ask their teachers questions about the structure of matter in the early stages of primary school.

Research Problem

From the aforementioned studies, it emerged that certain misconceptions about the topic of PNM persist from preschool to a higher educational level. Ayas et al. (2010) have stated that understanding of the PNM increased with educational level. Some studies (Valanides, 2000; Liu & Lesniak, 2006) have argued that the range and nature of student conceptions support the suggestions that atomism is primarily a function of school studies. Liu and

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Lesniak (2006, p. 322) suggest that "children's matter concept development is attributable to not only maturation by age but also school context, such as curriculum and instruction".

Although many research studies have been carried out on the understanding of PNM, only a few studies have addressed misconceptions about the topic of PNM among pre-service primary school teachers (Tatar, 2011; Valanides, 2000) and more recent cross-ages studies also usually did not include both pre-service primary school teachers and lower-secondary learners. In the Czech Republic, detailed research on the conceptual understanding PNM has not yet been carried out at any educational level.

Research Aim and Research Questions

The aim of the present study was to diagnose the prevalence of selected misconceptions in the PNM topic among pre-service primary school teachers (TEA) and to compare the findings with the results of lower-secondary learners ages 14-15 years (LEA).

The following research questions (RQ) were posed at the beginning of this research:

RQ1: Is there a significant difference between the frequencies of the occurrence of correct responses for each test question between TEA and LEA?

RQ2: Is there a significant difference between the choice of individual responses for each test question and the study group (TEA or LEA)?

RQ3: Is there a significant difference between the frequencies of the occurrence of the most frequent misconceptions between TEA and LEA?

Research Methodology

General Background

This study used quantitative methods using a multiple-choice diagnostic test to obtain data on the conceptual understanding of PNM from university and lower-secondary school students in the Czech Republic. Although children get acquainted with the particle structure of substances and the first models of the atom usually in the 6th grade of lower-secondary school (ages 11 years), the subject of atomic and nuclear physics is included mainly in the 8th and 9th grade (ages 13-15 years). Therefore, learners' misconceptions were explored at the end of the 9th grade when more comprehensive knowledge can already be expected in the field of PNM. Pre-service primary school teachers engaged in the research study were in the first, second, and third years of master's studies, in which the teaching of the basics of natural sciences and their didactics is usually included.

The test was administered to the LEA group in May and June 2017 and to the TEA group during the fall of 2017, using the paper-and-pencil test form. TEA and LEA completed the test in approximately twenty minutes. The duration of the test was chosen to facilitate its administration during the lesson, especially in the LEA group.

Participants

The research sample consisted of 197 TEA, enrolled in five-year master degree programs at the Faculty of Education of the Jan Evangelista Purkyně University in Ústí nad Labem (University A), which belongs to the younger regional universities, and at the Faculty of Education of the Masaryk University in Brno (University B), which is one of the largest traditional universities in the Czech Republic. The selection of the students covered all forms of their study. The structure of TEA is shown in Table 1.

Table 1
Structure of TEA

University	Structure of TEA			Total
	First-year student	Second-year student	Third-year student	
University A	-	55	41	96
University B	96	5	-	101

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The results of the TEA study group were compared with the results of 170 LEA ages 14-15 years from the fourth grade of an eight-year general secondary school and from six classes in the 9th grade of lower-secondary schools. The schools were located in the Ústí nad Labem Region, the Moravian-Silesian Region and the capital city of Prague. The structure of LEA is shown in Table 2.

Table 2
Structure of LEA

Study group	Number of LEA			Total
	Prague Region	Ústí nad Labem Region	Moravian-Silesian Region	
Lower-secondary school	47	74	19	140
Eight-year general secondary school	-	30	-	30

Comparisons were not made with respect to gender, but the number of males and females in the LEA participants turned out to be much the same. In the TEA group, however, women prevailed significantly. The size of both samples (TEA or LEA) was adequate for $\alpha = .05$ with the margin of error 3% (Barlett et al., 2001, p. 48).

This research study followed the ethical considerations outlined by Taber (2014). TEA were informed of the purpose of the study and their participation was voluntary. Parents of LEA have given their informed consent. The data collected were anonymous and only used for the purposes of the research; no references are made to the results of the TEA and LEA studies.

Instruments and Procedures

The multiple-choice diagnostic test used in the study was developed in three stages. In the first stage, the content of the test was determined. The test consisted of questions focused on the most common misconceptions on the topic of PNM, which have been repeatedly reported in many established studies on the topic of PNM; thus, its construct validity stems from its relation to these studies. The questions in the test were aimed at the conceptual areas listed in Table 3.

In the second stage, the first version of the test was taken by 30 learners in the fourth grade of an eight-year general secondary school and 14 university students. Students were interviewed to identify any problems that might have occurred in answering the test questions. On the basis of piloting, necessary modifications of the diagnostic instrument were made, and a 24-question test was formulated as seen in the Appendix.

Table 3
Conceptual Areas Including in the Multiple-choice Diagnostic Test

Conceptual area of the PNM	Questions in the test	Reference on research
Visibility of atoms	Q1	Griffiths & Preston, 1992 Harrison & Treagust, 1996 Lee, 1993 Unver & Arabacioglu, 2015
Animism (atoms are alive)	Q2, Q3	Griffiths & Preston, 1992 Harrison & Treagust, 1996 Palečková et al., 1997
Shape, size, and weight of atom	Q4, Q5, Q6	Griffiths & Preston, 1992 Kind, 2004 Unver & Arabacioglu, 2015

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Conceptual area of the PNM	Questions in the test	Reference on research
Space between atoms	Q7, Q8, Q9, Q11	Griffiths & Preston, 1992 Harrison & Treagust, 1996 Özmen, 2011 Tatar, 2011 Unver & Arabacioglu, 2015
Transfer of properties of macro-objects into the microcosm	Q7, Q10, Q12	De Vos & Verdonk, 1996 Harrison & Treagust, 1996 Özalp & Kahveci, 2015 Stepans, 2003 Unver & Arabacioglu, 2015
Processes taking place in atomic nucleus and shell	Q13, Q14	Unver & Arabacioglu, 2015

Participants could select an answer from four alternatives for each question, but they were also provided with a space marked "Other response" with room in it to supply an open-ended response. Each question had only one most acceptable answer from a scientific point of view, which is called the correct answer in the following text for simplicity. As far as the evaluation of the test is concerned, a participant of the study could receive one point for the correct answer to each question.

The reliability of the research instrument was identified using the Kuder-Richardson formula 20 (KR-20), which is appropriate for this type of test (Kuder & Richardson, 1937, p. 158). The reliability of the test achieved the value of .653 for the LEA group, the value of .480 for the TEA group, and the value of .569 for the entire sample of participants (LEA and TEA together). Kehoe (1995) points to a reliability of 0.5 that can be accepted for short tests (10-15 questions). Given the length of the test that involved 14 questions, the reliability values can therefore be considered satisfactory.

Data Analysis

The data consist of the responses of the TEA and LEA groups to the test. Quantitative techniques were employed to analyse the data. First, percentage analyses of the correct answers were performed in the TEA and LEA groups on the individual questions of the test. The 14 partial null hypotheses ($H_0 1 – H_0 14$) formulated assumed that there were no statistically significant differences between the frequencies of the occurrence of correct responses in the TEA and LEA groups for each question in the test (that is, hypothesis $H_0 1$ is related to question Q1, hypothesis $H_0 2$ to question Q2, etc.).

In a further analysis, the difference between the choice of individual responses for each test question and the study group was examined in more detail. For this purpose, Pearson's chi-square test of independence was used for the contingency table. The 14 partial null hypotheses ($H_0 1^* – H_0 14^*$) formulated assumed that there was no statistically significant difference between the choice of individual response for each question in the test and the TEA or LEA groups. The strength of the difference was examined using the Cuprov's contingency coefficient K (Chráska, 2007).

Finally, percentage analyses of the most frequent misconceptions in the TEA and LEA groups were performed. 25 strongly held misconceptions that were diagnosed in at least 10% of participants in one of the TEA or LEA groups were selected. The 25 partial null hypotheses (H_0M1b, H_0M2a, H_0M2d, H_0M3a, H_0M3c, H_0M3d, H_0M4a, H_0M4b, H_0M5c, H_0M5d, H_0M6b, H_0M7d, H_0M8b, H_0M8d, H_0M9b, H_0M9d, H_0M10c, H_0M10d, H_0M11a, H_0M11d, H_0M12b, H_0M13b, H_0M13c, H_0M13d and H_0M14c) were formulated. They assumed that there were no statistically significant differences between the frequencies of the occurrence of a misconception in both study groups.

The statistical software used to calculate the independence tests (paired difference test and Pearson's chi-square test of independence for the contingency table) was Statistica 13.3 (StatSoft, Inc., 2017). The level of significance $\alpha = .05$ was used in all tests. When the *p*-value obtained was below the significance threshold $\alpha = .05$, the null hypothesis was rejected.

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Research Results

The basic descriptive test characteristics for both groups are presented in Table 4. From the results shown here, it is clear that both tested groups achieved very similar values in individual statistical characteristics. The LEA group, however, shows greater variance; therefore, we noticed greater reliability of the test in this case.

Table 4
Basic Descriptive Test Characteristics

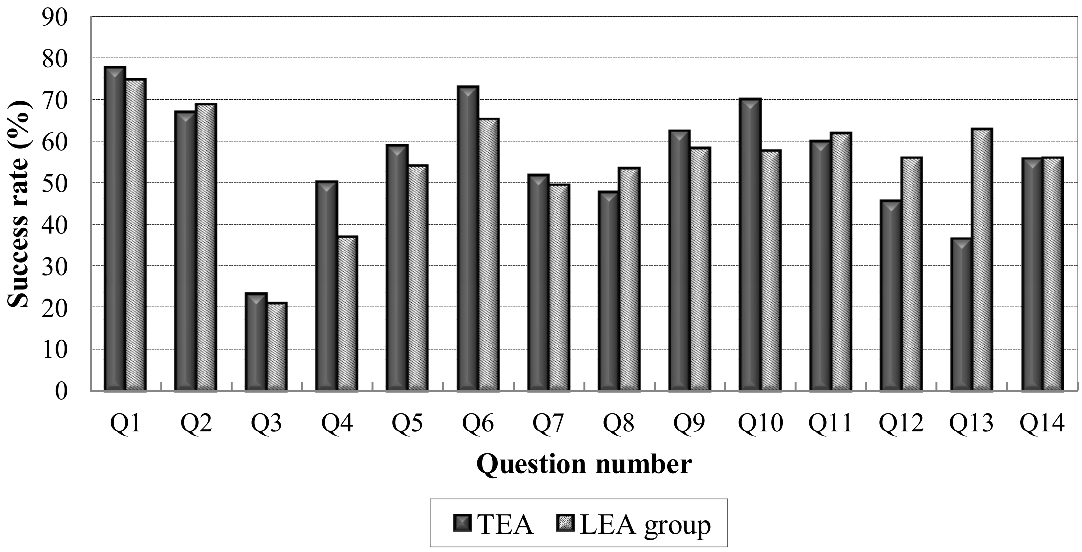
Test characteristics	TEA	LEA	Total
Number of respondents	197	170	367
Average score	7.74	7.69	7.71
Standard deviation	2.39	2.86	2.62
Median	8	7.5	8
Modus	8	7	8
Minimum	2	1	1
Maximum	14	14	14

The Occurrence of Correct Responses in Both Study Groups

First, the differences between the frequencies of the occurrence of correct answers between LEA and TEA were tested. The percentage of TEA who correctly answered the individual questions ranged from 23.35 to 77.66, and the percentage of LEA correct responses ranged from 21.18 to 74.71 (see Table 5). Since most of the questions were correctly answered by 30% to 80% of the study participants, it is possible to consider the test as an appropriate research instrument (Kehoe, 1995).

TEA and LEA were most successful in answering question Q1 'Can we see atoms?' (77.66% of TEA and 74.71% of LEA), the least successful were the TEA and LEA study groups in solving question Q3 'What happens to the atoms of an animal after it dies?' (23.35% of TEA and 21.18% of LEA). The percentage of correct responses of TEA and LEA is clearly indicated in Figure 1.

Figure 1
Comparison of the Success Rate of Questions in the TEA and LEA Groups



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Furthermore, it was examined whether the differences in the incidence of correct answers between TEA and LEA were statistically significant or not. The paired difference test of independence showed that there was a statistically significant difference between the frequencies of the occurrence of correct answers in the test questions Q4, Q10, Q12, and Q13, that is, the null hypotheses $H_0 4$, $H_0 10$, H012, and $H_0 13$ were rejected. Other null hypotheses, that is, there is no statistically significant difference between the frequencies of the occurrence of correct answers in the study groups of TEA and LEA, could not be rejected at the level of significance threshold α = .05. The results are shown in Table 5.

Table 5
Summary of the Success Rate of Individual Questions in the TEA and LEA Groups

Question	TEA %	LEA %	*p*
Q1	77.66	74.71	.255
Q2	67.01	68.82	.356
Q3	23.35	21.18	.309
Q4	**50.25**	**37.06**	**.006**
Q5	58.88	54.12	.179
Q6	73.10	65.29	.053
Q7	51.78	49.41	.325
Q8	47.72	53.53	.134
Q9	62.44	58.24	.206
Q10	**70.05**	**57.65**	**.007**
Q11	59.90	61.76	.358
Q12*	**45.69**	**55.88**	**.026**
Q13*	**36.55**	**62.94**	**.000**
Q14	55.84	55.88	.497

Note: The statistically significant differences between the relative frequencies of the answers in the LEA and TEA groups are marked in bold, the cases where the relative frequencies of the correct answers in the TEA group are statistically significantly lower than in the LEA group are marked with an asterisk.

The Differences Between the Choice of Individual Responses for the Test Questions and the Study Group

The differences between the choice of correct and incorrect answers for individual questions and the study group were also examined, that is, if the frequencies of answers to the question depended, or were independent of the study group. The results are shown in Table 6.

More detailed analysis using Pearson's chi-square test of independence for the contingency table showed that there was a statistically significant difference between the choice of answers and the study group for questions Q10, Q11 and Q13, that is, we rejected the null hypotheses $H_0 10^*$, $H_0 11^*$ and $H_0 13^*$. Other null hypotheses, that is, there is no significant difference between the choice of individual answers for each test question and the study group, cannot be rejected at the level of the significance threshold α = .05.

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Table 6
Pearson's Chi-square Test for Individual Questions of the PNM test

Question	χ^2 - test			Cuprov's *K*
	χ^2	*df*	*p*	
Q1	3.314	3	.346	–
Q2	3.127	3	.373	–
Q3	1.084	3	.781	–
Q4	34.483	3	.000	–
Q5	2.135	3	.545	–
Q6	4.940	3	.176	–
Q7	2.658	3	.447	–
Q8	6.452	3	.092	–
Q9	4.106	3	.250	–
Q10	9.074	3	**.028**	.302
Q11	10.215	3	**.017**	.312
Q12	3.990	3	.263	–
Q13	32.161	3	**.000**	.414
Q14	2.842	3	.417	–

Note: The statistically significant dependencies are marked in bold. Some rows were marked in grey (Q1, Q4, Q8), because Pearson's chi-square test cannot be considered sufficiently reliable in these cases due to the low expected frequencies in some cells in the contingency table (the expected frequencies were below the number 5 in 25% of the total number of cells).

The Most Frequent Misconceptions Diagnosed in the TEA and LEA Groups

Finally, some misconceptions will be discussed that were diagnosed throughout the test and can be considered important, particularly regarding the frequency of their occurrence and their severity. The selected misconceptions and the percentage of TEA and LEA who held these conceptions are summarised in Table 7. A misconception is denoted by the letter M and, furthermore, by a number and letter referring to the respective question in the test. For every misconception, there is a link to at least one source that mentions the particular misconception.

The paired difference test of independence showed that there was a statistically significant difference between the frequencies of the appearance of misconceptions between both groups in the misconceptions M4a, M4b, M6b, M8d, M10d, M11d, M13b, M13d, M14c, that is, we reject the null hypotheses $H_0$4a, $H_0$4b, $H_0$6b, $H_0$8d, $H_0$10d, $H_0$11d, $H_0$13b, H013d, and $H_0$14c. Other null hypotheses, that is, there is no statistically significant difference between the frequencies of the occurrence of misconceptions between both groups, cannot be rejected at the level of significance threshold $\alpha = .05$.

Statistical analysis showed that there was a statistically significant difference between the frequencies of occurrence of the most frequent misconceptions in the TEA and LEA groups in nine cases of 24 selected misconceptions. These nine misconceptions concern the shape, size, and weight of an atom (M4a, M4b, M6b), the space between atoms (M8d, M11d), the transfer of properties of macro-objects into the microcosm (M10d), and the processes taking place in the atomic nucleus and shell (M13b, M13d, M14c). It should be noted that seven of those nine misconceptions were found to occur significantly more frequently among the TEA group than in the LEA group. The only misconceptions M6b and M10d had a statistically more significant incidence in the LEA group than in the TEA group.

As clearly shown in Table 7, among the most strongly held misconceptions are the M3c, M7d, and M12b misconceptions with a frequency of occurrence greater than 30% recorded in both groups. In M4a, M4b, M8d,

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M13b, and M14c misconceptions, an incidence greater than 30% was observed in at least one of the study groups (although in all cases it was the TEA group).

Table 7

Overview of Selected Misconceptions and the Relative Frequencies of Their Occurrence in the TEA and LEA Groups

No.	Misconception	% of TEA	% of LEA	*p*
M1b	No, atoms cannot be seen; we can only believe that they exist. (Unver & Arabacioglu, 2015)	17.77	15.29	.262
M2a	Atoms are alive because they can grow and divide. (Harrison & Treagust, 1996)	10.15	13.53	.158
M2d	Only the atoms of living things are alive. (Griffiths & Preston, 1992; Unver & Arabacioglu, 2015)	13.20	8.82	.092
M3a	When an animate being dies, the atoms of which it was made stop moving. (Palečková et al., 1997)	10.15	8.82	.333
M3c	When an animate being dies, the atoms cleave to simpler parts, and those then create new atoms. (Palečková et al., 1997)	43.65	47.65	.221
M3d	Atoms cease to exist once an animate is decomposing. (Palečková et al., 1997)	17.77	21.18	.205
M4a*	**Atoms may have different shapes depending on the kind of matter they are composed of (they may be round, oval, oblong, etc.). (Unver & Arabacioglu, 2015)**	**38.07**	**24.71**	**.003**
M4b*	**Atoms are in the form of balls that are full inside. (Griffiths & Preston, 1992; Harrison & Treagust, 1996; Unver & Arabacioglu, 2015)**	**31.76**	**9.64**	**.0001**
M5c	Atoms do not have the same size because the size of an atom is determined only by the number of protons and neutrons in the atomic nucleus. (Unver & Arabacioglu, 2015)	19.29	22.35	.235
M5d	All atoms are equal but produce molecules of different sizes. (Kind, 2004)	16.75	20.59	.173
M6b	**All atoms do not have the same weight, because the weight of an atom depends on how many simpler atoms it is composed of. (Unver & Arabacioglu, 2015)**	**12.69**	**20.59**	**.021**
M7d	A piece of gold consists of gold atoms and matter that fills the space between the gold atoms. (Unver & Arabacioglu, 2015)	37.06	39.41	.322
M8b	Because there are no gaps in the particles of solid matter, atoms cannot move there. (Özalp & Kahveci, Tatar, 2011; Unver & Arabacioglu, 2015)	19.80	22.94	.232
M8d*	**Atoms do not move in a solid; only electrons move in atomic shells. (Unver & Arabacioglu, 2015)**	**31.98**	**20.00**	**.005**
M9b	When an iron rod is heated, electrons will release from the atomic nuclei; thus, enlarging the atoms. (Unver & Arabacioglu, 2015)	16.75	18.24	.354
M9d	During heating, only the rod increases in volume; the size of the atoms and the distance between them do not change. (Unver & Arabacioglu, 2015)	11.68	17.06	.070
M10c	When the coal splinters into dust, the atoms will also disintegrate. (Unver & Arabacioglu, 2015)	10.66	11.76	.369

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No.	Misconception	% of TEA	% of LEA	*p*
M10d	**When a piece of coal is hammered to dust, small parts of some carbon atoms fall off, which decreases the size of these atoms. (Unver & Arabacioglu, 2015)**	**10.15**	**20.59**	**.003**
M11a	If you remove all paper sheet atoms, a small amount of paper dust remains. (Unver & Arabacioglu, 2015)	14.72	19.41	.116
M11d*	**If you remove all paper sheet atoms, the energy remains. (Unver & Arabacioglu, 2015)**	**19.29**	**8.82**	**.002**
M12b	Air is elastic; therefore, the air atoms are also elastic; that is why they can be easily compressed and will not break in the event of collision with a train. (Harrison & Treagust, 1996; Unver & Arabacioglu, 2015)	39.09	31.18	.057
M13b*	**Electrons are one of the fundamental particles that an atom is composed of. If the electron separates from the atom, the atom divides. (Unver & Arabacioglu, 2015)**	**34.01**	**15.88**	**.0001**
M13c	All you have to do is break the shell of the atom. (Harrison & Treagust, 1996)	10.66	11.76	.369
M13d*	**Electrons cannot be torn off an atom. (Unver & Arabacioglu, 2015)**	**18.78**	**8.24**	**.002**
M14c*	**Atoms cannot transform because each of the protons, neutrons, and electrons in an atom is unique. (Unver & Arabacioglu, 2015)**	**31.47**	**22.94**	**.034**

Note: The cases of misconception, in which statistically significant differences were found between the relative frequencies of the answers, are indicated in bold. Asterisks are used to distinguish between misconceptions in which a statistically significant higher frequency of occurrence was observed in the TEA group than in the LEA group.

Discussion

The results of the research showed consistency with studies in the field literature, but also shed light on some findings that are not mentioned. Based on the results stated above, it is possible to answer the research questions as follows:

(RQ1) There is a significant difference between the frequencies of the occurrence of correct responses between TEA and LEA in four test questions.

(RQ2) Three test questions reliably demonstrated a significant difference between the choice of individual responses for the question and the test group.

(RQ3) There is a significant difference between the frequency of the occurrence of misconceptions between both groups in nine cases of 25 investigated misconceptions, of which seven misconceptions occur significantly more frequently among TEA.

Regarding RQ1, based on the findings of other studies, we assumed that the TEA group would be more successful in choosing the correct answers for each question. It turned out, however, that the TEA responded statistically significantly better than LEA for only two questions (Q4 and Q10). The question Q4 concerned the shape of an atom (Q4). For this question, it turned out that almost a third of LEA (31.76%) had an idea of the atom as a sphere that is full inside (misconception M4b), while in the TEA group this idea was significantly less widespread (9.64%). This often frequented misconception shows a clear parallel to the ideas of Greek atomists, according to which atoms are inviolable, that is, indivisible, absolutely rigid, and without emptiness (Hejnová & Hejna, 2018). School teachers often use this idea as the simplest model of the atom as a rigid ball, which better matches the ability of younger learners in particular to accept such an idea. This may be the reason for the significant incidence of this idea in LEA. For the question Q10, the TEA group had the correct answers with high frequency (70.05% correct answers). Even in this case, however, the strong influence of the transfer of what is happening with the piece of coal, that is, the macroscopic material, at the atomic level can be inferred. For example, the misconception M10c ('When the coal

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splinters into dust, the atoms will also disintegrate.') appeared in approximately 11% of TEA, which is consistent with the results of a study by Unver and Arabacioglu (2015, p. 74) conducted with pre-service science teachers.

The surprising finding was that for two questions (Q12 and Q13), in contrast, the LEA group was statically significantly more successful. The question Q12 was aimed at the transfer of properties of macro-objects into the microcosm. This question showed a very strong misconception of M12b in both groups that air is elastic and therefore air atoms are also elastic. 39.09% of TEA and 31.18% of LEA were in favour of this idea, which is a relatively serious finding, as other research has not shown such a high prevalence of misconception, e.g., Unver and Arabacioglu (2015, p. 73) reports the incidence of this misconception in pre-service science teachers 15.1%.

Also, in the question Q13, LEA were significantly more successful than TEA, even twice as much (36.55% TEA, 62.94% LEA). On the contrary, a third of the TEA group showed a very strong misconception of M13b ('Electrons are one of the fundamental particles that an atom is composed of. If the electron separates from the atom, the atom divides.'). Similarly, the study by Unver and Arabacioglu (2015, p. 73) showed this misconception in 20% pre-service science teachers. The M13d misconception ('Electrons cannot be torn off an atom.') demonstrates that TEA, in particular, did not differentiate well between the actions occurring in the electron shell and the nucleus and the consequences which these actions lead to. This is a basic knowledge of atomic and nuclear physics which should be understood by all secondary school graduates. However, the conducted research has shown that a considerable number of TEA are not familiar with even the most basic knowledge.

As far as RQ2, only three test questions (Q10, Q11 and Q13) reliably demonstrated a significant difference between the choice of the answers for the questions and the test group, which to some extent corresponds to the results obtained in the previous analysis of differences between the frequencies of the occurrence of correct answers; a statistically significant difference between the frequencies of the occurrence of correct answers between TEA and LEA was in the test questions Q10 and Q11; for the question Q4, Pearson's chi-square test is not sufficiently reliable.

Regarding RQ3, the prevalence of many misconceptions has been shown to be the same in the TEA group as in the LEA group, but some misconceptions have occurred significantly more frequently in the TEA group, which is somewhat surprising. For example, for the question Q8, two very strong misconceptions appeared in both groups (M8b and M8d). The M8b misconception ('Because there are no gaps in the particles of solid matter, atoms cannot move there.') points out that about a fifth of LEA s and TEAs consider atoms small pieces of solid bodies, between which there is no space. In Unver and Arabacioglu (2015) the same misconception was studied in a group of pre-service science teachers, whose incidence was comparatively high (23.3%). Similar results were shown by the study Özalp and Kahveci (2015), where this misconception was diagnosed in 27.3% ninth graders. This idea that atoms are 'densely sown' side by side (Driver et al., 2003) is probably why almost a third of TEA think that atoms do not move, but electrons are moving in atomic shells (M8d).

Specifically, of the misconceptions concerning animism (see the misconceptions M2a, M2d, M3a, M3c, M3d in Table 6), that is, the idea that an atom is alive (having the characteristics of a living organism) belongs among the most common, which was also confirmed in this study. A more frequent incidence of two concepts was revealed in either group: 'atoms can grow and divide' (M2a), and 'only atoms of living organisms are alive' (M2d). In both cases, the incidence was approximately 10%. Furthermore, in our research a very powerful idea (M3c) appeared in both groups, that 'when an animate being dies, the atoms split into simpler parts, which then create new atoms' (43.65% of TEA and 47.65% of LEA). The same question was also included in the Trends in International Mathematics and Science Study (TIMSS) (Palečková et al., 1997) conducted in 1995 in 43 countries around the world for seventh and eighth graders. In this study, about 22% of the students chose the correct answer in both age categories. We recorded very similar results in this study, essentially the same for the TEA and LEA groups.

Mention should be made of one more significant misconception about M14c ('Atoms cannot transform because each of the protons, neutrons, and electrons in an atom is unique.'), which occurred statistically more significantly in the TEA group. Almost a third of TEA think that the electrons of different atoms are unique. The cause of this misconception may be poor understanding of the fact that the different properties of atoms are related to their different structures, not to their constitution.

Participants in our study could also provide their own response. Both TEA and LEA responses, however, were rare. For most of the questions, there were one to three own answers; only for Q14, 14,6% of the participants chose their own answer. Among the own answers were those that could be considered correct but were not directly related to the question; for example, in Q9 ('Do the atoms in an iron rod expand when the rod is heated?') where one of the learners wrote that when they warm up, the atoms start to move faster. Some of the children's responses indicated that they were thinking more deeply about the question and trying to formulate their original answer,

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for example, in Q11 ('Imagine that all atoms of a sheet of paper have been removed. What would then be left?') where two learners replied that after removing all the atoms of a paper sheet, 'the ink atoms would remain' or 'substances of a different kind contained in the paper would remain'. For Q14 ('How can the atoms of one element be transformed into the atoms of another element?') 11 children gave their own answer, but most of them were incorrect or inaccurate (for example, 'atoms cannot change under any circumstances'; 'they can, but it is a matter of millions of years, for example, diamonds, previously it was ordinary carbon, then with the influence of pressure and heat it gradually transformed'; 'may change by the addition or removal of an electron or proton'). It is also worth noting that about 13% of TEA and 10 % of LEA think that the cause of the transformation of the atom is sunlight or thunder and lightning. The learners' own answers also pointed to some other misconceptions. A student, for example, stated in Q7 that an atom is a very small piece of gold with gold properties, which is the typical child's initial idea of an atom as a small piece of material substance or an ultimate piece of material substance, which we obtain by gradual division of the material.

Influencing and eliminating misconceptions is not an easy task because of their considerable resistance. However, there are some appropriate teaching techniques that can effectively help pre-service primary school teachers overcome their incorrect conceptions. These include, for example, instructional approaches based on constructivism, such as the method called Concept Cartoon (Naylor & Keogh, 2010; Pekel, 2021; Samková, 2018), and science-based instruction methods that engage students in observation and experiments (e.g., Unver & Arabacioglu, 2015) and allow them to better develop correct ideas about fundamental physical phenomena.

Limitations of the study

Undoubtedly, there are limitations to the research presented, for example, the use of an available sample of respondents, especially with regard to their random selection. It should also be noted that the participants of the TEA group focus more on the humanities, and the natural sciences are not their main field of study in the university.

Conclusions and Implications

Although there are many cross-age studies aimed at understanding of PNM, almost no research has been performed involving lower-secondary learners and also pre-service primary school teachers, who in their university studies are not primarily focused on natural science.

The prevalence and diversity of the observed misconceptions among TEA in this study indicate that most of them are not familiar with the nature and constitution of matter and that the issue is not adequately addressed during their education. The results obtained with TEA demonstrate the existence of a number of misconceptions similar to those observed with LEA, some of them can be considered very strongly-held misconceptions with a frequency of occurrence higher than 30% and some misconceptions were observed to even be present significantly more frequently in the TEA group. This study confirmed that age maturity and mere knowledge of scientific concepts such as atoms, molecules, etc. do not have to be sufficient to allow students to better understand and correctly grasp the key concepts of PNM.

To a deeper conceptual understanding of the PNM, the content of the curriculum but also suitable teaching activities during school studies play a crucial role because students need both a sufficiently long time and suitable opportunities to rethink and grasp key concepts of atomism. Given the importance of primary science education, it would be appropriate to allow pre-service primary school teachers to specialise more in learning subjects focused on natural sciences already within the frame of their pre-graduate training. This part of university education of primary school teacher trainees could be accentuated more in this way. Students could be offered science-based teaching modules made up of experiments and other suitable activities, particularly argumentation-based ones, and at least among those portions of students, who would like to study the topic in more depth.

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Appendix - The Multiple-Choice test

1. Can we see individual atoms?

a) Yes, the atoms are large enough for us to be able to see them under a normal microscope.
b) No, atoms cannot be seen; we can only believe that they exist.
c) Yes, large atoms can be seen even with the naked eye.
d) Yes, we can see atoms, but only with a special laboratory instrument.
e) Other response:

2. Are atoms alive?

a) Yes, because atoms can grow and divide.
b) No, atoms do not have the characteristics of living organisms.
c) Yes, atoms are alive because they move.
d) Only atoms of living things are alive.
e) Other response:

3. Animate beings consist of many atoms. What will happen to these atoms after the animal dies?

a) The atoms stop moving.
b) The atoms return to the environment.
c) When an animate being dies, the atoms cleave to simpler parts, and those then create new atoms.
d) The atoms cease to exist once an animate is decomposed.
e) Other response:

4. What is the shape of the atoms?

a) Atoms may have different shapes depending on the kind of matter they compose (they may be round, oval, oblong, etc.).
b) Atoms are in the form of balls that are full inside.
c) Atoms are flat (as when we smash a ball made of modelling clay).
d) The only thing we can say about an atom is that it has a positive nucleus and an electron shell.
e) Other response:

5. Are all atoms of the same size?

a) They are not because the size of an atom is determined by the number of protons, neutrons, and electrons that the atom is composed of.
b) They are because there is only one basic type of atom in the universe from which all more complex atoms have been created.
c) They are not because the size of an atom is only determined by the number of protons and neutrons in the atomic nucleus.
d) All atoms are equal but produce molecules of different sizes.
e) Other response:

6. Do all atoms have the same weight?

a) No, because atoms of gases have no weight at all.
b) No, because the weight of an atom depends on how many simpler atoms it is composed of.
c) Yes, all atoms are particles of the same weight.
d) No, because atoms have a different number of protons, neutrons, and electrons.
e) Other response:

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7. Do the atoms of gold have the same properties as a small piece of pure gold?

a) Yes. Gold is hard, and therefore the gold atom is also hard.
b) No, a single atom of gold does not have the same properties as a piece of gold.
c) Yes, the atom of gold is shiny, like the gleam of any item of gold.
d) No, since a piece of gold is composed of both gold atoms and matter that fills the space between these atoms.
e) Other response:

8. Do atoms in a solid move?

a) Yes, the atoms in a solid vibrate.
b) No, they cannot move because there are no gaps between the particles in a solid.
c) No. The atoms do not move because the atoms in a solid are heavy.
d) No, the atoms do not move; only electrons move in atomic shells.
e) Other response:

9. Do the atoms in an iron rod enlarge when the rod is heated?

a) When heating an iron rod, only the nuclei of the atoms will grow.
b) When heating an iron rod, electrons will release from the atomic nuclei; thus, enlarging the atoms.
c) Heating the rod will increase the distance between the atoms and the range of their vibrations.
d) During heating, only the rod increases in volume; the size of the atoms and the distance between them do not change.
e) Other response:

10. Coal consists of carbon atoms. What happens to the carbon atoms after a piece of coal is hammered to dust?

a) The carbon atoms will not change.
b) The blows of the hammer will cause a change in the size of the atoms.
c) When the coal splinters into dust, the atoms will also disintegrate.
d) Small parts will fall off from some carbon atoms, and so these atoms will become smaller.
e) Other response:

11. Imagine that all atoms of a sheet of paper have been removed. What would then be left?

a) Some paper dust would remain.
b) Nothing would be left.
c) Only a tiny piece of paper of very low weight would remain.
d) Energy would remain.
e) Other response:

12. What happens to the air atoms when they collide with a train moving at high speed?

a) At the moment of collision, the atoms are protected by their rigid shells; much as a nut shell protects the nut.
b) Air is elastic, therefore, the air atoms are elastic, too; that is why they can be easily compressed and will not break in the event of collision with a train.
c) If the speed of the train is sufficiently high, some of the air atoms will break on impact, breaking into small fragments.
d) In a collision with a train, the air atoms will not change in any manner whatsoever.
e) Other response:

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13. Does an atom need to be broken to free an electron?

a) No, the electrons can break off without breaking the atom.
b) Electrons are one of the fundamental particles that an atom is composed of. If the electron separates from the atom, the atom divides.
c) No; you can break the shell of the atom.
d) Electrons cannot be removed from the atom.
e) Other response:

14. How can the atoms of one element be transformed into the atoms of another element?

a) The cause of the transformation of atoms into different atoms is sunlight.
b) Unstable atoms may spontaneously change to other atoms during radioactive decay.
c) Atoms cannot transform because each of the protons, neutrons, and electrons in an atom is unique.
d) Atoms may be transformed into other atoms during the occurrence of such natural phenomena as thunder and lightning.
e) Other response:

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