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Ingrid Paśko, Jan Rajmund Paśko

Is natural science education fully effective?

Introduction

Scientists, educators and teachers agree that natural science education is a key component of the teaching process, in particular when it comes to young people. It appears that natural science education, especially at an early stage, is an easy task for teachers because regardless of our interests, we all need to be in contact with nature. However, this is a superficial view because, despite the common belief, natural science teaching is a task that is difficult and comes with great responsibility. Whatever is "damaged" during the first years of primary education is, in many cases, irreparable.

Nature has accompanied people from the dawn of mankind. Everything that surrounds us can be regarded as nature with the exception of products of human activity. Initially, natural science education took place within the environment, before writing was invented. Every form of teaching has a goal. It is fair to say that the goal of teaching is to convey knowledge that is considered useful or even necessary from the point of view of a teacher. However, there is a dilemma here: what knowledge can be deemed useful and necessary? Can we define it as that knowledge we need in everyday life or should the definition be broader and include information that lets us understand the processes taking place in the surrounding world? Is it sufficient to know the properties of water? Should we know why water can be in a liquid, solid or gas state? Should the main objective of natural science education be observing and describing different phenomena and natural objects in order to know how to use them in everyday life? During such observations, is it important to predict the consequences of the observed and described natural phenomena?

In the 17th century, *Orbis sensualium pictus*, a book by John Amos Comenius was published (Komeński 2015). In this book, considered a prototype of modern textbooks, we can read:

The air – breathes gently.

The wind – blows strongly.

A storm – throws down trees. The water – springs out of a fountain, stands in a pond, glides in a stream.

The fruits of the earth: A meadow yields grass with flowers and herbs. A field yields cereal and vegetables. Mushrooms, wild strawberries and blueberries come up in woods.

This is practical, descriptive knowledge based on what people knew about natural science at the time.

Over 100 years ago, in 1919, the second edition of the book "Zasady metodyki ogólnej nauk przyrodniczych" [The General Methodological Principles of Natural Science] was published, where M. Heilpern writes: "Despite the fact that natural science questions occupy the minds of all people from an early age, that they underpin people's philosophy and direct all their actions in practical life, school teaching was not based on knowledge. Sometimes the knowledge was completely ignored" (Heilpern 1919, p. 2). Next, the author states: "The goals of natural science as a school subject in primary and secondary schools are fundamentally different from its scientific goals. Schools must, first of all, take into account the goals of general upbringing and education. The subject matter of natural science is too extensive, the methods too detailed and the generalisations too inaccessible to young minds for natural science to be, even partially, fed to these minds in any significant form that corresponds to the scientific level, especially of contemporary knowledge" (Heilpern 1919, p. 4). This statement can be interpreted in two ways. 1. Comprehensive natural science knowledge is too broad for pupils to master and, thus, needs to be taught in a fragmentary manner. 2. It is too difficult and therefore current scientific ideas should not be used.

Before the Second World War, teaching natural science was based on the distinction between animate and inanimate objects. In 1933 D. Gayówna wrote guidelines for teaching the curriculum in the fifth grade of primary school. These guidelines include information about plants and animals based on observation of nature or own farms (Gayówna 1933). In 1936 M. Sobolewski wrote a textbook for seventh grade primary school about inanimate nature. It includes information about organic substances (processed cereals and potatoes, milk, eggs, fats, hard coal and crude oil products). All information is provided in a practical and descriptive form. Two-thirds of the volume of the textbook is taken by physics-related content (Sobolewski 1936). In the teaching of natural science in the pre-war period, even in higher grades of primary school, only the descriptions of natural phenomena and processes were used. An example of this approach is an experiment where hydrogen is generated from water and iron where only a description is given followed by a simple statement that a gas was obtained (Gayówna, Żłobicki, Adwentowski 1934, p. 178).

After the Second World War the teaching of natural science continued to be dominated by describing and observing natural phenomena and objects. Therefore, we can conclude that natural science education is still tainted by beliefs from alchemy, i.e. describing the macro world as observed directly with the senses. In many natural science textbooks of the time, we can read that coal burns in oxygen, i.e. that oxygen reacts with coal. But how are pupils supposed to imagine how this process takes place? What does oxygen look like? Even though pupils can see what coal looks like, they cannot see how it reacts with oxygen. This is the difficult part to grasp for pupils. But it needs to remain this way as we are dealing with purely descriptive natural science. Another example is dissolving sugar in water. How does this happen? The textbooks also do not clarify this. Nowadays, based on conducted research, we can explain to children how sugar dissolves in water using the molecular theory of matter. Such an explanation is understandable to children (Paśko 2016).

Research report

A research project was carried out to determine whether students of a Pre-school and Early-school Education (PPiW) degree course could explain selected natural phenomena.

The following hypothesis was formulated: Students of the PPiW degree course can explain selected natural phenomena based on the molecular theory of matter.

Detailed hypotheses:

Based on the molecular theory of matter, students of the PPiW degree course are able to explain what wind is.

Based on the molecular theory of matter, students of the PPiW degree course are able to explain what air consists of.

Based on the molecular theory of matter, students of the PPiW degree course are able to explain why ice is solid and water is not.

Based on the molecular theory of matter, students of the PPiW degree course are able to explain how odours and scents spontaneously drift through the air.

Based on the molecular theory of matter, students of the PPiW degree course are able to explain why wind moves tree branches.

The research project involved 124 participants and was conducted over a period of four years. Each year, during a lecture in the summer semester, third year Bachelor's degree students were asked to answer some questions in writing. The questions were asked one after another and students had just over a minute to answer each of them.

The following questions were asked:

1. What is wind?
2. What does air consist of?
3. Why is ice solid and water not?
4. How do odours and scents spontaneously drift through the air?
5. Why does the wind move tree branches?

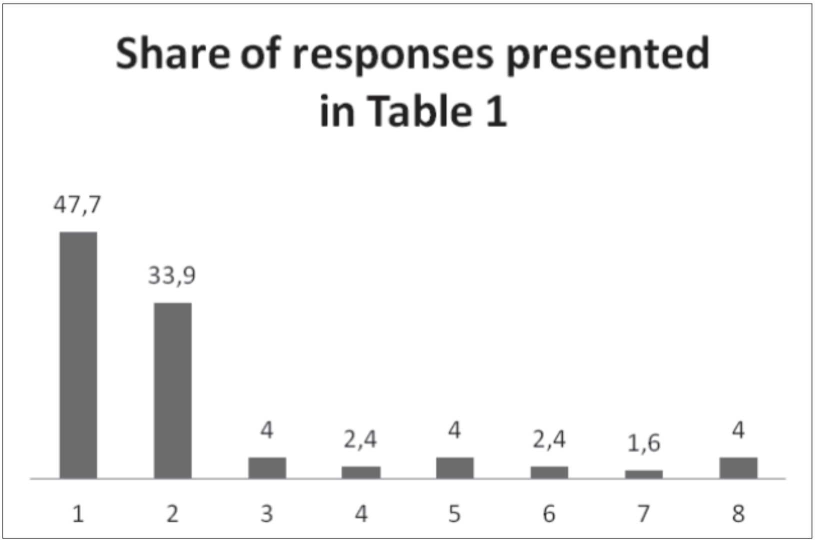
The given answers were categorised.

The answers to the question "What is wind?" can be categorised into eight groups. Table 1 shows the number of answers in each group.

Table 1 Answers to the question "What is wind?"

No.	Answer group	Number of answers
1	Air movement	59
2	Climatic event, weather phenomenon	42
3	A breath of air	5
4	The air that surrounds us	3
5	A certain force	5
6	It is an element	3
7	Movement of molecules	2
8	Other	5

Figure 1 Share of responses presented in Table 1.



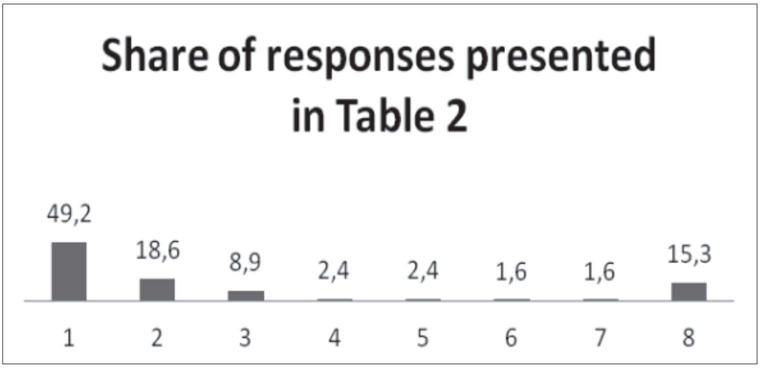
The percentage share of responses is shown in Figure 1. Most students, i.e. nearly 50%, defined wind as the movement of air. Less than 40% described the wind as a climatic event, a weather phenomenon. In contrast, only 1.6% stated that wind is the movement of molecules.

The answers to the question "What is air?" can be categorised into eight groups. Table 2 shows the number of answers in each group.

Table 2 Answers to the question "What does air consist of?"

No.	Answer group	Number of answers
1	Of nitrogen, oxygen and noble gases	61
2	Of nitrogen and oxygen	23
3	Oxygen, carbon dioxide	11
4	Oxygen, nitrogen, carbon dioxide	3
5	Oxygen	3
6	78% nitrogen, 21% oxygen, 1% other gases	2
7	Oxygen, nitrogen, carbon dioxide with pollutants	2
8	Gases, elements	19

Figure 2 Share of responses presented in Table 2



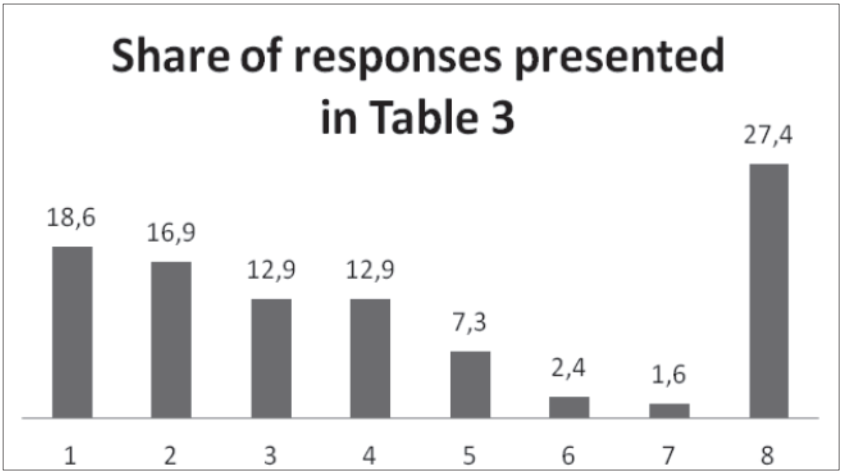
The percentage share of responses is shown in Figure 2. About 50% of the respondents gave an almost correct answer. About 19% of the respondents knew that air consists of oxygen and nitrogen.

The answers to the question "Why is ice solid and water not?" can be categorised into eight groups. Table 3 shows the number of answers in each group.

Table 3 Answers to the question "Why is ice solid and water not?"

No.	Answer group	Number of answers
1	Because at lower temperatures water turns into ice	23
2	Ice melts	21
3	Because water freezes	16
4	Because water turns into ice	16
5	Ice is solid	9
6	Because as the temperature drops, molecules get closer, their density increases and the solid becomes heavier	3
7	Ice freezes and water is liquid	2
8	Other	34

Figure 3 Share of responses presented in Table 3



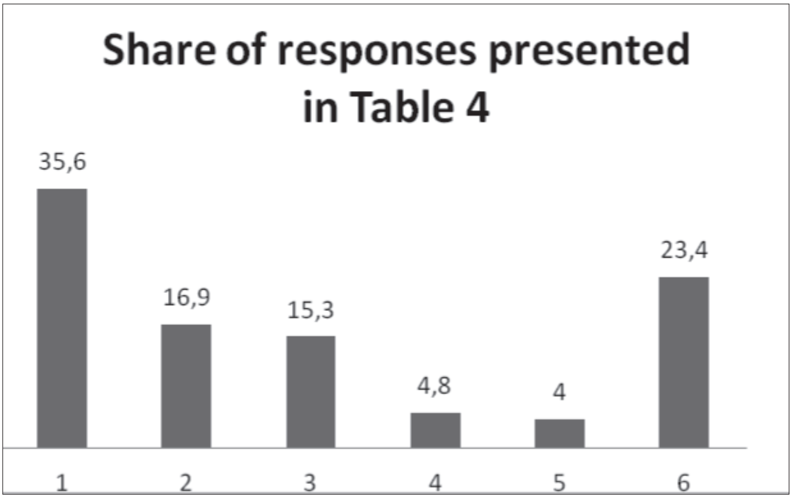
The percentage share of responses is shown in Figure 3. The majority of answers boiled down to saying that water turns into ice or the other way round. About 18% of respondents said that for water to turn into ice, a lower temperature is needed. Only 2.4% stated that, as the temperature drops, water molecules come closer together.

The answers to the question "How do odours and scents spontaneously drift through the air?" can be categorised into six groups. Table 4 shows the number of answers in each group.

Table 4 Answers to the question "How do odours and scents spontaneously drift through the air?"

No.	Answer group	Number of answers
1	Because diffusion takes place	44
2	Because air molecules and odour molecules mix	21
3	Because the odour mixes with the air	19
4	Because it is lighter than air	6
5	Air movement	5
6	Other	29

Figure 4 Share of responses presented in Table 4



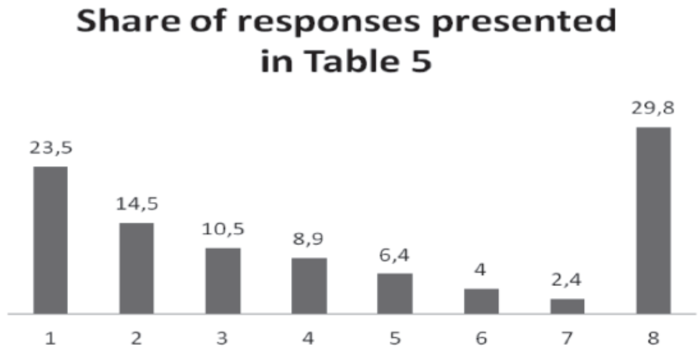
The percentage share of responses is shown in Figure 4. About 35% of respondents stated that diffusion takes place. In contrast, 21% of respondents explained that it is because air molecules mix with odour molecules. Approximately 15% said the air mixes with the odour.

The answers to the question "Why does the wind move tree branches?" can be categorised into eight groups. Table 5 shows the number of answers in each group.

Table 5 Answers to the question "Why does the wind move tree branches?"

No.	Answer group	Number of answers
1	Because the wind becomes more condensed.	29
2	The wind is strong	18
3	Because the branches are light	13
4	This is due to strong air movements	11
5	Because the branches offer resistance	8
6	A force acts on the branches	5
7	Due to a strong blast	3
8	Other	37

Figure 5 Share of responses presented in Table 5



The most common answer, amounting to over 23%, was that the wind becomes more condensed. Less than 15% of the respondents stated that the wind was strong. In the remaining answers, like in the previous cases, it was not clarified why the wind moves tree branches.

Discussion of research results

Based on the research results, we can conclude that the entire cycle of natural science education in schools was conducted ineffectively in the case of the studied group of university students. They were not taught to such an extent as to be able to give correct answers to questions about natural phenomena occurring in their surroundings. Therefore, the question arises whether teachers cannot teach, or that perhaps they do not put enough effort into their teaching. Given the fact that students go through several stages of education conducted by various teachers and the respondents attended many different schools, these two statements are rather unlikely; they can be true for specific cases, but not for the entire population of teachers. Therefore, the reason why students failed to learn these concepts may lie in the fact that the content is very difficult to master. A more likely reason is that there are flaws in the natural science education system.

Having analysed the provided answers, we can conclude that the respondents were guided only by the criteria of describing the matter in a macro scale, i.e. describing directly observed phenomena. In only 4.2% of the answers (26 out of the total of 620) respondents took into account the movement of molecules and as many as 3.4% of these answers (21) referred to the same question.

What attracted our attention were the answers given to the question about the odours and scents drifting spontaneously through the air. 21 respondents, which amounts to 16.9%, explained that it is due to the mixing of molecules, which is true. On the other hand, 35.6% of the respondents explained this phenomenon as diffusion, without explaining the concept at all. It is interesting to reflect as to why the respondents used the molecular theory of matter only in this question as an explanation.

In early natural science education, pupils learn, among others, about water and its states of matter, air and wind, but they do not learn about how odours and scents drift, thus they do not learn about the phenomenon of diffusion. Natural science is based mainly on observing selected phenomena and their consequences; these are observations that relate to the macro world. At this level of education, pupils are not taught about the reason why a given natural phenomenon occurs because that would require describing the micro world, i.e. going down to the level of atoms, ions and molecules. Many educators are of the opinion that the micro world is too difficult to grasp for pupils in the early years of primary school, since it is abstract and inaccessible to direct observations.

Only at a later stage of school education do pupils learn about the molecular theory of matter. Therefore, the studied group of university students should use molecular theory of matter in their answers to the above questions. In the first years of school education, teaching about natural science refers to the macro world. This creates an image in the pupils' minds based mainly on what they are able to observe, e.g. the natural phenomenon itself (water – changes in the states of matter) or its consequences (wind – broken branches) and possibly also the content they had to memorise (the composition of air). In the following years of school education, pupils learn about the molecular theory of matter mainly during chemistry classes.

It appears that the reason the respondents did not use the molecular theory of matter to explain the selected natural phenomena lies in negative transfer. M. Sawicki (1981) raises the question of negative transfer in the education process. Strongly rooted ideas referring to the macro scale interfere with the acquisition of new knowledge.

It is possible to eliminate negative transfer in comprehensive natural science education by introducing the molecular theory of matter at an early stage of primary education. Previous studies proved that primary school age children find it easy to use this theory to explain basic natural phenomena that they know from everyday life. It only requires the development and preparation of appropriate teaching resources. (Paśko, Zimak 2012)

In order to explain the processes that take place in the micro world, we do not need to introduce concepts that are difficult to define. It is enough to explain to pupils that the surrounding world is made up of tiny particles which are invisible to our eye and are constantly moving. The behaviour of the observed matter depends on the type of movement of these particles. In order for pupils to be able to visualise the moving particles, we need to use carefully prepared animations.

Conclusions

Explaining basic natural phenomena with the molecular theory of matter should be introduced at an early stage of primary education. Contrary to popular belief, references to the molecular theory of matter do not cause difficulties for pupils of this age and, what is more, they even arouse their curiosity and spark genuine interest in natural phenomena and processes. Thanks to that teachers can provide adequate explanation of how natural phenomena occur at the first and further stages of education.

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Abstract

The introduction outlines how natural science was taught in the past and how it is taught now. Next, the research results are presented with the respondents being university students of Pre-school and Early-school Education degree courses. As part of the study, the respondents had to answer five questions about common natural phenomena. The analysis of the answers gave rise to the conclusion that the examined university students were not able to explain the natural phenomena using the molecular theory of matter; this is due to negative transfer at an early stage of natural science education. Based on the results of the study, it is suggested that natural phenomena and processes should be explained using the molecular theory of matter even at an early stage of primary education.

Key words: natural science education, natural phenomena, the molecular theory of matter, teaching

Ingrid Paśko, PhD
Pedagogical University of Krakow, Poland
email: ingrid.pasko@gmail.com
ORCID: 0000-0002-9422-9900

Prof. Jan Rajmund Paśko
Pedagogical University of Krakow, Poland
email: janraj@onet.eu
ORCID: 0000-0001-6035-1898