LEARNING ABOUT THE SCIENTIFIC METHODS IN THE INSTRUCTION IN SUBJECTS RELATED TO SCIENCE

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Abstract
Training students to learn and solve problem situations on their own is one of the basic goals of the educational process. The successful realization of this complex task, among other things, implies that the students continuously learn about the scientific methods. This knowledge is essential for learning about the natural and social phenomena. This is why it is necessary to continuously learn about the scientific methods in the process of realization of specific instructional content. The content from mathematics and science can serve this goal. In this paper, we are going to analyze the most commonly used scientific methods and present examples how the students can learn them from the youngest age.

1. INTRODUCTION

The scientific methods are the basic tools used by people to learn about the natural and social phenomena, relations and processes in an adequate way. The basic fact supporting this opinion is that each scientific method is a way of observation of such facts that will enable the observer, i.e. the researcher to discover general laws for analyzing objects, phenomena and processes. When learning about the natural and social phenomena, relations and processes the students are in a similar position as the scientists, because for the first time they “discover” the scientific truths on their own or with the help of their teachers. For this reason, the scientific methods that are part of the natural and social sciences are also used as instructional methods.

Having in mind the previously said, it is very important for the students to learn scientific methods from the earliest age, because their proper use contributes for:

- Development of the thinking properties
- Learning the methods for drawing conclusions (inductive conclusions, deductive conclusions and analogous conclusions) and their proper use.

We should bear in mind that the development of the properties of thinking, the instruction about the scientific methods and the introduction of the methods for drawing conclusion need to be adjusted to the individual abilities of each student. It goes without saying that this adjustment should be done by the teachers, however, the basics for the fulfillment of this important task need to be provided by the syllabi and textbooks, which is not always the case.

In order to see the extent to which the syllabi and existing textbooks for science serve this purpose we need a thorough analysis. Nonetheless, even without such an analysis, from the results of the PISA project we can see that there are serious weaknesses that hinder the
accomplishment of the goals. Furthermore, by an individual research it is impossible to give an answer to the question what and how needs to be changed in the educational system in order for the students to learn the scientific methods and get trained to use them. This should be a task of the competent institutions for high education and the expert bodies in the Ministry of Education and Science.

Having in mind the previously said, especially the volume of the necessary researches, further on in the paper we are going to scrutinize only the scientific methods. We are going to present examples, which we tested in practice and were proven to help the students from the earliest age to learn about the scientific methods and their proper use.

2. THE SCIENTIFIC METHODS AND THE SCIENCE INSTRUCTION

In the most general sense, a method implies a way in which we acquire information about a subject that is studied by science. This is why, we can say that a scientific method is an analysis of facts that enables the researcher to discover general laws referring to the subjects, processes of phenomena that are studied.

Observation is a scientific method that is carried out according to a previously devised plan in order to discover, determine or study specific properties of particular objects and phenomena or their connection with other objects and phenomena. The objects and phenomena are most commonly observed in their natural environment.

The scientific observation is holistic and it implies a complete description of the object, phenomenon or the process in their spatial and time context. The observed phenomenon (object, process) needs to be analyzed in the context of all phenomena (objects, processes) that occur at the same time and that can influence it. A complete description allows us to properly understand the observed phenomenon.

Further on, the observation can be:
- **Natural**, in which the object, occurrence and process are observed without the use of technical means and with the help of technical means.
- **Observation without participation of an observer**, in which the observer does not take part in the events. He observes them from a distance. Also, there is **observation with participation of an observer**, in which the observer, at the same time, is also a participant in the event.
- **Unstructured**, which implies that the observer has not previously determined what he will observe exactly. Contrary to this, a **structured observation** is carefully planned in terms of the aspects that are going to be observed, and for this reason the observer has previously prepared a protocol of observation and a system of categories (modalities) in which he only records the frequency of occurrence of an element of the observed phenomenon (process). The structured observation is the most precise and objective method of observation and is very similar to the experimental researches, however the shortcomings arise due to the rigidity in the planning, which does not allow registering the unexpected elements, which can be very important.
The greatest shortcoming of the method of observation is that it is limited only to the visible. Very often there are hidden elements that are unnoticeable through external observation, which can be crucial for the understanding of objects, phenomena and processes. On the other hand, an advantage of the method of observation is that by using it we can research what people do in fact, not just the things that are in their awareness.

The learning of this method can be accomplished through several observations of objects and phenomena, as presented in the example below. During the process, the students will make different mistakes, and this is why it is important for the teachers to monitor their activities and simultaneously correct any possible mistakes.

**Example. Recording the vegetation of randomly chosen areas.** This is done by using a construction in the form of a square with a wooden frame covering an area of $1m^2$ and a rope which divides the square into smaller squares with equal areas. We set the square on a randomly chosen area (this is best if we throw the frame behind us without looking). Afterwards, we make a list of all the plants and their number in the square. In order to acquire representative data, the recording procedure is repeated at least five times on different locations.

Clearly, there needs to be difference between observation and plain perception. The perception is just a direct reflection of a given object or phenomenon in the moments they are perceived by our senses, whereas observation is a planned, organized and guided perception of a specific object or phenomenon with the goal to accomplish a particular goal.

An experiment is a method of studying objects, phenomena and processes, in which the researcher intervenes in their natural state and development, by creating artificial conditions, deconstructing them, or by combining them with other objects, phenomena and processes.

During the experiment, each object, phenomenon and process is observed, and because of this we can say that the experiment and observation are two closely related methods. To conclude, an experiment is a method of studying objects, phenomena and processes, in which a parameter is generated and measured in strictly controlled conditions, all with the purpose of determining and measuring its influence, while all other parameters are kept under control.

The instruction in the subjects related to science is especially suitable for learning about the experiment as a scientific method. Further on, we are going to analyze two examples from biology.

**Example. Studying the growth conditions of the plants.**

**Light.** Experiment tools: two pots with wet soil and a cardboard pipe closed on one side.

Activities: In each of the pots place several grains of peas that were soaked in water overnight. Place the pots on the windowsill and cover one of the pots with the cardboard pipe to prevent the light from reaching inside (Image 1). Make several holes on the pipe so the air can circulate. Some light will penetrate through the holes as well. Because of this, you need to position this pot in a place by the window where there is shade, thus minimizing the influence of the light. Pour water onto the two pots each day and provide sufficient warmth, water and air, the only difference being that one of the pots will receive very little light. Record the results.
**Humidity.** Experiment tools: two pots, wet and dry soil.

Object of the experiment: peas.

Activities: Fill one of the pots with wet soil, and the other with dry soil, which you have previously placed into a furnace. In each of the pots put several grains of peas, which were soaked into water overnight. Place the pots on a windowsill, where there is sufficient warmth and light. In one of the pots pour wet soil each day (Image 2). In the other pot do not do this. Record the results.

**Warmth.** Experiment tools: two pots with wet soil.

Object of experiment: peas.

Activities (the experiment is carried out when it is very cold, preferably when there is ice): Fill the pots will wet soil and pour water regularly. In each of the pots put several grains of peas, which soaked into water overnight. Place one of the pots on a windowsill in a warm room. Place the other pot outside of the same window. (Image 3). Record the results.

**Oxygen.** Experiment tools: two pots with wet soil, transparent plastic bag and a clip.

Object of experiment: peas.

Activities: Fill the pots with wet soil and regularly pour water. In each of the pots put several grains of peas, which were soaked into water overnight. Place the pots by the window and wrap one of the pots with the plastic bag and close it by using the clip (Image 4). Record the results.

The experiment and observation are two closely related methods. In the next example we are going to show how the students can use them to acquire practical knowledge about the earthworms.

**Example.** Study the life of an earthworm.

Experiment tools: two transparent plastic panels, three wooden rods, screws, two types of soil, leafs and opaque cloth.

Object of experiment: earthworm.

Activities: The two plastic panels are fixed with the screws on the wooden frames (see the image). Then, we pour different layers of soil (sand and peat) and pour water. Afterwards, we place ten to twelve earthworms and wilted leafs and grass, which the earthworms are going to feed on.

This lombricario is covered by opaque cloth, thus stimulating the darkness underneath the soil. A few days later, the earthworms will dig tunnels through the soil and mix the different layers of soil, which will merge in the course of time. The earthworms take the leafs and the grass into the soil. Since they do not eat them completely, they enrich the soil with nutritious ingredients. Not only that, but their tunnels also provide air circulation to the root.

The observation and experiment are characteristic for the experimental sciences. Mathematics is not an experimental science,
but these methods are important in the mathematics instruction, especially in primary education. These methods are closely related to the laboratory work in mathematics, especially in geometry instruction, in which they are used for creating conditions that help the students to notice the obvious laws, the facts in geometry or the ideas that can be used as proofs for some claims. It is desirable that they are set as a separate goal in the mathematics instruction in order to become efficient means in it. This means that the teachers need to train the students to observe and experiment.

Although observations and experiments are important for instruction, we should emphasize that these methods are not the main in a research. This is why, the teachers need to explain adequately to the students that the results of the observations and experiments should not be considered as a proof referring to a property and that they should only be used as tools for discovering a property.

Comparison is an intellectual operation, which results in the discovery of similarities and differences between the objects and phenomena under study. When using this method, it is necessary to follow these rules, known as principles of comparison:

1) The comparison should make sense, i.e. we need to compare objects that have a connection.
2) The comparison needs to be carried out in a planned way, i.e. there is a need to separate the means that are being compared.
3) The comparison needs to be complete, i.e. carried out completely.

The method of comparison can be found everywhere. For example, in the discovery of the theorem of the sum of the interior angles of a triangle, after the experiment and observation are finished, we perform parallel comparison of the results that the student has previously calculated or have been calculated by other students. Almost each use of the methods of experiment and observation is accompanied by the method of comparison.
The learning of the method of comparison can be best done by using examples from science, such as the following.

**Example. Presenting the similarities and differences between humans and apes.** At first glance we can notice the similarity between the human and the ape. They do not have a tail or cheek bags. However, we can reach a valid conclusion for their shared origin by comparing the similarity of the overall internal built of the body, especially in the skeletal composition (see the Image on the right) and the muscles.

Although, there are noticeable similarities between humans and apes in their constitution and the way of acting, still there are important differences that highlight their different evolution.

To be more specific, apes do not walk erect. Their bodies are built so they can climb trees, whereas humans have bodies that are adjusted for walking erect. This is why humans have longer legs and monkeys have significantly longer arms.

The legs of the apes are built as arms, i.e. as an organ for grabbing things, and this is why they have long toes and movable thumbs, whereas humans have feet that are more flat, the heel is more prominent and the toes have very limited movability (see the Image above).

The analysis and synthesis, as scientific methods, are very important for the progress of all sciences. They are present in the instruction process in different ways: as methods for solving problems, as methods for introducing terms and study of their property, as methods for proving claims, etc.

*An analysis* denotes the deconstruction of a specific object or a phenomenon into consisting elements. The goal is to provide individual study of these elements, bearing into mind that they are parts of a whole. The analysis, as an intellectual operation, begins with the consequences and moves towards the reasons that have lead to the consequences. *A synthesis* denotes the composition of the parts or properties of the objects and phenomena into a whole. The synthesis begins with the reasons and moves towards the consequences, resulting from the reasons.

The analysis and synthesis are the most important psychological characteristics of thinking, because in the thinking process first we analyze, then we do a synthesis of the results from the analysis and finally we generalize, systemize or abstract, which are the result of the analysis and synthesis. We should bear in mind that in the intellectual processes, the analysis continuously transforms into synthesis and vice versa. Therefore, we can say that the process of cognition consists of two parts, analysis and synthesis. The analysis and synthesis as methods are mutually connected and practically they form a unified *analytical-synthetic* method.

The analysis separates the solution of a given problem into several parts, which are unified into a solution of the problem through synthesis. This is especially prominent in the
solving of constructive tasks in geometry, as well as in the solving of problem tasks. The constructive tasks in geometry are most commonly solved according to this pattern: analysis, construction, proof, and discussion. The analysis and the construction itself have crucial roles in the proof of the validity of the construction. This is also true for the discussion.

It is very important that the students learn the analytical-synthetic method. This is why the teachers need to take advantage of each occasion and use this method in the instruction process. We can say that the subjects related to science offer endless possibilities for proper learning of this method. The following example confirms this.

**Example. Creating the notions food chain, food web and food pyramid.**

**Analysis.** When studying the living organisms we come to the conclusion that they are either autotroph or heterotroph. When analyzing the way of nourishment we can see that there is cause and effect relationship between plants and some animals, as well as among the animals. For example, in the forest we have:

- leaf – caterpillar – passerine – bird of prey
- leaf – caterpillar – passerine – weasel

(see the Image). We can notice that in both cases the leaf, caterpillar and bird are present. As far as their numbers are concerned, we know that there are much more caterpillars than passerines, and that there are much more passerines than birds of prey. This fact is confirmed in the second example (see the Image).

**Synthesis.** From the analysis we came to the conclusion that nourishment in nature is carried out according to a strictly determined cause – effect relationship and that each living organism has a determined position in a given chain that is called the food chain. Some food chains are connected by shared members and these food chains form a so-called food web. Finally, the relations in terms of number of members in a habitat are presented through a food pyramid, in which we can see that at each higher level of the food chain there are significantly
less organisms: there are significantly less caterpillars than leaves, there are significantly less passerines than caterpillars and there are significantly less birds of prey than passerines.

Generalization is a result of the intellectual unification of separate general properties, which are essential for a given class of objects and phenomena. We can say that a generalization is moving from the observation of a given set of objects $A$ towards the observation of a greater set of objects $B$, which may contain the primary set of objects $A$.

For example, we do a generalization when we:

1) Move from observation of triangles towards observation of polygons.
2) Move from observation of exponents with natural exponents towards observation of exponents with integers, or later towards observation of exponents with rational exponents, which can finally be followed by real number exponents.
3) Replace a constant with a variable
4) Move from observation of linear motion towards the observation of uniform linear motion towards the observation of non-uniform linear motion, etc.

We can see that in some cases we can generalize from objects towards a complete class that encompasses these objects, and in other cases we can generalize from the given set towards the more general set. The learning of the method of generalization is very important because its use contributes for the development of the thinking qualities. In biology instruction, this method can be learned through many examples like the following:

**Example.** When learning about frogs we notice that they have the following characteristics:
- They live on land, however, they are dependent on water, especially in the period of reproduction.
- Their skin is constantly wet.
- They breathe with lungs and with the help of their skin.
- Their heart consists of one ventricle and two antechambers. The mixing of the oxidized and reduced blood takes place in the ventricle.
- Their breeding is sexual. Fertilization is done in the outside water environment, and the young ones develop through the process of metamorphosis.

We can notice that these characteristics are shared by the salamanders, and for this reason we group them in the same class of animals called *amphibians*, thus making an intellectual unification of separate general properties which are fundamental for the particular animals, i.e. we make generalization.

The process that is opposite to generalization is called specialization. In this process, we separate a property from the set of properties of the subject, phenomenon or process that is studied. We can say that specialization is moving from a given set $M$ towards its subset $N$. For example, we make a specialization when we move from analyzing polygons towards the set of regular polygons. The specialization can continue with an analysis of regular polygons with specific number of sides: regular pentagons, squares, equilateral triangles, etc.

Generally, we make a specialization when in a given set we move into one of its subsets (from the set of integers towards the set of prime numbers), and we make a replacement of a variable with a constant and introduce a limitation (triangle $\rightarrow$ isosceles triangle $\rightarrow$ equilateral triangle).

**Example.** The students are introduced with the following characteristics of the land mammals:
- Their body is covered with hair.
- They have a constant body temperature.
- They have mammary glands.
- They give birth to young ones who feed on the milk from the mother to a particular age.
The students are told that bats meet the mentioned traits, i.e. that they are mammals. However, bats have a membrane between the toes (see the Image above) that allows them to fly. This implies that bats are different than the other mammals on the grounds of an additional property, meaning that in this case we make a specialization of the set of mammals.

Systematization is an intellectual activity which organizes studied objects in a system on the grounds of a chosen principle (property). Systematization is preceded by: analysis, synthesis, generalization and comparison, whose results are used and realized by systematization. As a result of systematization we construct systems of notions, which are a part of some deductive theory. The most important part of systematization is classification, which is distribution of the objects in groups on the grounds of constant similarities and differences among them. We should mention that systematization is not equal to classification, but that classification is part of systematization. Bearing this in mind, we can say that the proper acquisition of the method of systematization by the students is especially important for their further development and that this goal can be best achieved through science and biology instruction.

Example. A classic example of systematization is the separation of the living world into five kingdoms on the grounds of their characteristics: the kingdom of bacteria, the kingdom of protozoans and algae, the kingdom of fungi, the kingdom of plants and the kingdom of animals. The specialization continues further on. The kingdom of animals is divided into: invertebrate animals and vertebrate animals. The further specialization of the vertebrate animals results in the following division: fish, amphibians, reptiles, birds and mammals.

In the cognitive process of the real world, the objects and phenomena reflect in people in two ways: as sensatory reflections and in the form of notions which represent an image of the real objects. The notions are created in the awareness of people by neglecting the inessential properties of the studied object or phenomenon and by generalization, which makes easier the study of the objects or processes that have different forms in the real world.

The intellectual operation with which we neglect the inessential properties and with which we emphasize the essential properties of a given object or phenomenon is called abstraction. Abstraction can be sensory and intellectual. Intellectual abstraction that is the result of generalization creates a new ideal object, called a notion. All notions are formed with the help of intellectual abstraction. We should stress that the intellectual separation of the essential and inessential properties is done through generalization, and because of this, the abstraction cannot be done without generalization. Accordingly, the abstraction and generalization are key intellectual operations in the creation of the notions.

The method of abstraction is very important for learning new content. For this reason the teachers need to highlight it as much as possible in particular cases.

We are going to present one example of abstraction.

Example. An oil pipeline needs to be built between two places A and B. The pipeline is a real object characterized by the following properties: length, capacity, form of pipes, inner coating, the metal quality of pipes, etc.

When starting the design, the engineer is first interested in the length of the oil pipeline and its trace, without considering the other properties of the object. Thus, the first abstract model of the oil pipeline is created: the curve from point A to point B. Then, the engineer studies the capacity, which depends on the cross section of the pipes, the form of the pipes, as well as the internal coating, which are crucial for the friction. If the engineer takes into account the trace of the oil pipeline, the second abstract model of the oil pipeline is created, which is a geometric figure. At a given moment, the engineer will take into account the metal quality of the pipes, as well as the external coating, which will provide protection of the metal.
from corrosion, meaning that there is a third abstract model of the oil pipeline, which is a geometric area.

*Specification* is an intellectual process that is opposite to abstraction. It discovers the content of the scientific abstractions by using facts or relations.

The specification can be done by *illustration, confirmation of an abstract situation or by using a property in specific conditions*.

### 3. CONCLUSION

In instruction, the previously analyzed scientific methods intertwine and therefore their separate analysis only makes sense in the process of study, but not in practice. As we have said, the learning of the scientific methods in instruction is one of the primary goals. The teachers should aim for these methods to be permanently learned by all of the students, however special attention should be paid in the work with the gifted students.

This is very important, especially if we know that:
- The future science staff will be formed by the gifted students.
- The learning of practical knowledge, skills, and abilities, which are necessary for the students, does not mean thorough learning of the scientific methods.

In the history of science there have been attempts for finding a universal scientific method, and through this to discover a universal procedure for training the young population to do scientific-research work. However, as we can see from the division of the scientific methods, that is not possible. Therefore, starting from the end of the previous century, in most of the educational systems the partial learning of the scientific methods was emphasized. Having this in mind, the teachers need to use them properly in each occasion, without underlining the scientific method, acting in an analogue manner as in the previously presented examples, which would result in greater number of students who will learn these methods.

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