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SCIENCE MISCONCEPTIONS OF PRIMARY GRADES STUDENTS – METHODS FOR OVERCOMING THEM

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Abstract. Students' achievements, the knowledge they acquire during schooling, remain among the most frequently researched topics today. The other side of the coin consists of students' misconceptions, which can contribute to a better understanding of the learning process and outcomes. This paper focuses on an overview of insights into the process of forming Science misconceptions, which are based on constructivist learning theories, the common mechanisms for creating scientifically accurate knowledge and misconceptions, the identification of typical Science misconceptions, and possible teaching strategies for overcoming them.

Science misconceptions are not necessarily bad; they enable researchers and teachers to better understand the learning process and outcomes, as well as to plan effective teaching strategies. Essentially, the way scientists overcome previous insufficient or incorrect knowledge is the same as the process through which students can overcome their own misconceptions.

One of the specific teaching strategies that has proven to be effective and aligned with the described theoretical principles is the predict-observe-explain method. Using examples related to the states of matter and the magnetic properties of materials, this paper illustrates how primary grades students can be guided through confronting their own misconceptions and overcoming them.

Keywords: misconceptions, Science, experiential knowledge, teaching strategies, conceptual changes

INTRODUCTION

The human need to understand the world around them, especially nature and its laws, dates back to the earliest stages of civilization. Long before starting school children exhibit the same intrinsic curiosity, most commonly in the form of "Why?". Asking questions and searching for answers about how the world around them functions continues throughout schooling and persists into adulthood.

This initial curiosity, or the wonder about how and why things around them "behave" in a certain way, creates a similarity between the spontaneous activities of a child and a scientist. The school should nurture this curiosity through appropriate teaching activities to form a hierarchically structured system of concepts based on scientific facts.

The curriculum of interdisciplinary subjects *Svet oko nas (World around us)* and *Priroda i drustvo (Nature and Society)*, which are mandatory in the Republic of Serbia for children aged 7–11, indicates that the teaching process should start from unsystematized knowledge based on experience. However, the goal of learning these subjects is directed toward scientifically systematized knowledge in the fields of nature, society, and culture (Educational gazette, 10/2017).

However, the knowledge that students acquire by combining existing knowledge, experiences, and beliefs is often in contradiction with scientific concepts, even when these concepts are taught in school. The aim of this paper is to provide an overview of these incorrectly learned concepts in the field of natural sciences (*Science misconceptions*) – how they arise, which misconceptions are common in early school age, and which teaching strategies can be used to correct them.

THE ORIGIN, DETECTION METHODS, AND TYPICAL SCIENCE MISCONCEPTIONS

Knowledge of natural sciences serves as a foundation of human activities in many areas of life. *Mathematical competence and competence in science, technology, and engineering* is an essential part of *Competencies for lifelong learning* and is incorporated in educational systems from early childhood in the curricula of different educational systems. Within this competence, the domain of natural sciences and technology is defined as *the ability and willingness to explain the natural world by making use of the body of knowledge and methodology employed, including observation and experimentation, in order to identify questions and to draw evidence-based conclusions... Competence in science, technology, and engineering involves an understanding of the changes caused by human activity and responsibility as an individual citizen* (The European Commission, 2019: 9). Developing this competence requires understanding how conceptual changes occur and how they fit into the cognitive structure of students.

From an early age, even before formal schooling, children encounter natural phenomena and develop a worldview related to what they will later learn in Science. This children's worldview is based on concepts developed through their own experiences. These early concepts are acquired spontaneously in direct interaction with the environment, helping children develop an understanding of how the world functions and create mental models to explain certain phenomena. Experiential concepts serve as a foundation, a resource that supports the development of scientific concepts, but this process is reciprocal—scientific concepts influence previously formed experiential concepts, integrating them into a structured system of concepts (Vygotsky, 1983).

Although experiential knowledge is essential for children's understanding of their environment and the relationships within it, its content is often in contradiction with scientific explanations and can pose an obstacle to further learning of scientific concepts. In such cases, experiential knowledge is referred to as *misconceptions* (Pine, Messer & John, 2001; Allen, 2010; Petrovic, 2006). Misconceptions appear in the literature under various names: preconceptions, preconceived notions, naive theories, everyday knowledge, initial understanding, intuitive understanding, naive/false beliefs, interpretative models, children's science, alternative frameworks (Antic, 2007; Cvjeticanin, Segedinac & Halasi, 2010; Tartas, 2015; Driver & Easley, according to Loxley et al., 2017; diSessa, 2014).

Essentially, the mechanism behind the formation of misconceptions shares commonalities with the concept formation process as interpreted by constructivist theories. Constructivists view learning as construction – the active creation of mental models when encountering new experiences, within the context of existing experiences and knowledge. This aligns with Piaget's constructivist principle that new ideas/knowledge always emerge from previous ones. A new fact will make sense only if it fits well with the already existing model of thinking. In other words, prior knowledge not only support but constrain learning in various domains (Allen, 2010; Martin, Sexton & Franklin, 2009: 47; diSessa, 2014). When multiple misconceptions build upon one another, they interconnect and form a *misconception web*, reinforcing individual *misconceptions* and creating a system of knowledge based on non-scientific concepts (Allen, 2010; Blagdanic & Bandur, 2018). If incorrect ideas make sense to a child and form a coherent system, it is difficult to predict how school teaching will influence these ideas (Osborne & Freyberg, 1996). This understanding of conceptual change contradicts the view of learning as a simple transmission of knowledge from teacher to student.

Conceptual change does not simply mean replacing old ideas with new ones or merely adding new knowledge to a child's existing cognitive system. Because of this, children often hold on to their ideas, even when they significantly differ from scientific explanations, especially when these ideas have proven "valid" in real-life situations. Due to their rich experiential base, misconceptions that are *counterintuitive*—those that conflict with what seems obvious and repeatedly confirmed to the child—are particularly resistant to change. An example of such a misconception is the belief that the Moon is a source of light. This understanding comes from the repeated experience that visibility at night improves when the sky is clear and the Moon is visible and decreases when is obscured by clouds. Since that idea is useful and meaningful for the child, they often resist replacing it with a scientific explanation that does not seem logical or acceptable to them (Loxley et al., 2017; Antic, 2007). In such cases, school-age children tend to create inconsistent knowledge structures or form hybrid theories that combine experiential ideas with scientific explanations (Radovanovic, 2017) – they may refer to scientific ideas in school settings but revert to experiential ideas in everyday situations. As a result, these naive theories remain hidden from both teachers and students (Mintzes & Wandersee, 1998) and often persist into adulthood. It is important to note that even the most successful students have misconceptions that remain unnoticed during schooling (Allen, 2010).

Research on misconceptions has been ongoing for several decades and is conducted using various methods—most commonly through knowledge/misconception tests, which assess not only what students know but also which distractors (misconceptions) most frequently attract students (Yin, Tomita & Shavelson, 2008; Ünal & Coştu, 2005; Petrovic, 2006; Radovanovic, Stepanović Ilic & Slisko, 2014). To gain a deeper insight into the nature of misconceptions, knowledge/misconception tests are often combined with interviews to explore the *roots of misconceptions* and the impact of different teaching strategies on their correction (Ünal & Coştu, 2005; Kojović Traparić & Blagdanic, 2023; Sarioglan & Gedik, 2020). In addition to gathering information directly from students, teachers can also provide insights into common student misconceptions based on their professional experience (Pine, Messer & John, 2001).

The findings of these and other studies indicate a consistent presence of Science misconceptions across different countries and age groups (Sfard & Cobb, 2014). Regarding physical phenomena, the concepts of floating and sinking have been shown to be complex, confusing at various ages, despite being closely related to students' everyday experiences (Yin, Tomita & Shavelson, 2008; Radovanović, 2017; Unal, 2008; Harrell & Subramaniam, 2014). Typical misconceptions about floating and sinking include: large/heavy objects sink, while small/light objects float; objects with a hole sink; sticky liquids affect whether an object floats; flat objects float, while sharp edges cause objects to sink (Unal, 2008; Kojović Traparić & Blagdanic, 2023; Yin, Tomita & Shavelson, 2008). There are also widespread students' and teachers' misconceptions about light, such as: the Moon is a source of light; inadequate shadow position and size in relation to the light source, etc. (Lindstrand et al., 2016; Grigorovitch, 2014; Pine, Messer & John, 2001; Miscevic, Blagdanic, & Bosnjak Stepanovic, 2021). Other common misconceptions include: living things are those that move (e.g., a wind-up toy duck that moves is considered alive); arrows in a food chain indicate who eats whom; the living being at the end of the food chain eats all living beings that precede it in the chain; water does not evaporate on cloudy days; powdered materials are in a liquid state; water vapor is not water; heavy object of the same shape fall faster than light ones; force is something applied only to people (Allen, 2010; Dabell, 2010; Griffiths & Grant, 1985; Stanisic, Blagdanic & Marusic Jablanovic, 2021; Blagdanic, Radovanovic & Bosnjak Stepanovic, 2019; Cvjeticanin, Segedinac & Halasi, 2010; Pine, Messer & John, 2001). There is a specific kind of misconception that originates from language. It manifests itself in words that sound similar, but have different meanings, so they are a frequent reason for misconceptions. Examples of such misconceptions are the meaning of the concept *material* (Material is cloth or fabric) (Pine, Messer & John, 2001) or the plasticity of materials (Plastic means that something is made of plastic).

SCIENCE MISCONCEPTIONS – METHODS FOR OVERCOMING THEM

To overcome *misconceptions* in *Science teaching*, it is important to view learning not as *replacement* of existing knowledge with new knowledge, but as an active and conscious *reconstruction* or *repair* of existing knowledge through interaction with new knowledge (Antic, 2007; Yin, Tomita & Shavelson, 2008; Sfard & Cobb, 2014).

The first approach to learning (*knowledge replacement*) is based on a "conflict" between existing and new knowledge, to abandoning incorrect knowledge in favor of the correct explanations provided by the teacher. The second approach (*knowledge repair*) views Science learning as a gradual restructuring process of students' misconceptions (Blagdanic, Radovanovic & Bosnjak Stepanovic, 2019), which can be encouraged by provoking cognitive conflict through the creation of teaching situations in which "students' current conceptions clash with empirical evidence" (Sfard & Cobb, 2014: 548). Accordingly, students' misconceptions are not inherently negative or something that should be eradicated without a trace. They are an early version of a formal concept (Sfard & Cobb, 2014) and should be recognized by teachers and used in lesson planning. Students' misconceptions should be seen as an opportunity for teachers to create instructional strategies that will lead students accept new knowledge as relevant both in the school context and in everyday situations, based on insights into students' knowledge about a particular natural phenomenon (Blagdanic, Radovanovic & Bosnjak Stepanovic, 2019).

In this process, the first step a teacher should take is identifying students' misconceptions about the phenomena to be studied. Teachers can gain this understanding in two ways. The first is by becoming informed about the typical misconceptions students (from different countries) have about certain phenomena The second way is by investigating the specific misconceptions of the students they work with, using methods similar to those used by scientists when researching Science misconceptions (knowledge tests, discussions and idea exchanges among students about a presented problem, answering teachers' questions, proposing solutions to specific problems, etc.).

Once the teacher identifies students' (mis)understanding of a particular natural phenomenon, it is necessary to create a teaching situation in which the student becomes dissatisfied with their previous understanding. This generates an authentic need for the child to change their interpretation of the phenomenon. Thus, misconceptions need to be "brought to light" by both the teacher and the student. In the next phase, the teaching should offer activities and new experiences that lead to cognitive conflict and a search for new solutions, resulting in the new meanings that are understandable and credible to the student (Posner et al., 1982). In other words, learning occurs when cognitive accommodation is supported (Nusbaum and Novick, according to Cosgrove & Osborne, 1996).

Even if an experiment provides evidence contrary to the student's beliefs, it will not necessarily lead to abandoning the misconception, as students in such situations often focus only on evidence that supports their personal theories (Antic, 2007; Pine, Messer & John, 2001). Therefore, it should not be expected that a new interpretation of a phenomenon will occur easily or quickly but rather only when the meaningfulness of the new (scientific) explanation is confirmed in various situations (both in school and in everyday situation) (Blagdanic, Radovanovic & Bosnjak Stepanovic, 2019).

Considering all the points discussed in this section, an analogy can be drawn between the way scientists acquire new knowledge and *conceptual change* of students. Namely, changes in *conceptual change* among scientists and students occur under the following conditions: (1) when they are dissatisfied with their existing knowledge, i.e., they recognize inconsistencies in their previous understanding of a phenomenon, (2) new conceptions are intelligible, (3) plausible, and (4) fruitful for future requirements (Hewson & Gertzog, according to diSessa, 2014).

The *predict-observe-explain* method represents a possible concretization of the interpretation of *conceptual change in Science*. If a teacher aims to demonstrate a scientific phenomenon through an experiment, the process consists of three steps: students predict what will happen when a certain procedure is carried out (*predict*); observe what happens, measure, and record data, if necessary (*observe*), and explain what actually happened (*explain*) (Yin, Tomita & Shavelson, *2008*). The teacher's role is to guide this process and help students move from an explanation based on observation to forming a correct conclusion. In this model, students directly test their previous beliefs and face a situation where their existing knowledge is questioned. At this point, the need for *conceptual change* arises. Confronting students with their own misconceptions through the *predict-observe-explain* method has a positive impact on overcoming Science misconceptions (Yin, Tomita & Shavelson, 2008). A study on misconceptions about floating and sinking among students aged 10–11 showed that after conducting an experiment using the *predict-observe-explain* method, students recognized inconsistencies in some of their previous beliefs and began searching for a universal explanation that would apply to all individual cases (Kojovic Traparić & Blagdanic, 2023).

SCIENCE MISCONCEPTIONS AND SERBIAN CURRICULUM FOR PRIMARY GRADES

In the first cycle of primary education in Serbia (ages 7-11), there are two school subjects where teachers may encounter students' Science misconceptions. These are the previously mentioned subjects „The World Around Us" (1st and 2nd grades) and „Nature and Society" (3rd and 4th grades). These subjects are taught twice a week throughout all four grades.

The goal of these subjects is for students to get to know themselves, their natural and social environment, and develop skills for a responsible living in it. These subjects include content from different sciences: biology, geography, physics, chemistry, history, as well as content related to human relationships, traffic, and ecology. The content of "The World Around Us" and "Nature and Society" is interdisciplinary. The interdisciplinarity of this content is a result of the interconnectedness of phenomena and processes in the nature and society (Blagdanic & Bandur, 2018).

Regardless of the science they come from, all content is developed through grades in a spiral-ascending model. This means that if we analyze any topic from the third or fourth grade, we will notice its conceptual core in the first grade. This means that topics are repeated from grade to grade, but in a way that their extent (the number of concepts) and intensity (complexity of concepts) increases (Lazarevic & Bandur, according to Blagdanic & Bandur, 2018).

The curricula for "The World Around Us" and "Nature and Society" were analyzed (Educational gazette, 10/2017, 16/2018, 5/2019, 11/2019), and themes were identified that relate to phenomena where Science misconceptions can be expected (in accordance with the results presented in the previous sections). Of course, it is possible that there are other misconceptions that the teacher will identify in their classroom.

The results are presented in Table 1.

Table 1. The distribution of possible Science misconceptions by topics and grades

Grades	Areas and topics			Sum by grades
	Materials	*Living beings*	*Movement*	
1st grade	Materials and their properties			1
2nd grade	Materials and their properties	Common characteristics of living beings – movement	Factors affecting the body movement – shape, surface and environment	3
3rd grade	States of matter Water cycle – evaporation, condensation Air as a thermal insulator	Food Chain	Gravity – Effect of body shape on fall speed Factors affecting the body movement – force Light sources (natural and artificial)	7
4th grade	Magnetic properties of materials Air – oxygen as a combustion agent			2
Sum by areas	7	2	4	13

There is an uneven distribution of potential Science misconceptions across different ages. There are more at older ages, which is expected because more abstract phenomena are taught then. The characteristics of these phenomena are often not directly perceptible but only indirectly based on their consequences (e.g., *air as a thermal insulator, magnetic properties of materials, air – oxygen as a combustion agent*). Also, some of these phenomena are counterintuitive (e.g., *gravity – effect of body shape on fall speed, light sources*), If we analyze the distribution of these „critical" topics, it is concluded that the number of potential misconceptions should be more evenly distributed between 3rd and 4th grades. This particularly applies to content on movement – some of it could be moved to the 4th grade. The distribution by topics shows that the majority of misconceptions relate to Materials and Movement, meaning they originate from Physics and Chemistry. There are significantly fewer biological misconceptions. In the analyzed curricula, there are no notes related to potential students' misconceptions.

It is evident that there are many opportunities for the teacher to plan teaching activities about the expected misconceptions. In the next chapter, we will present two examples of teaching strategies based on these results and the *predict-observe-explain* method.

TWO EXAMPLES OF CORRECTING SCIENCE MISCONCEPTIONS IN TEACHING

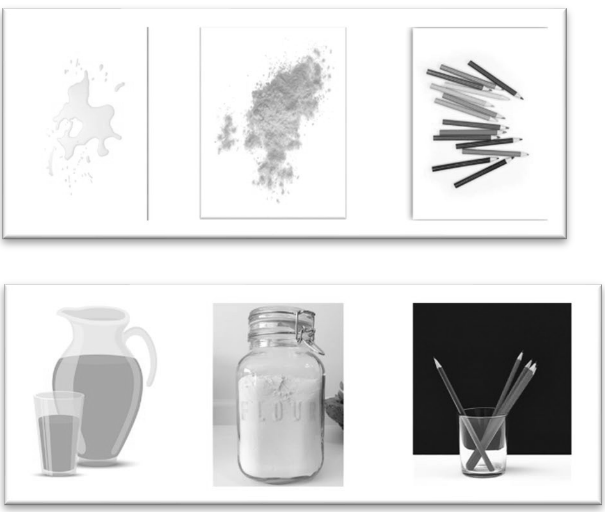
Example 1 – The Borderline Case of Powdered Materials

One of the common dilemmas about the states of materials concerns the state of powdered materials such as fine kitchen salt, flour, or washing detergent (Allen, 2011; Blagdanic, Radovanovic & Bosnjak Stepanovic, 2019). This example belongs to the *borderline cases* of a phenomenon because it can be interpreted in different ways—these materials can be poured (which is one of the essential attributes of the liquids), yet they lack rigidity and structural integrity, which are key characteristics of solid materials (Russell, Longden & McGuigan, 1991).

With this in mind, the teacher can present the following problem situation:

Ana asked me for help in solving a scientific puzzle that has been bothering her: "In the kitchen, I have a jar of salt. I was sure that salt is in a solid state, but I noticed that it does not have a fixed shape—it has taken the shape of the jar it is in. Also, it is difficult to hold in my hand. If I slightly open my fingers, it will pour out like water. Does this mean that salt is a liquid?"

The teacher can then test the properties of powdered materials with students by comparing them to water and pencils, which are clear examples of liquid and solid materials/objects. The presence (or absence) of a fixed shape is compared, as it is one of the key attributes in determining the state of matter (*Picture 1*). Based on these examples, it may seem that powdered materials are more similar to liquids.



Picture 1. Demonstrating the (non)existence of a fixed shape in materials/objects

In a similar way, students can test holding water, flour/salt, and pencils in their hands. The conclusion will likely be similar to the previous one – powdered materials appear to have properties of liquids. After this, the teacher can ask students what else they could do to be sure whether the salt in Ana's puzzle is in a solid or liquid state. If students do not have an idea, the problem situation continues:

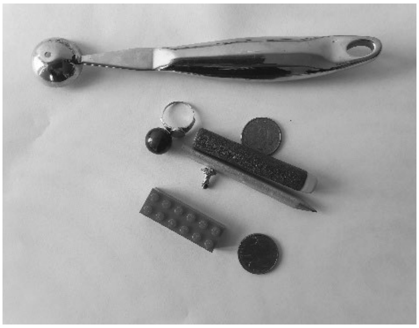
If you're unsure, my grandmother gave me some advice when I explained what was puzzling me. She told me to use a magnifying glass. This advice helped me – maybe it will help you too. Good luck!

Following this, students observe salt using a magnifying glass and notice that it consists of tiny grains–salt crystals. The teacher then assigns them a task to carefully isolate a single grain of salt and determine whether it has the characteristics of a solid or liquid material. Once students recognize all the characteristics of solid materials in the isolated grain of salt and confirm that it lacks any of the examined properties of liquids (it does not flow freely, it maintains a fixed shape, etc.), they arrive at the conclusion that powdered materials are simply finely ground solid materials. It is only due to this fine granulation that they may initially seem not to be solid.

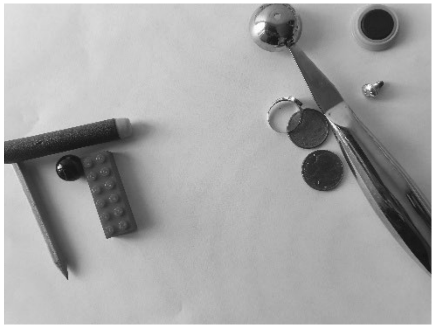
Example 2 – Predict-Observe-Explain Method and Magnetic Properties of Materials

When describing ideas that are correct in some situations, but are not rules (which are correct in all situations), and therefore are not scientifically correct, we refer to such misconceptions as *overgeneralised knowledge* (Pine, Messer & John, 2001). This is the case with the common statement made by many students (as well as adults) that *a magnet attracts metals*. In reality, a magnet attracts only three metals (iron, nickel, and cobalt), so the previously mentioned statement cannot be considered scientifically accurate or precise. This misconception is supported by students' everyday experiences in which magnets attract metal paperclips, nails, and similar objects. It is further solidified by imprecise sentences in *Science* textbooks, such as *"A magnet attracts objects made of metal."*

Accordingly, the teacher can create the following situation – Various objects made of different materials are placed in front of the students, including several metal objects, some of which are made of *non-magnetic* metals, such as silver, gold, aluminum (*Picture 2*). Students are asked to predict which objects/materials the magnet will attract and which it will not. Based on their predictions, they sort the objects into two groups (*Picture 3*).

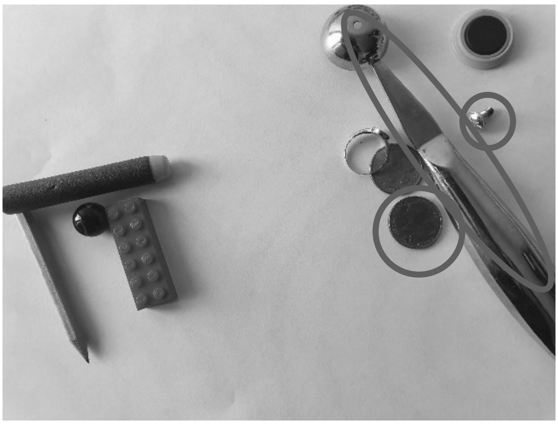


Picture 2. Presented objects



Picture 3. Grouping of objects based on prediction

After that, students receive a magnet to test the accuracy of their predictions. They observe that the magnet attracts a metal spoon, one metal coin (but not another that looks identical), and a screw (*Picture 4*).



Picture 4. Findings after testing with a magnet

The fact that two seemingly identical coins are not the same – one is attracted by the magnet while the other is not, causes particular confusion among students. In this situation, *anomaly manoeuvres* occur – creating scenarios that use students' *misconceptions* as a starting point for problem-solving, leading to an unexpected outcome. From the situation shown in *Picture 4* and the subsequent discussion, students can easily correct the statement "A magnet attracts metals" by adding a single word: "A magnet attracts *some* metals." At this point, a *restructuring manoeuvre* takes place, helping students accommodate the unexpected outcome into their conceptual system (Erikson, according to Cosgrove & Osborne, 1996).

CONCLUSION AND IMPLICATIONS

Understanding students' misconceptions and developing appropriate teaching strategies for overcoming them has been the focus of researchers for several decades. Understanding Science misconceptions supports students' scientific literacy in a way that goes beyond merely teaching scientific facts – it involves the use of teaching strategies based on the methodology of acquiring knowledge in the field of natural sciences. To achieve this goal, it is necessary to communicate research findings to teachers. Availability of research results on Science misconceptions would facilitate the identification of misconceptions in classroom.

Using an analogy with medicine, the process of overcoming Science misconceptions can be described through four essential segments necessary for their effective "treatment": understanding the mechanism (*how misconceptions arise*); detecting symptoms (*manifestations of misconceptions*); *diagnosing misconceptions*, and planning and implementing an appropriate *treatment* (*overcoming misconceptions through adequate teaching strategies)*. However, this analogy should not be taken in an oversimplified or literal manner. While we aim to overcome Science misconceptions, they should not be viewed as anomalies or obstacles in teaching that must be eradicated as quickly as possible. Students' misconceptions are a part of the learning process, as they consist of personal, intuitive knowledge that children construct. The role of the school is to help students organize this knowledge into an accurate system of scientific concepts, based on an understanding of misconceptions and how they arise (Pine et al., 2001). Thus, *students' misconceptions* should serve as a starting point for designing *teaching situations* that encourage students to confront their own *misconceptions* and recognize their limitations. When this happens, there is a greater chance that *students' misconceptions* will be modified in knowledge based on scientific facts.

In this context, it is important to examine both initial teacher education and ongoing professional development – whether knowledge about *students' misconceptions* is included in teacher training and professional development programs. Otherwise, there is a high risk that teachers will treat *misconceptions* merely as "weeds" to be eradicated because they contradict the scientific explanation of a phenomenon or the concepts prescribed in the curriculum.

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