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Change in Elementary School Students' Misconceptions on Material Systems after a Theoretical-Practical Instruction

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Abstract

Students get to Elementary School with a series of misconceptions which are not necessarily in agreement with the scientific knowledge. Misconceptions result from the student's attempts to understand their previous experiences resulting from their interaction with their environment and they must be taken into account in educational practice to design appropriate instructional strategies that will impulse their evolution into more scientific-academic concepts. This research aims to detect the initial knowledge that twenty-one fifth grade Elementary Education students (ages ranged: 10-11 years old) have about material composition. A questionnaire was used as an instrument to determine initial misconceptions. Based on the students' answers, important misconceptions were identified, and an appropriate instructional strategy was design to foster the students' conceptual change about the studied topic. A post-task questionnaire conducted after the instruction revealed the suitability of the proposed instructional design.

Keywords: Misconceptions; Experimentation in chemistry; Elementary school; Conceptual change.

Introduction

Teaching and learning chemistry could be considered as a complicated task mainly due to the high conceptual nature of the discipline, with a vast amount of interlinked and abstract concepts (Johnstone, 2000; Tümay, 2016). Consequently, quite often chemistry is a priori considered as a difficult topic to learn among students and even a hard-to-teach subject among instructors.

In the teaching-learning process, students construct their own knowledge as an iterative process, in which the new concepts or ideas need to make sense in the frame of the

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conceptions that they already possessed (Taber, 2009). However the real implementation of such constructivist approaches in Primary School is not always easy (Ari, Kizilaslan Tunçer & Demir, 2016), and as previously stated by Bedir (2015), their success has a high dependence on the teachers' skills in the use of methods and techniques based on student-centered activities. Accordingly, detecting the ideas that students already have prior to the instruction is a key stage, since it constitutes the linkage between old and new concepts. Moreover, before starting any kind of instruction, students already possess understanding about many scientific topics that form a mental framework, referred to as the scaffolding (Horton, 2007; Kleichmann et al., 2016). At this point it is a must to define misconceptions, which are individual constructions or mental representations of the world that students have adopted in order to understand the environment and to act accordingly. Misconceptions are characterized for being firmly held by the students, who are not often willing to change (Treagust & Duit, 2008; Dağdelen & Köstereliöğlu, 2015). It is important to notice that these conceptions lead to conceptual mistakes and might be an obstacle for learning scientifically correct concepts. Thus, in the building up of the learning process, students need to arrange all the new information to get it fit into the scaffolding. Sometimes these arrangements do not agree with the current scientific thought, which gives rise to misconceptions (Taber, 2001), and therefore, the new knowledge is constructed into a conceptually faulty base. Misconceptions should not be considered as a handicap for students to incorporate new knowledge, but a necessary starting point from which student will be able to build new scientific understanding from a constructivist point of view (Furió-Mas, Calatayud & Barcenas, 2007). Thus, misconceptions should be taken into account when planning and implementing instruction (Taber, 2008) and must be considered by the teacher during the educational process to ease the rebuilding of the knowledge in a significant way, which would turn into meaningful learning (Martins Teixeira & Moura Bezerra Sobral, 2010). When providing effective instructional approaches, to overcome misconceptions, students will be able to connect the former and new conception in order to later acquire a real meaning.

The resistant nature of misconceptions may discourage teaching efforts, and research on educational science has put effort in developing strategies to induce the transformation of misconceptions into scientific conceptions, or at least, to more scientifically accurate concepts. This set of strategies or instructions was named as "conceptual change" (Leach et al., 1997). The conceptual change could be defined as the modification of students' conceptions and their substitution by other, more scientifically accepted ones, which ensures the appropriate learning (Harahan, 1994). In fact, learning scientific concepts should not only consist of replacing an idea with another scientifically accepted one, but in making connections between spontaneous student theories and scientific theories. Students must get to understand the superiority of accepted theories, and to achieve that situation they should be faced with conflictive situations that cannot be solved by using their own theories.

The educator should drive students to situations that cannot be explained with their previous ideas. The perception of inconsistency among students' cognitions generates psychological discomfort and that motivates them to attempt to resolve the dissonance by incorporating scientific knowledge in a natural way (Posner et al., 1982). Therefore, the cognitive conflict, as defined by Lee & Byun (2012) is a perceptual state of the discrepancy between one's mental model and the external information recognized (internal-external conflict), or between different mental models of one's cognitive structure (internal conflict). Thus, this cognitive conflict initiates the first step in the process of the conceptual change, and therefore is imperative for achieving a conceptual change (Treagust & Duit, 2008). The new information must be understandable by the students, consistent with other theories and with their own experiences.

The concept of substance is among the most important in chemistry, since it is a key issue to recognize and identify the field of the chemistry study. The concept is not only relevant from an academic point of view, but also in a daily life context since the identification of dangerous substances must be acknowledged to avoid the interaction with them (Fernández-González, 2013). Despite the fact of its importance, the concept of substance is normally used as a synonym for material, product, object, and some others. Thus, the recognition of the diversity of matter is a fundamental goal of chemistry teaching (Martínez Losada, García Barros & Rivadulla López, 2009). For this reason, material systems are introduced firstly in Elementary Education through Science Education subjects and they are studied more in-depth in secondary education.

Misconceptions are very persistent in chemistry at all educational levels (Oliveira, Gouveia & De Cuadros, 2009; Stains & Sevian, 2014; Tümay, 2016). More precisely, specific studies regarding the alternative conceptions that students of Secondary Education level have about the nature of matter and its changes, have been extensively reported (Akgun & Aydin, 2010; Calik, Ayas & Coll, 2007; Johnson, 2005; Kingir, Geban & Gunel, 2013). In contrast, the number of studies at the Primary Education level, about this specific topic, is considerably more limited, mostly because authors have traditionally considered them as scientifically complex and with a sort of abstraction more suitable for Secondary Education Level (Rubio Cascales, 2010).

Regarding the Elementary School, Cañada et al. (2012), noticed that students at this educational level have some difficulties to distinguish between pure substances and mixtures, especially naturally occurring homogeneous mixtures, such as milk. Martín del Pozo and Galán Martín (2012) reported similar findings in a study performed with students from the 2nd, 4th and 6th grades of Elementary Education (ages ranged: 8-11 years old). In this case, for instance, the majority of the students identified granite as a substance, regardless of the fact they could clearly observe the different minerals that form the granite stone. Authors conclude that in this case, the natural origin overrides the student's observation. Furthermore, the authors also point out that students identify manufactured processed materials, such as iron or copper as mixtures. Furthermore, Durmus and Bayraktar (2010) conducted a research where different instructional methodologies were applied to foster a conceptual change in 4th grade students. This report explains how the conceptual change texts are as effective as hands on laboratory experiments, and both together are effective in overcoming misconceptions regarding the matter and matter changes.

Pine, Messer and St. John (2014) have evaluated science misconceptions of elementary school students from the teachers' point of view by interviewing 122 elementary school science teachers in England. In this research, regarding the material systems classification, a teacher reported that a child believed that rocks could not be natural because they are dead. On the other hand, this report also points out the limitation of students understanding of the material system, since many of them considered that the term 'material' was restricted to cloth and fabric, and did not consider rocks and plastic to be materials. According to Vogelezang (1987), elementary school students have important experiences with pure substances and mixtures, although they are not aware of the chemical sense of this problem. The same author also points to the perception as an important factor to classify material systems for children.

Thus, the purpose of this study is to ascertain the previous ideas of students in the 5th grade of Elementary Education on material systems and, more precisely, on the differences between pure substances and mixtures, and to investigate the effectiveness of conceptual change and laboratory instruction on these misconceptions. To achieve this goal, a three-step methodology is proposed. Firstly, a questionnaire was designed to investigate the students' initial ideas about material systems. In a second stage, these initial findings were employed to design a proper instructional strategy to in order to induce on students the overcoming misconceptions. Finally, the effectiveness of the whole process was evaluated through a post-task questionnaire.

The Study (Method)

Sample composition

This study follows a descriptive and interpretative methodology with the aim of describing, explaining and understanding mental representations that the 5th grade of Elementary School students have in relation to different material systems. The considered sample consists of 21 students of the 5th grade (ages ranged: 10-11 years old) of a Public School of Elementary Education in Badajoz (Spain).

Methodology

The experience was implemented along four weeks, in May 2014. Firstly, a pre-test was conducted aimed to find out the students' misconceptions about material systems. Two weeks later, students were given a total 90-minutes instruction divided in two sessions of 30 and 60 minutes, respectively. This instruction was designed bearing in mind the detected misconceptions, as it can be observed in Figure 1. Sessions are described in detail below, the first session was a theoretical one and the second one consisted on lab-work.

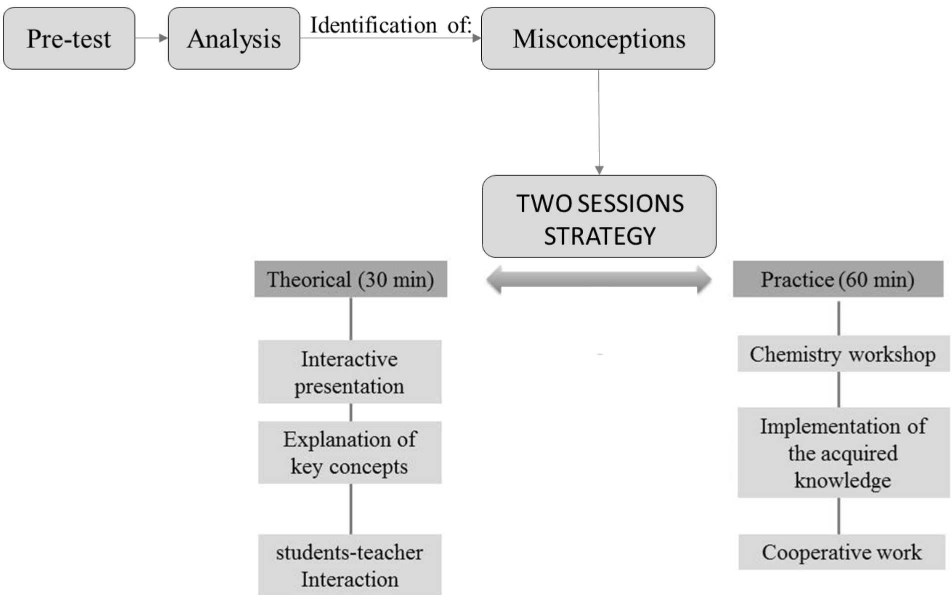

Figure 1. *Scheme of the applied instruction*

In the first session, an interactive overhead presentation was used to cover the key concepts (pure substance / mixture) and students-teacher interaction was promoted throughout. In general, along Primary Education pure substances are very scarcely studied. The study of the inert matter is mainly focused in mixtures, without mentioning that those mixtures are actually made of pure substances. In a way, this causes that students unconsciously associate pure with natural and mixture with artificial. Thus, taking these premises into account, the next items were considered in the presentation for the first session: 1) classification of the matter according to origin and composition; 2) definition of pure substance and examples; 3) definition of homogeneous / heterogeneous mixtures and examples; 4) quick test consisting on classifying like pure substance or homogeneous / heterogeneous mixtures everyday objects. The second session consisted on a 60-minutes lab workshop where students experienced with everyday material systems. The workshop was planned to foster the cooperative participation of the students. Students were arranged in groups, and each group was provided with different materials of daily use such as salt, sand, milk, olive oil, water, sugar and ethanol. Then, they were asked to classify and mix the different materials, and after that they were asked to take notes of the observations. The next list of activities was proposed, to be implemented during the practical session:

1) Classify the next elements like pure substances or mixtures: sugar, salt, steel nails, olive oil, granite stone, sand and water.
2) Prepare different mixtures with the elements of the list described above. Students were asked to prepare at least seven mixtures, explain what happened in each case and classify the resulting mixtures like homogeneous or heterogeneous.
3) Separate milk into its components. It was faced with this experiment one of the most strongly settled misconception, which is considering pure substances to all natural products. By means of this experience, students proved and saw with their eyes that milk is formed by several substances. Vinegar was added to milk, which induced protein precipitation. After protein precipitation it was easy to observe a liquid supernatant and a solid precipitate. In this way, it was easy for the students to understand that there are naturally occurring substances that are not pure substances, but mixtures.

The two sessions described so far, took place in the same week. After that, a post-test was conducted in the fourth week. Pre- and post-test results were compared in order to gauge the effectiveness of the proposed methodology.

Instruments

The instrument used in this research was a questionnaire, designed from previously published studies in relation with the same topic (Martín Del Pozo & Galán Martín, 2012). The questionnaire consisted in three closed questions, where the students were asked to select the right answer in two different situations (question 1 and 2) and order different daily-used materials according to their nature (question 3). In all cases, students were asked to properly justify their answers (Figure 2). In order to assess the students' initial ideas about matter systems and the students' performance after the instruction, they were asked to complete the questionnaire before (pre-test) and after the instruction (post-test).

1. Mixing water and oil, the result is a mixture:
[ ] Homogeneous
[ ] Heterogeneous
Why?

2. Milk is:
[ ] A pure substance
[ ] A mixture
Why?

3. Classify these products as "pure substance" or "mixture": yoghurt, salt, coke, diamond, water, copper, ice, iron, oil, granite stone, silver, and sand.
Justify your election.

Figure 2. *Pre- and post-test questionnaire used as instrument to assess students' ideas about material systems after and before the instruction.*

Data Analysis

Bar plots were used to represent the answers for closed questions. The qualitative treatment of answers to the open-ended questions was done by grouping them under different categories, according to the main idea the students expressed through those answers.

Results and Discussion

Firstly the pre-test and the two-session instruction strategy were completed and after that all the information was collected and analyzed. Results are presented and discussed in the same order as test questions answered by the students. For each question, a detailed analysis of the responses is presented, followed by a comparison between the data obtained before the instruction (pre-test) and after the instruction (post-test).

In the first question, students were asked about a mixture of water and olive oil. Specifically, they had to answer whether the mixture was homogeneous or heterogeneous and they had also to provide a short explanation justifying the selected option. According to the answers provided to the closed question homogeneous/heterogeneous, 71% of the students selected the wrong option “homogeneous mixture” in the pre-test (Figure 3), in other words, prior to the instruction most of students did not know how to classify properly the mixture of water and olive oil.

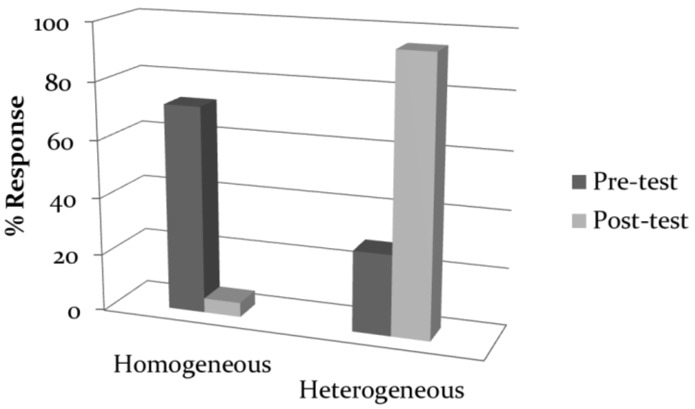

Figure 3. *Bars diagram representing the answers of the students to the closed question homogeneous/heterogeneous for an olive oil / water sample.*

The reasons provided by the students to support their selection of homogeneous or heterogeneous were analyzed. The evolution of these reasons is schematically represented in Figure 4. Regarding those selecting “homogeneous mixture”, 25% of them gave a right definition: “a mixture of olive oil and water is a mixture where the components are distinguished”. This was the most frequent answer between those selecting homogeneous, followed by “components have different density” in 10% of the cases, “components are undistinguished” in 5% of the cases. Therefore, 25% of the students selecting homogeneous in the pre-test knew that substances remain separate in the mixture, but they were not able to match it with correct criterion homogeneous/heterogeneous, this lead us to think that the origin of this misconception could be related even with the linguistic competence. In this pre-test, only 25% of the students selected heterogeneous, and only 5% of those justified properly their selection with answers like of “the components of the mixture are distinguished”. Only 4% of the students did not provide any answer for this question.

After the didactic instruction, 95% of the students classified the mixture as heterogeneous (Figure 3), which, to some extent, supports the success of the applied strategy. In this case, regarding the explanations provided to justify the selection of heterogeneous in the post-test, 40% of students used phrases related to "mixture where the components are distinguished".

However, it is worthy to mention that an important percentage of the students that selected heterogeneous in the post-test, namely 28%, justified their selection based on the different densities of the mixture components. Some of the answers provided by the students in this case were "the mixture is heterogeneous because of the higher density/viscosity of the oil" (Figure 4). Indeed, the densities of water and olive oil are different but it is not the reason of the formation of a heterogeneous mixture, thus, the answer was considered wrong, since it proved the students' lack of knowledge about miscibility and immiscibility. Esprivalo Harrell and Subramaniam (2014) have recently found similar misconceptions in a study with elementary pre-service teachers. In this case, according to the authors, a number of participants equated density with buoyancy predicting that heavier objects will sink while lighter objects will float. Finally in the post-test, only 5% of the students selected homogeneous, and 5 % of those, justified their selection as "components are distinguished" which supports again, a possible linguistic origin for the misconception. According to our findings, the didactic instruction had a positive effect, and the misconception evolved toward the scientifically correct concept. In fact, different authors have reported that misconceptions describe a rapid evolution in fundamental ideas about chemistry between the ages of 6 and 12, but only very slow change thereafter, in spite of intensive instruction in chemistry (Ngai, Sevian & Talanquer, 2014).

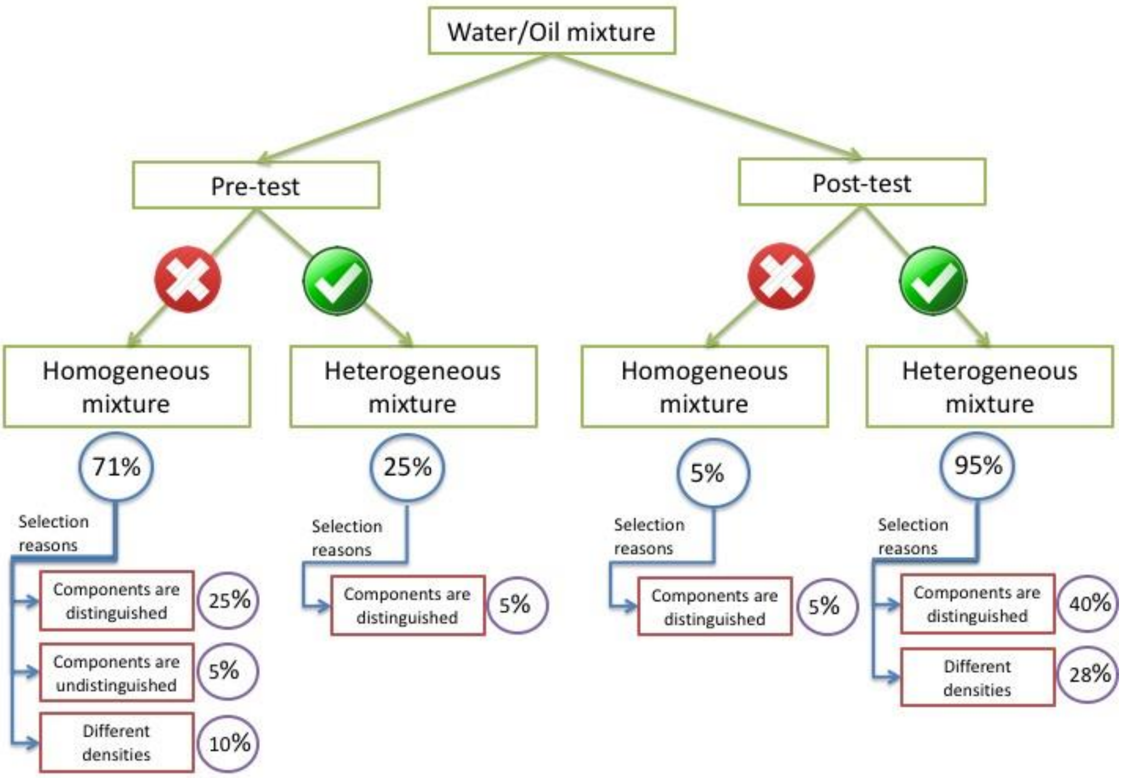

Figure 4. *Reasons provided by students to justify their classification of the mixture oil/water as homogeneous or heterogeneous in pre-test and post-test*

In the second question, students were asked to select whether milk is a pure substance or a homogeneous mixture. Before instruction (pre-test) 86% of the students selected wrongly that milk is pure substance. Figure 5 shows the percentages of selected choices in the pre and post-test and the evolution of the reasons provided by students to justify their selection, before and after the instruction.

Within the reasons they provided supporting this selection, 43% of students identified milk as a pure substance, because of its natural origin, with answers kind of: “because milk comes from cow” or “because a mixture is to mix something and the milk is natural”. These answers show that for students the terms “natural” and “pure” have the same meaning. The origin of this mistake could be influenced by the fact that milk is normally advertised on TV as “pure milk from cow” contributing to people misunderstanding of both concepts. On the other hand, their visual experience leads the milk to be classified as a pure substance because they cannot distinguish its components, they can only see a white liquid. The second most common reason supporting the selection of pure substance in the pretest was that milk is formed by a single component, and this was the explanation provided by 14% of students selecting “pure substance” in the pretest. Only 14% of the students identified milk like a mixture in the pre-test but in this case they were no able to provide a solid justification for their selection.

These results are similar to the obtained by Martínez Losada, García Barros and Rivadulla López (2009). Both studies highlight the difficulty for students to differentiate a pure substance from a homogeneous mixture. After instruction, 65% of students classified properly the product (Figure 5). However, the most important advance was found in the justifications provided by students as support of their selection of “mixture”, because 65% of them correctly argued “milk is a mixture because is formed by several components”.

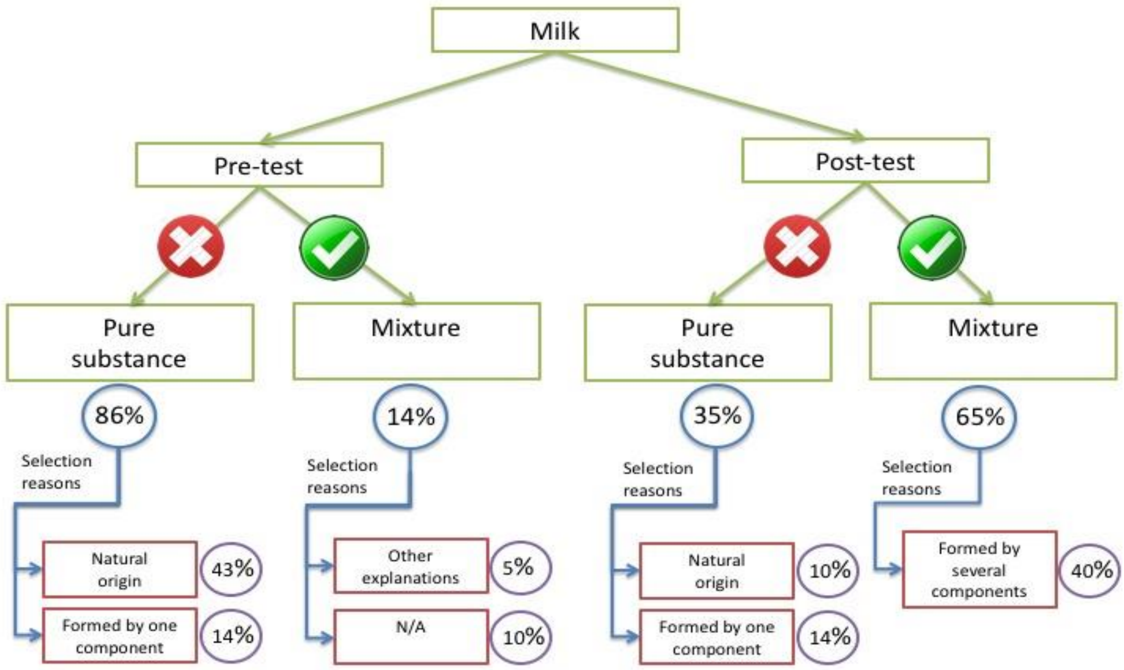

Figure 5. *Reasons provided by students to justify their classification of milk as pure substance or mixture in pre-test and post-test.*

Thirdly, students were asked to classify twelve products as pure substances or mixtures. The products were strategically selected and they were yoghurt, salt, coke, diamond, water, copper, ice, iron, olive oil, granite stone, silver, and sand. Results of the classification are summarized as bar diagrams in Figure 6, where it is shown the percentage of election for each product before and after the didactic instruction. Regarding pure substances, the obtained results showed that students had problems prior to instruction to classify iron, copper and silver as pure substances, probably because those materials are normally found industrially manufactured. When students were asked to justify their classification it was found that the origin of the products, i.e. natural or manufactured, remained versus composition. Students used justifications such as "They are processed substances" or "It is artificial" to justify the election of iron, copper and silver as mixtures. Namely, 19% of students based their selection of pure substances before instruction on "natural origin", 19% based it on answers like "no manufactured", 48% were not able to give a reason for their selection of pure substances, and 10% of students gave other sorts of reasons. Salt was also wrongly classified like mixture by more than 50% of the students in the pre-test (Figure 6). After instruction, percentages of the right choice for pure substances increased in almost all cases, except for water and ice that suffered a weak regression. An explanation could be found that during instruction students worked with mineral water and tap water as homogeneous mixtures.

Regarding the justifications that students gave to their selection of pure substances, the percentage of students using a correct reason, such as "it is formed by one component", increased from 5% in the pre-test to 76% in the post-test, nevertheless, even after instruction 10% of students continued justifying their selections like pure substances based on the natural origin, although the percentage of students basing their selection on this reason drops from 19% in the pre-test to 10% in the post-test. In the case of mixtures, before instruction students had difficult in classifying olive oil, granite stone and sand as mixtures. The analysis of the reasons gave by the students to support their selection showed that again, the natural origin prevailed over visual assessment, especially in the cases of granite stone and sand in which different components of the mixture can be visually observed. Namely, in the pre-test, 38% of students based their selection of mixtures on reasons like "manufactured", only 10% based it on the right reason "it is formed by several components" and 43% were not able to give a reason to support their selection of mixtures.

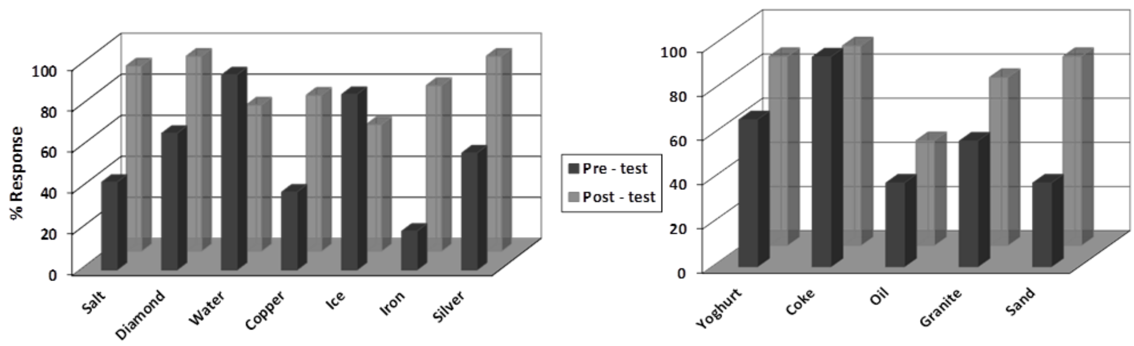

Figure 6. *Bars diagram representing the answers of the students to the classification pure substance (left)/mixture (right).*

After instruction the percentage of students classifying properly mixtures increased considerably in all cases, except for olive oil, in which case the percentage of students classifying it like mixture after instruction increased very weakly with regard to the pre-test. Finally, it is worthy to mention that after instruction, the percentage of students basing their selection of mixtures on the right reason “it is formed by several components” increased up to 85%, and only 10% of students continued stuck in the reason “manufactured”. This, in a way, demonstrates the success of the developed two-session instruction strategy.

Similar findings and misconceptions have been previously reported by Martín del Pozo and Galán Martín (2012) and by Furió-Mas, Calatayud and Barcenas (2007). Ben-Zvi, Eylon and Silberstein (1986) tried to explain the origin of the misconceptions in this topic taking into account that students think of a compound as a random mixture of atoms because they do not have a right microscopic representation of the substance structure concept.

Conclusions

The presence of misconceptions in students of fifth grade Elementary Education has been studied. According to the results shown in this research, students did not differentiate between a pure substance and a mixture, especially if the mixture is a natural product like milk. Hence, students had a restricted concept of mixtures that was focused on what they perceive and it excludes products that are naturally mixed, including heterogeneous samples like granite stone or sand. In addition students had difficulties with respect to the distinction between homogeneous and heterogeneous mixtures. Therefore, from this study we conclude that the concepts of pure substance and mixture are difficult to assimilate by the students.

Overcoming misconceptions is possible if a proper instruction is used in class. According to the results shown in this manuscript, a two-session instruction strategy, consisting of an interactive overhead presentation followed by a lab workshop session has been proved to be effective. The teacher guidance during the instruction fostered the students to confront their initial knowledge with the scientific one. As a result, students realize that different or additional conceptions were needed to explain and classify the composition of matter. Finally, instruction efforts must be provided to promote the change of students' misconceptions into more accurate scientific conceptions. This change must be addressed in Elementary Education because these ideas persist and are shaped as mental structures that impede the scientific learning.

This is an initial study into the use of practical activities in elementary school science class, and the results encourage future studies with larger sample size and different science topics.

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