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Analysis of Common Misconceptions of Students in 6th Grade Natural Sciences Simce Test

Análisis de errores frecuentes de los estudiantes en las pruebas Simce de Ciencias Naturales de 6º básico

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Abstract

It is common that students beginning their preparation in courses of Sciences bring their own ideas of how the world works, although those ideas or preconceptions differ from scientific concepts accepted as correct. In Chile, the Ministry of Education, through the didactic guides, has referred to the areas of science in the national curriculum, in which students present conceptual errors, which is consistent with international evidence. The learning objectives of the national curriculum are evaluated by the Simce test, and it is to use a set of elements destined to the construction of this evaluation that it has been verified that 6th grade students have a difficulty in responding to some content, evidencing in their answers, common conceptual errors in all curricular axes. The results obtained in the present study confirm the common errors reported and gives the possibility of using the evaluation not only as a measurement of student achievement, but also as a source from which information can be extracted, supporting the formation of teachers and students.

Keywords: misconception, preconception, natural sciences test

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Resumen

Es común que los estudiantes inicien su preparación en cursos de Ciencias Naturales teniendo ya sus propias ideas de cómo funciona el mundo, aunque muchas veces esas ideas o preconceptos se contrapongan a los conceptos científicos aceptados como correctos. En Chile, el Ministerio de Educación, a través de las guías didácticas, se ha referido a las áreas de las ciencias que son abordadas en el currículum nacional, en las cuales los estudiantes presentan errores conceptuales, lo que concuerda con la evidencia a nivel internacional. Los Objetivos de Aprendizaje del currículum nacional son evaluados por la prueba Simce, y es utilizando un *pool* de ítems destinado a la construcción de esta evaluación que se ha constatado que los estudiantes de 6° básico presentan dificultad para responder algunos contenidos, evidenciándose en sus respuestas, errores conceptuales comunes en todos los ejes curriculares. Los resultados obtenidos en el presente estudio confirman los errores frecuentes reportados y abren la posibilidad de utilizar la evaluación como una práctica no sólo de medición, sino también como una alternativa de la que se pueda extraer información que apoye la formación de estudiantes y docentes.

Palabras clave: error conceptual, preconcepción, Simce Ciencias Naturales

Scientific concepts are those ideas that enable us to appreciate the patterns and relationships between the way things are made and the way they behave (Bradley, 1996); in other words, scientific concepts help us understand the world around us (Eggen & Kauchak, 2004). When talking about the way in which children and young people perceive scientific concepts in the school context, we refer to how students understand the world, including their own everyday experience and skills (Johnston & Gray, 1999; Martin, Sexton, & Gerlovich, 2002).

When students begin a new learning unit in Natural Sciences, they already have their own scientific ideas based on their experiences, which may be partially formed or scientifically inaccurate (Johnston & Gray, 1999; Treagust, 1988), being an important part of the origin of conceptual errors in sciences (Campanario & Otero, 2000). Therefore, these errors (as we shall call them for the sake of simplicity) can be grouped into various categories according to the way in which they originate, such as, for example, in preconceptions, which constitute concepts rooted in experience; beliefs, which correspond to views obtained from non-scientific sources, like religion; domestic, regarding the use of words and terms that have different meanings in everyday life and in scientific language; interpretative, which arise when the student changes their previous idea to a new incorrect idea, using genuine scientific information that has been provided to them, among others (Hanuscin, 2007).

In the field of the sciences, the appropriation of misconceptions by students has been observed at all levels of education, from nursery school to higher education (Brumby, 1984; Cofré, Vergara, Santibáñez, & Jiménez, 2013; Eaton, Anderson, & Smith, 1984; Kind, 2004; Mahmud & Gutiérrez, 2010; Pathare & Pradhan, 2010; Rodríguez, Mena, & Rubio, 2010; Sadler & Sonnert, 2016; Thompson & Logue, 2006; Wescott & Cunningham, 2005). The literature shows, particularly in basic education, that there are errors of content related to heat and temperature (Gonen & Kocakaya, 2010; TessIndia, 2009; Weiss, 2000), the characteristics of cells (Vijapurkar, Kawalkar, & Nambiar, 2013), systems of organs (Allen, 2010; Dry, 1998; Ozgur & Pelitoglu, 2008), transfer and transformation of energy (Herrmann-Abell & DeBoer, 2011), energy and photosynthesis (Panagiota & Galanopoulou, 2006), trophic chains and webs (Allen, 2010; Stamp & Armstrong, 2005), and changes of state of matter (Fries-Gaither, 2008; Kind, 2004), among others.

In Chile, the national curriculum (Bases Curriculares) for the fifth and sixth grades of primary school is organized on an axis of skills, promoting the development of various abilities and procedures in scientific work, which must be articulated with the conceptual nuclei of three areas of content: Life Sciences, Physical

and Chemical Sciences, and Earth and Universe Sciences. In the document "Guía Didáctica" (Teaching Guide) (MINEDUC, 2013), the Ministry of Education reports frequent errors or preconceptions of students at these educational levels, including the following:

In the Life Sciences Area

Confusion about concepts of molecules and cells; incomprehension of the levels of organization of cells in tissues and organs; the functioning of the organs is isolated and decontextualized, as well as the functioning of the systems; digestion starts and ends in the stomach; trophic webs organize living beings in a fixed way, which are considered to be closed and permanent systems, with the connections between them representing who eats whom (and not "where" the matter and energy are transferred); regarding the flow of matter and energy they assume that all types of food obtained by a consumer contribute equal nutrients and energy; they assume that trophic relationships are unalterable over time and function independently of human activity.

In the Physical and Chemical Sciences Area

Students think that energy is present in living beings, but not in inert objects; energy is a synonym for 'electrical energy'; force and energy are synonyms; they assume that only warm objects transfer heat or that inanimate objects do not transfer heat; they think that temperature is a phenomenon that is manifested by measuring it; they confuse the concepts of heat and temperature; they think that the temperature of an object only changes when it was previously cold; they do not understand that particles, in the various states of matter, are organized in different ways; evaporation and boiling are synonyms; changes in state are a property of "the water" or that states of matter of other substances are similar to water; matter is found in three states and must always go from solid to liquid to gaseous; the only substance that changes state is water; they do not relate the change of state to interactions between the particles of the substance that becomes warmer or cooler.

In the Earth and Universe Sciences Area

They believe that glaciers are formed by salt water; they think that water resources are unlimited.

The Simce test for sixth grade assesses the Learning Objectives of the content areas and skills proposed in the national curriculum for the fifth and sixth grades of primary school (Agencia de Calidad de la Educación, 2014). This test is built using items that have been tested previously in an experimental test, with the purpose of assuring its validity and reliability (Agencia de Calidad de la Educación, 2014). The main purpose of this study is to identify common errors of sixth-grade primary students based on the analysis of items from the experimental tests of sixth grade students applied in recent years.

Methodology

Sample

The 2013 and 2015 experimental tests for Natural Sciences were applied to a group of establishments selected based on stratified sampling, with the explicit strata being financing, Simce performance, and the rural context. The 2013 experimental test was applied in the Metropolitana, Coquimbo, and Bío Bío regions, while the 2015 experimental test was implemented in the Metropolitana, Valparaíso, and Bío Bío regions. In both cases, a total of approximately 16,000 students were selected.

Tests

The sixth-grade census-based Simce test measures the skills and Learning Objectives of the present curriculum. It consists of closed multiple choice questions with three and four options, and open or response questions constructed by the student. The curriculum establishes four thematic areas that are assessed in the test: Life Sciences, Physical and Chemical Sciences, Earth and Universe Sciences, and Scientific Inquiry Skill.

The experimental tests analyzed are equivalent to the census-based tests in terms of content and skills, but are used solely for the purpose of testing questions that will be used in subsequent census processes, so as to include psychometrically validated items in these tests, ensuring the comparability, validity, and reliability of the instruments.

Analysis and selection of items

Among the items available in the experimental tests of Natural Sciences for sixth grade, applied in 2013 and 2015, it was decided to use the classic parameter of difficulty as the first filter (*p*-value), which indicates the percentage of the sample who correctly answered the item, considering correct choices below 0.5 as a cut-off point, that is, less than 50% of the students responded correctly. As a second filter, it was heuristically defined that difficult questions are likely to reflect a conceptual error when there is a distractor that is chosen more often than the correct answer or when a distractor is selected by more than a third of the students for questions with four choices. The questions selected by applying these filters are submitted to expert judgment.

Results

Multiple selection items from the sixth-grade tests applied in 2013 and 2015 were analyzed. Of the total items included in these tests, 52% of them showed a p-value of less than 0.5, that is, less than half of the students answered correctly and, therefore, they would be considered for the analysis according to the difficulty criterion proposed and submitted for the search for distractors chosen more often than the correct answer or distractors chosen by more than a third of the students. It is noteworthy that, of the total number of items included in the tests, 33% of them have a p-value lower than 0.4, that is, in these items, less than 40% of the students respond correctly.

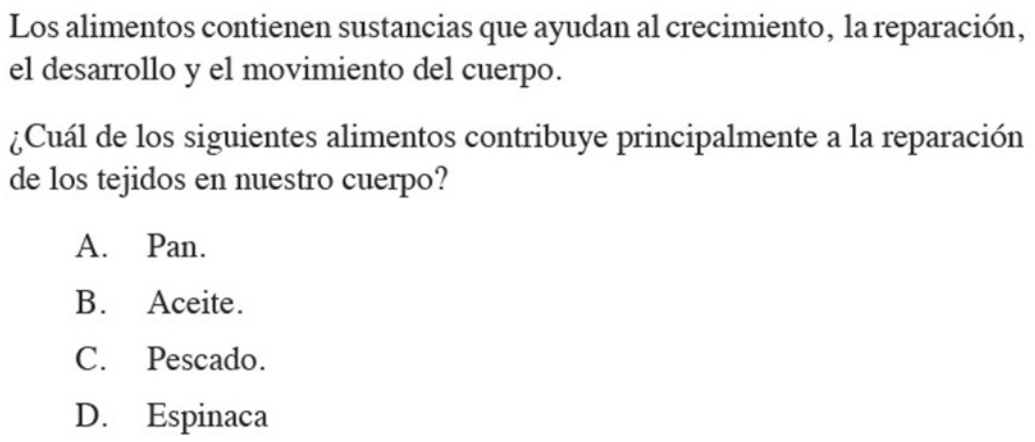
Of the total questions included in the 2013 and 2015 experimental tests, the distribution by area and cognitive domain assessed is as shown below:

- Thematic area Life Sciences: 42%
- Thematic area Physical and Chemical Sciences: 37%
- Thematic area Earth and Universe Sciences: 21%

- Cognitive domain Knowledge: 50%
- Cognitive domain Application: 27%
- Cognitive domain Reasoning: 23%

Within the area of Life Sciences, 56% of the items are difficult, while in the Physical and Chemical Sciences that figure is 50%, and for the Earth and Universe Sciences area it is 49%.

In the Life Sciences area, 17% of the items considered difficult are in the conceptual nucleus corresponding to the organization of cells in tissues, organs, and systems. Difficulty is also observed in items associated with systems of the body, with the digestive system standing out with 17% of the total difficult questions in the area. Some 11% of the difficult questions in this area are related to items associated with consumption of food and its benefits, which demonstrates the difficulty of students in relating the consumption of food to processes such as tissue repair or growth. Figure 1 shows an experimental item in 2015 referring to this content.


Los alimentos contienen sustancias que ayudan al crecimiento, la reparación, el desarrollo y el movimiento del cuerpo.

¿Cuál de los siguientes alimentos contribuye principalmente a la reparación de los tejidos en nuestro cuerpo?

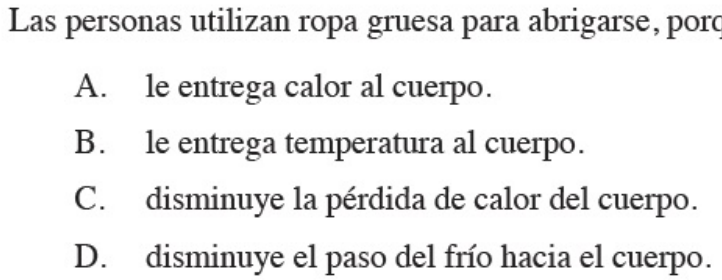
A. Pan.
B. Aceite.
C. Pescado.
D. Espinaca

Figura 1. Ítem de Ciencias de la Vida referido a beneficios del consumo de alimentos.

Answer C is chosen by 37.14% of the students, but the distractor D is selected by 36.05%, which is a similar level to that of the correct answer.

Another important conceptual nucleus in which a large number of difficult questions were found in the area (27%) relates to the transfer of matter and energy between organisms.

In the area of Physical and Chemical Sciences, we find two important conceptual nuclei. The first includes content related to the transfer of heat and the difference between heat and temperature, where 30% of the difficult questions in this area are in this content. In the question shown in Figure 2, we can see a frequent mistake committed by the students.


Las personas utilizan ropa gruesa para abrigarse, porque la ropa:

A. le entrega calor al cuerpo.
B. le entrega temperatura al cuerpo.
C. disminuye la pérdida de calor del cuerpo.
D. disminuye el paso del frío hacia el cuerpo.

Figura 2. Ítem de Ciencias Físicas y Químicas referido transferencia de calor.

When looking at the students' answers, we see that 33.26% think that warm clothing generates and transfers heat to the body, rather than isolating heat (choice A). On the other hand, 30.18% believe that option B is correct and only 16.56% correctly answer that it is due to the decrease in the body's heat loss.

The second important conceptual nucleus in this area relates to changes in the state of matter and the characteristics of the particles of which it consists. In this case, 33% of the difficult items in the area are questions relating to this content. For example, we can see confusion when recognizing the changes of state in the question in Figure 3: Some 36.04% of the students think that the change from liquid to solid is fusion, opting for the distractor A.

¿En cuál de las siguientes situaciones se puede observar el proceso de fusión?

A. Al poner agua en el congelador para hacer hielo.

B. Al derretir chocolate para cubrir un queque.

C. Al disolver azúcar en el té caliente.

D. Al hervir agua para cocer fideos.

Figura 3. Ítem de Ciencias Físicas y Químicas referido a cambios de estado

Another noteworthy confusion is that the students tend to explain microscopic phenomena, such as the behavior of molecules or particles, in function of the physical characteristics, which is reflected, for example, in the response to the question shown in Figure 4. Another recurring response considers cells as constituting matter, rather than molecules.

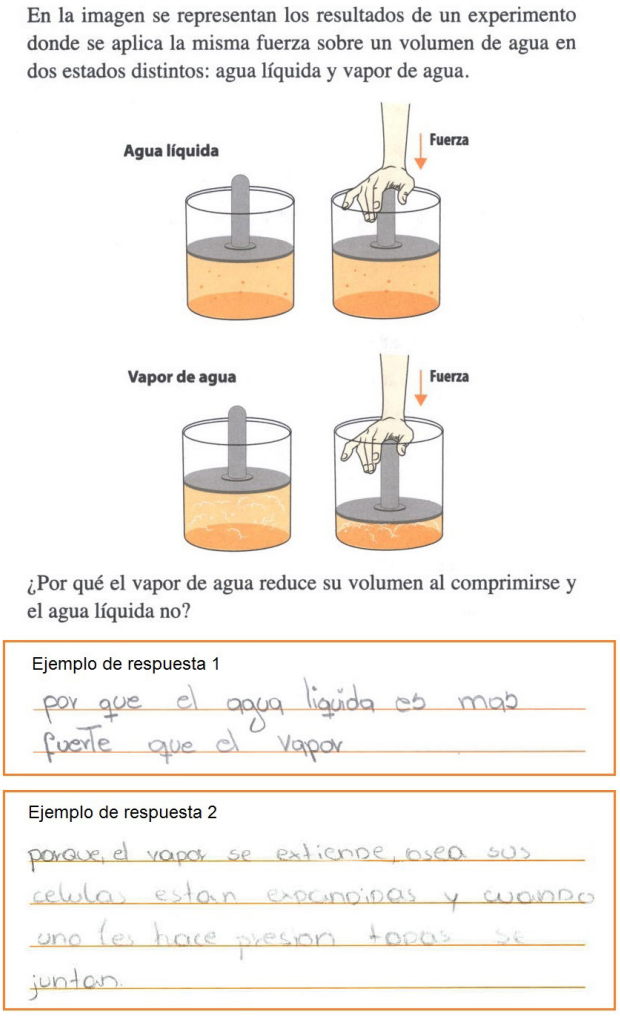
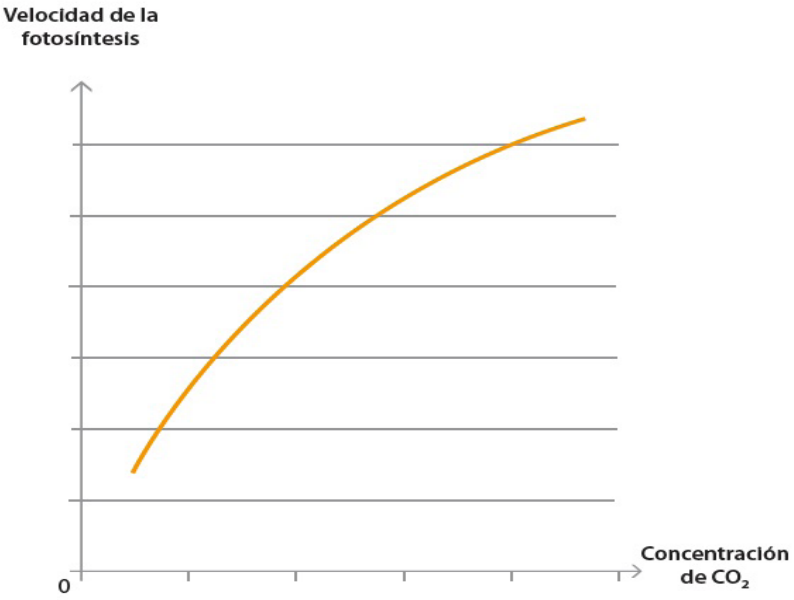


Figura 4. Pregunta abierta de Ciencias Físicas y Químicas.

As regards the area of Earth and Universe Sciences, a conceptual nucleus that accounts for 29% of the difficult questions is that of the distribution of water and the effects of human activity on that resource.

It is interesting that, transversally in all of the areas, we find questions referring to scientific research skills that are difficult for students, particularly those that call for the formulation of a question that can be answered experimentally and those that ask for the explanation of phenomena using experimental evidence, as shown in Figure 5.

Matías cultiva sus verduras dentro de una caja grande de plástico. Para que su cultivo sea más productivo, Matías aumentó la concentración de CO_2 dentro de la caja cada vez más, obteniendo como resultado los datos que se muestran en el siguiente gráfico.



¿Qué efecto tiene el aumento de la concentración de CO_2 en las verduras que cultiva Matías?

A. Aumenta la producción de azúcar en la fotosíntesis.
B. Mantiene la actividad fotosintética estable en el tiempo.
C. Disminuye la producción de oxígeno liberado al medio ambiente.

Figura 5. Ítem de habilidad de investigación. Explicar a partir de una investigación.

This question is related to the concept of photosynthesis; however, the answer is not mediated by the level of appropriation of this concept, but by the ability to interpret information. In fact, despite the fact that the correct answer is A, 42.1% of the students who answered believe that distractor B is correct.

The summary of the conceptual nuclei where errors are observed, by disciplinary area, is presented in Annex 1.

Discussion and Conclusion

The construction of national assessments such as the Simce tests is a complex task, because it requires having a pool of calibrated items for the student population assessed. This is particularly difficult in cases in which curricular expectations differ significantly from the learning achievements of the students, as in the case of the Natural Sciences subject.

However, this difficulty in the design of the instruments opens up the possibility of analyzing items that present greater difficulty to the students, as well as those that should be discarded as a result of their unexpected statistical behavior; generally items of high difficulty and very attractive distractors for most students. All of this is done to identify patterns and frequent mistakes in the answers of sixth-grade students. Specifically, the results of this study have demonstrated errors in the different curricular areas evaluated.

Within the area of Life Sciences, learning is aimed at the appropriation of basic concepts related to the cell, levels of organization of living beings; balanced eating; integrated functioning of the different systems of the human organism; and the flow of energy and matter. We have specifically observed errors in all these conceptual nuclei, since, for example, there is no understanding of how cells form functional units, such as tissues and organs. Students also show serious difficulties in describing how energy flows between organisms, how it is distributed in a trophic web, and they also have difficulties in analyzing the role of organisms in a web. On the other hand, it has been common to see foods rich in vitamins, such as fruits and vegetables, chosen as responses to questions related to the participation of nutrients in tissue repair.

In the area of Physical and Chemical Sciences, the curriculum emphasizes transformations and sources of energy, the notion of heat and its relationship with temperature, and the states of matter and the changes between them. In this area we also find errors associated with these conceptual nuclei. Consequently, students show serious difficulties in distinguishing between heat and temperature, as well as in describing heat as an energy flow or transfer. In this regard, students tend to assign the characteristics of temperature to heat, and they are also familiar with talking about a non-existent "cold flow" and ignoring the effect of a heat insulator, as can be observed in the example shown in Figure 2. It is also common for students to be unable to describe the processes of change of state, as demonstrated in Figure 3, and to have difficulties in describing the behavior of matter using the corpuscular model, as shown in the example of the open question in Figure 4.

In the area of Earth Sciences and the Universe, learning is covered related to the distribution of water on planet Earth, care of water reserves, and the effects of human activity on ecosystems. Specifically, we have identified that mistakes occur in these topics, as there are difficulties in identifying the main water sources and their distribution and, more worryingly, there is no clear recognition of activities that contribute to protect these sources and the consequences of activities such as dumping sewage in a river, for example. Many of the errors noted in this analysis are consistent with the current literature that records errors in students of this age (Allen, 2010; Dry, 1998; Fries-Gaither, 2008; Gonen & Kocakaya, 2010; Herrmann-Abell & DeBoer, 2011; Kind, 2004; Ozgur & Pelitoglu, 2008; Panagiota & Galanopoulou, 2006; Stamp & Armstrong, 2005; TessIndia, 2009; Vijapurkar, Kawalkar, & Nambiar, 2013; Weiss, 2000). Similarly, the teaching guides of the Ministry of Education indicate the conceptual nuclei found in our analysis as errors of preconceptions of students. The content for which no references were found in the literature is the function, importance, and participation of nutrients in tissue repair, showing that students assume in their responses that foods rich in vitamins, such as fruits and vegetables, are the main actors in the functions of growth, repair, and development, and do not understand that each nutrient has a major function, although physiologically several nutrients can participate in the same activity (Sesso & Rimm, 2013).

Conceptual errors affect the way in which students understand the ideas of science, since experience

and common sense can cause mistakes and misconceptions that prevent students from learning successfully (Eaton, Anderson, & Smith, 1984). Through this analysis is not possible to determine where these preconceptions or misconceptions come from, although we noted that a major source of errors is the student experience itself, but it is not exclusively responsible, since family members, when asked about matters that involve science, commonly give incorrect explanations instead of admitting ignorance (Thompson & Logue, 2006). Other sources of these errors are materials found in the media, such as television, internet, and advertising, which may be considered to be reliable by students, and they can also include teachers, textbooks, and other school materials, and the interference of everyday language with science and culture (Pozo, 1996).

As regards teachers, it is known that in Chile teachers feel less secure than the international average, particularly in content related to Chemistry, Physics, and Earth Sciences (OECD, 2006). As Vergara (2006) stated in a study on Biology teachers, they attached great importance to memory, rather than understanding concepts, conducting classes where students were not the protagonists, and they considered practical experiences not to be very effective. The low importance they ascribe to laboratory work has also been reported in basic education at the fifth- and sixth-grade levels (Cofré, Galaz, García, Honores, Moreno, Andrade, & Vergara, 2009).

It is because of this that it is important to consider what is stated in the literature of Natural Sciences as "teaching by conceptual change", which refers to considering the prior knowledge (and experiences) of the students (previously stated by Piaget, 1971 and Ausubel, 1978), in order to identify preconceptions and thus guide planning of more appropriate activities for the understanding of the concepts and, above all, to encourage the student to modify that knowledge structure (Mahmud & Gutiérrez, 2010). It is at this point that the teacher plays a relevant role, since it has been pointed out that a teacher who is able to identify a frequent error in a multiple-choice test has better results in the classroom than a teacher who does not (Sadler, Sonnert, Coyle, Cook-Smith, & Miller, 2013).

Nevertheless, it has been stated that the main difficulty in acquiring scientific concepts does not lie solely in the existence of students' preconceptions, but also in the methodology used in the teaching that is at its origin (Calatayud & Gil Pérez, 1993; Mahmud & Gutiérrez, 2010), with intervention necessary by introducing a more creative way of thinking that forces us to imagine new possibilities, posing problems, issuing hypotheses, designing experiments, and carefully analyzing the results, seeing how the initial preconception is put to the test.

It has been stated that the purpose of teaching science at school is to get students to adopt knowledge, skills, and attitudes that allow them to understand how the sciences have an effect on their lives and on the environment (Nwagbo, 2006; OECD, 2000; Vázquez & Manassero, 2002; Vilches, Solbes, & Gil, 2004). Therefore, science education is a necessity in a globalized world and it is imperative that students achieve an understanding of the natural and technological world in order to decide about their well-being and that of society in an informed manner (López, 2006). This objective is achieved by incorporating knowledge from different subjects (Biology, Physics, and Chemistry), promoting natural curiosity, relating practical experiences that allow scientific ideas to be understood, and using the knowledge and ideas of science, applying scientific skills. In other words, the student will understand the world with the support of the teacher, discussing content, ideas, and concepts, and being helped by their own experience. Chile's results in international assessments such as PISA, focused on scientific competence, show that 32% of the students evaluated do not reach level 2, which implies a mastery of basic scientific content, literal interpretation of information, and the ability to draw simple conclusions or in familiar contexts (OCDE, 2009).

Given these antecedents, studying the errors that students commonly make can be a good mechanism of intervention and, the earlier they are detected, the more efficient the orientations for the restructuring of

these preconceptions or errors can be, thus contributing to better learning of concepts, scientific ideas, and acquisition of skills. It is in this context that assessing learning should be considered to be a teaching practice not only focused on measurement and rating, but also as a tool from which appropriate information can be extracted to make sound educational decisions in favor of students and the teaching body. Following this logic, in this study we have shown that, by analyzing the data from the measurements, it has been possible to identify a large variety of errors that are consistent with the existing antecedents and others that are proposed for verification in subsequent analyses.

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Annex

Annex 1
Núcleos conceptuales en donde se observan errores, por área disciplinar

Ciencias de la Vida.
Organización de células en tejidos, órganos y sistemas
Sistema digestivo
Consumo de alimentos y sus beneficios
Transferencia de materia y energía entre organismos

Ciencias Físicas y Químicas.
Transferencia de calor
Diferencia entre calor y temperatura
Cambios de estado de la materia y las características de las partículas que lo conforman

Ciencias de la Tierra y el Universo.
Distribución del agua
Efectos de la actividad humana sobre el agua