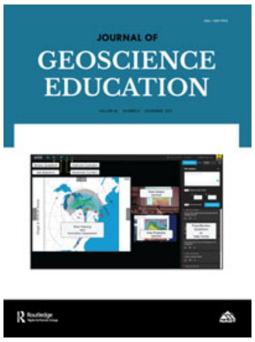

Journal of Geoscience Education

ISSN: 1089-9995 (Print) 2158-1428 (Online) Journal homepage: https://www.tandfonline.com/loi/ujge20

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To cite this article: Claudia Vergara-Díaz, Karla Bustamante, Luisa Pinto & Hernán Cofré (2020) Exploring Chilean seventh grade students' conceptions of Earth dynamics before and after model- and inquiry-based instruction, Journal of Geoscience Education, 68:4, 360-370, DOI: 10.1080/10899995.2020.1725406

To link to this article: https://doi.org/10.1080/10899995.2020.1725406

Published online: 21 Feb 2020.

JOURNAL OF GEOSCIENCE EDUCATION
2020, VOL. 68, NO. 4, 360–370
https://doi.org/10.1080/10899995.2020.1725406

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Exploring Chilean seventh grade students' conceptions of Earth dynamics before and after model- and inquiry-based instruction

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ABSTRACT

International research has recognized numerous alternative conceptions and obstacles to learning about Earth dynamics. The objective of this research was to evaluate the impact of a teaching intervention that incorporates models and scientific inquiry to promote understanding about Earth dynamics in a group of seventh grade students at a school in Santiago, Chile. Through a quantitative approach, a quasi-experimental design was implemented with pre- and post-test evaluation of a control and an experimental group. Student-centred lessons were implemented in the experimental group, where data and evidence were analyzed, and analogical models were used to represent the collision of tectonic plates and the formation of relief. In the control group, the teaching of the same contents was carried out by a more "teacher-centred" approach. The participants were 60 7th grade students (36 girls and 24 boys) aged between 12 and 14 years. Student performances were measured with an instrument created and validated in a previous research project, which addressed three main topics: Earth layers, Earth dynamics and continental drift. We identified 26 misconceptions, many of which have not been described by previous studies. At the end of the intervention, both groups improved their knowledge about Earth sciences, but the effect was greater in the experimental group (mean $= 26.8$, $t = -10.24$, $r = 0.81$, $p < 0.001$) compared to the control group (mean $= 22.4$; $t = -8.3$; $r = 0.65$, $p < 0.001$). The results suggest that student-centered strategies represent an effective means for decreasing students' misconceptions about plate tectonics and Earth science concepts in general.

ARTICLE HISTORY

Received 25 April 2019
Revised 28 January 2020
Accepted 31 January 2020
Published online 20 February 2020

KEYWORDS

Teaching Earth sciences; inquiry; analog models; plate tectonics

Introduction

Purpose and goals for learning

Chile is located along the longest subduction zone on Earth, spanning the western margin of the South American continent (Charrier, Pinto, & Rodríguez, 2007; Luebert & Pliscoff, 2018). As a consequence, the Chilean population constantly faces geological hazards such as earthquakes, tsunamis and volcanic eruptions, among others (e.g., Barrientos, 2007; Ruiz & Madariaga, 2018; Stern et al., 2007; Vargas, Pérez, & Aldunce, 2018). The capacity for making informed decisions requires relevant knowledge about Earth dynamics and the potential social impacts of natural processes (e.g., Saragoni, 2012; Vargas et al., 2014, 2018). For example, a civil engineer must be able to identify the safest areas for construction projects, especially large buildings, bridges, and tunnels, and propose technical measures that mitigate risk. All people should be familiar with the most accessible evacuation routes and appropriate actions to take in the event of high-risk geological events.

However, achieving scientific literacy on this topic in Chile faces two major challenges. First, acquisition of this knowledge is dispersed throughout different grades, without a clear learning progression. This trend is evident not only in the natural sciences, but also in the social sciences as well (Mineduc, 2012, 2014). In Chile, students in the fourth, seventh and ninth grades study Earth science as part of the natural sciences curriculum (Mineduc, 2012, 2014). Secondly, teaching Earth science to 4th and 7th grade students appears to be a challenging task for their teachers. Most teachers at these grade levels in Chile neither possess sufficient disciplinary knowledge, nor the pedagogical capacities to instruct students in geoscience (Cofré et al., 2010, 2012; Vergara & Cofré, 2008). For example, only 22% to 39% of the science teachers feel well prepared to teach Earth science on different educational levels (Cofré et al., 2012). Furthermore, most of the elementary science teacher education programs include just a few courses devoted to natural science, and usually they do not include the topic of Earth science (Cofré et al., 2010, 2015).

International research on geoscience teaching has identified several misconceptions held by students, textbooks and even science teachers, as well as obstacles to learning inherent in understanding the phenomena and explanations associated with Earth dynamics (Ault, 1984; Clark, Libarkin, Kortz, & Jordan, 2011; Dolphin & Benoit, 2016; Francek,

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2013; King, 2008; Libarkin, Anderson, Dahl, Beilfuss & Boone, 2005; Orion & Ault, 2007; Orion & Libarkin, 2014). In addition, research on geoscience education has begun to show that there are certain strategies, such as inquiry-based learning, the use of models, and engaging with historical cases, which can be effective in challenging the preconceived explanations that students have generated to understand geological phenomena that affect them in their daily life (Dolphin & Benoit, 2016; Dolphin et al., 2018; Gobert & Clement, 1999; Hubenthal, 2018; Hubenthal, Stein, & Taber, 2011; King, 2006). The need to study the efficiency of teaching strategies for facilitating an understanding of Earth dynamics is urgent.

The main objective of this study is to assess student understanding of Earth dynamics before and after an instructional sequence incorporating models and scientific inquiry. The students were drawn from a seventh grade classroom at a school in Santiago, Chile. The study: 1) describes students' misconceptions of three main topics in geoscience (Earth layers, Earth dynamics, and continental drift), and 2) evaluates the efficacy of inquiry-based instruction utilizing models to improve student understanding.

Literature context

The following characteristics of geoscience should be considered, when planning teaching lessons on Earth dynamics: geoscience is an interpretive and historical science; it requires three-dimensional thinking; the development of geological time perspectives is crucial; and finally, geoscience extrapolates processes observed in present time to account for natural phenomena both past and present (Ault, 1984; King, 2008; Orion & Ault, 2007).

Alternative conceptions of Earth processes are widespread not only among students of all ages, but also among primary and secondary school science teachers (King, 2006, 2008). Some conceptual and factual errors are frequently identified in science textbooks. For example, King, Fleming, Kennett, and Thompson (2005) showed that many English textbooks characterized the mantle as "liquid", "semi-liquid" or "semi-solid", whereas current scientific knowledge indicates that the mantle is almost entirely solid. In a later study, King (2010) showed that of the conceptual errors contained in textbooks used in England and Wales, approximately 30% correspond to confusion about the physical properties of the Earth's layers and their thickness (Francek, 2013; King, 2008). A more recent study with Honduran students aged between 9 and 14 years identified many alternative conceptions, including the belief in the presence of non-concentric layers, the presence of physical objects within the Earth and the existence of mythical creatures (Capps, McAllister, & Boone, 2013). (For an exhaustive compilation of geoscience misconceptions see Francek, 2013).

There are several obstacles to comprehension of plate tectonics. First, there needs to be an understanding of general concepts such as the layering of the Earth. The importance of unobservable processes on many scales in time and space (e.g., at great depth in subduction zones over tens of millions of years) poses a further obstacle (Clark et al., 2011; Dolphin & Benoit, 2016; Gobert & Clement, 1999; McDonald et al., 2019). How students conceive of plate motion is another obstacle. Many think of plates as rigid, separate entities that move, rub and collide with each other (Dolphin & Benoit, 2016). This imagery hinders the understanding of the elastic properties of the Earth. In the same vein, Hubenthal (2018), found that, before instruction, only 18.5% of 81 undergraduate students that participated in the study recognized that rocks which make up tectonic plates behave elastically.

Studies in different countries have asserted that high school students draw on supernatural or mythological beliefs to explain the phenomena of earthquakes (Mejías & Morcillo, 2006; Tsai, 2001). Another alternative conception of earthquakes shared by students is the idea that earthquakes are related to hot climate or volcanic eruptions (Mejías & Morcillo, 2006). These authors identified epistemological obstacles to learning about the theory of plate tectonics and the origin of earthquakes. These obstacles are: a) The impossibility of observing directly the mechanism that triggers earthquakes; b) The belief that the Earth has remained unchanged since its creation; c) The global scale on which earthquakes occur; and d) The unscientific catastrophism that associates geological phenomena with human catastrophes (Mejías & Morcillo, 2006). Some of these obstacles to learning have been identified in other geoscience topics such as the formation of rocks (Kortz & Murray, 2009).

Since most of the misconceptions described above are resistant to change (Posner, Strike, Hewson, & Gertzog, 1982), traditional and didactic teaching inadequately challenges them. Science teachers should carefully sequence student-centered activities (e.g., Hubenthal, 2018; Hubenthal, Stein, & Taber, 2011). Successful student-centered strategies that can mitigate learning difficulties include scientific inquiry, historical case studies, and analog models (Dolphin & Benoit, 2016). Research in science education has consistently shown that inquiry-based instruction helps improve students' conceptual knowledge, as well as their general attitude toward science (e.g., Al-Ismaily, Kacimov, Al-Maktoumi, & Al-Busaidi, 2019; Cheng, Wang, Lin, Lawrenz & Hong, 2014; Marshall, Smart, & Alston, 2017; Minner, Levy, & Century, 2010). For example, in a large-scale study including more than 15,000 sixth-to-eighth-grade students, Marshall et al. (2017) showed that students taught by teachers with professional training for guided inquiry-based instruction, gained greater knowledge in Earth science (and other scientific topics), than students instructed by teachers who did not participate in such programs. Other studies suggest that inquiry-based instruction may play a role in narrowing the performance gap in science (Marshall & Alston, 2014) and have a positive effect on science achievement for students with disabilities (Rizzo & Taylor, 2016). Inquiry-based teaching can help students overcome the difficulty of observing Earth's dynamic mechanisms directly and appreciate how scientists collect the evidence for explaining geological phenomena.

Model-based teaching (e.g., visualization through analog structures, student-generated diagrams) (Gilbert & Justi, 2016) can serve as a useful strategy for understanding geoscience concepts. Models and analogies facilitate concrete perception of abstract concepts and global scale phenomena (Dolphin & Benoit, 2016; Dolphin et al., 2018; Gobert & Clement, 1999; Hubenthal, 2018; Hubenthal, Stein, & Taber, 2011; King, 2006). Models and inferences presented in historical case studies can also help students understand geological concepts. According to Dolphin (2009), the analysis of original historical texts, alongside evidence for the gradual establishment of scientific models, helped 9th grade students understand the evolution of the theory of plate tectonics and consequently, to develop a more scientific and accurate understanding of tectonic phenomena.

Finally, the integration of these teaching strategies contributes to the improvement of students' understanding of the generation of scientific knowledge in geoscience in particular and the nature of science in general (e.g., Dolphin et al., 2018).

Methods

Study population and setting

This study is quantitative in nature, with a quasi-experimental design and a pre-posttest approach. It is part of a larger study that included the development of instruments to assess geoscience knowledge of students and science teachers, pre-service and in-service development programs for teachers, development and implementation of curricular materials for teaching geoscience topics, and the implementation of inquiry and model-based instruction in some schools of central Chile. Sixty seventh grade students, 36 girls and 24 boys (12 to 14 years old) from one urban school in Santiago, Chile, participated in the study. Compulsory schooling in Chile comprises 8 years of basic or elementary education (ages 6–13) and 4 years of secondary education (ages 14–17) delivered in three types of institutions: public schools (51%), privately owned but publicly subsidized schools (41%) and wholly private schools (8%). One of the elementary school science teachers from this institution participated in the project's initial development of a program in geoscience education. This teacher's participation justified the choice of school for the present study. The school classes A and B were designated as the control group or experimental condition randomly. The control group had 27 students, and the experimental group had 33 students. The school has 543 students from 1st to 8th grade, and 56% of the population are "priority students", i.e., they have a low socioeconomic status. The school has a medium level of achievement in national assessments.

Materials and implementation

Eight 90-minute lessons were conducted, of which the first and the last were devoted to the assessment of geoscience knowledge. The experimental intervention occurred during the remaining six sessions. Model and inquiry-based lessons were implemented in the experimental class, whereas teacher-centered lessons were conducted in the control group (Table 1).

To create the geoscience unit for the experimental group, an approach combining scientific inquiry and conceptual change was used (Settlage & Southerland, 2012; see also previous section). In consideration of the students' preconceptions as identified by the pretest, different activities were designed. The aim of these activities was to promote understandings of the general geoscience concepts and how scientists study natural phenomena related to this discipline (Vergara & Cofré, 2012). The lesson sequence included the use of analog models, followed by engagement with questions and a discussion of the historical context and the nature of science related to the generation of geological knowledge (e.g., Dolphin & Benoit, 2016; Dolphin et al., 2018; Gobert & Clement, 1999; Hubenthal, 2018; Hubenthal, Stein, & Taber, 2011; King, 2006).

Table 1 describes the lesson activities in the experimental and control groups. The textbook provided the material covered and taught in the control class. In general, groups of students discuss the textbook activities given by the Ministry of Education (Mineduc). For example, one of the most frequent activities shows an image of the Earth at three different moments in time: 300 million years ago, 65 million years ago, and 15 million years ago. In this lesson the teacher asks questions about the changes from one moment in time to the next. The textbook represents the Earth' layers in a static model: Core, Mantle and Crust. The text also presents a dynamic model: Core, Mesosphere, Asthenosphere, Lithosphere. Teaching focuses student attention on the textbook content.

For the experimental class, the lesson sequence includes three activities and their materials. The second lesson encompasses earthquakes and volcanoes in Chile (e.g., asking the students, if they remembered the last big earthquake in Chile in February 27, 2010). The third lesson incorporates questions for students that focus on how geoscientists find answers; for example: "How do we know if the continents have always been located where they are today?" To answer this question, students worked in groups on a paper and pencil activity simulating the actual collection of evidence indicating there once existed a supercontinent. Students followed these directions: "It states that scientists have proposed that a single continent called Pangea existed long time ago. For this, there is a series of evidences: fossils, age of the rocks, and water level in the Earth, among others". Students must propose how the Pangea supercontinent would look like based on the evidence provided. Each group was also provided with a puzzle displaying all pieces of evidence, glue and paper. Students had to choose one piece of evidence at a time, sort the pieces of the puzzle, and propose their model of Pangea, including explanation of how they organized the pieces of the puzzle. Finally, the students share their results and discuss them in a plenary session. They consider the variation between groups' models despite being based on the same evidence. The difference and relationship between

Table 1. Details of the learning sequence (intervention) applied to the experimental class and control class (L = Lesson).

L	Learning objective	Activities and materials used by the experimental group	Activities and materials used by the control group
1	Identify previous ideas concerning Earth dynamics	Administration of a pretest questionnaire assessing beliefs and knowledge about geoscience.	Administration of a pretest questionnaire assessing beliefs and knowledge about geoscience.
2	Identify previous ideas concerning Earth dynamics.	Lessons start with the question: Why is Chile so long and narrow? Students are asked to draw in groups a cross-section at the latitude of Santiago from the Pacific Ocean to the Andes mountain. Afterwards, the students present their drawings to the class. Finally, other leading open questions were: How often have earthquakes occurred in the last 50 years? The students worked in groups and then reached a consensus.	Students work with school textbook (pages 150 to 154). They read "Has our planet changed?" and answer questions in groups. For example: a) Explain, through a summary, the main ideas of the continental drift theory. b) Create a timeline that allows you to put in chronological order the events that occurred during geological time.
3	Understand the theory of continental drift in its epistemological, methodological and conceptual aspects of movements and continental plate tectonics	Lessons start with the question: How do we know that the continents move? Group work with a puzzle to build the Pangea supercontinent (Figure 2). Based on different pieces of scientific evidence, each group should propose a hypothesis of what this first continent was like. Presentation of key concepts concerning continental drift and the nature of science.	They read a demonstration of the movement of the Earth's crust and then explain that these movements give rise to Pangea through the geological ages. After that, the plate tectonic theory was explained. Students read the textbook and analyzed a map with 9 tectonic plates. Then, the convergent, divergent and transform boundaries are explained with a text, with a drawing exemplifying each one of the boundaries. At the end, they read and answer questions from the textbook, such as: a) explain the plate tectonic theory.
4	Using analog models, relate the movement of tectonic plates with the formation of relief	Lessons starts with the question: Why does Chile have such a long and narrow shape? How can the process that has generated this form can be modeled? Group work with analog models on the subduction movement of plates. Each group predicts how the configuration of sand will change after applying force. Afterwards, students observe changes in the relief according to the model. Finally, an explanation that relates the operation of the model to the phenomenon of subduction is proposed.	Using an analogy, teacher explained the Earth layers, specifying their thickness and its main characteristics (using the static and dynamic model of the Earth in the textbook).
5	Relate volcanic activity to plate tectonics	Lessons start with the question: How are volcanoes formed? How does the characteristics of the lava relate to the shape of the volcano? Group work with an analog model of a volcano. Two mixtures of different viscosity are prepared, and the students first observe and compare the preparations and infer the displacement of the lava in the model. They analyze the different types of volcanoes according to lava characteristics and characterize volcanic eruptions in Chile.	With power point support, students are shown a volcano and it is compared to a mountain. Students offer their ideas about how volcanoes form and which is their structure by drawing (it is used as a guide for the textbook).
6	Know the volcanic diversity of the country and its consequences for the human population	Group work with a worksheet that includes the location of active volcanoes in Chile and the world. The question for this lesson is: How are volcanoes distributed in Chile? Presentation of the Pacific Ring of Fire and its relationship with tectonic plates.	The volcanic eruption process is explained and examples of Chilean volcanoes that have been active in recent years (ppt) are given. They learn about the types of lava and eruptions that volcanoes have, taking as reference the images on the textbook.
7	Recognize the formation of relief in the natural landscape	Pedagogical Fieldtrip: Lo Valdés, San José de Maipo, the Andes east of Santiago. The students responded to the question: How has the relief of the central zone of Chile changed? Students identified traces of the movement of the mountain range, such as recognizing layers of land and identifying marine fossils.	Pedagogical Fieldtrip: Lo Valdés, San José de Maipo, the Andes east of Santiago. The students responded to the question: How has the relief of the central zone of Chile changed? Students identified traces of the movement of the mountain range, such as recognizing layers of land and identifying marine fossils.
8	Evaluate the learning about geology	Administration of post-test of the questionnaire assessing beliefs and knowledge about Geoscience topics.	Administration of post-test questionnaire assessing beliefs and knowledge about Geoscience topics.

inference and observation is also discussed. Misconceptions about the explanations regarding fossils in the Andes were identified and confronted with data and scientific evidence presented in the activity. Figure 1 shows some pictures of students working.

In lesson four, groups of students work with analog models developed for an activity focused on the following question: How is the landscape configured? This activity focuses on the misconceptions about plate tectonics specifically related to the formation of mountains. Following instructions about modeling the processes of mountain building, the students make a "cake" with white and black sand (See Figure 2). Students observe the model and make predictions of what would happen if a force is applied to one side of the box. At the end, they answer some questions on a worksheet. The students then infer from the changes in the

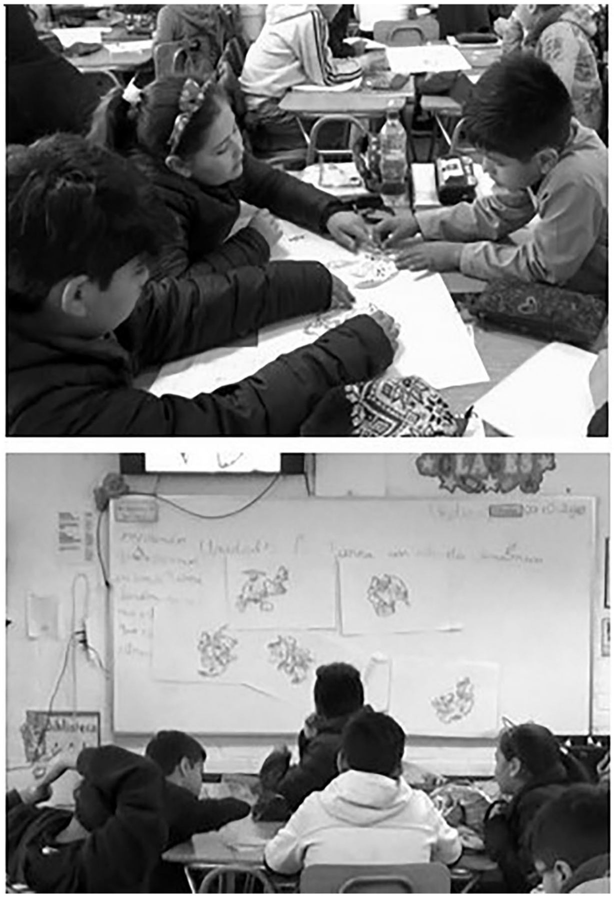

Figure 1. Students working with the puzzle of continents that shows evidence (fossils, age of the rocks, direction of movement of glaciers). From these data they must assemble the Pangea continent. The puzzle is available in https://www.pinterest.cl/pin/719661215434289834/.

model how the movement associated with plate subduction has influenced the development of the Andes.

In the fifth lesson, the students work in groups with an activity focused on the following questions: How are volcanoes formed? How do the characteristics of lava relate to the shape of the volcano? For this model we used an acrylic box with a hole to introduce an L-shaped tube. A conical structure is formed with newspaper and fixed to the tube. The volcano is molded with toilet paper and glue, and students wait until the model is dry and painted. Two mixes are prepared with cornstarch, one with a cornstarch/water proportion of 2:4 (less viscous; blue) and a second mixture with cornstarch/water proportion of 3:4 (more viscous; red) (See Figure 3). The students first add the blue mixture and then the red using a 60 ml syringe. This activity addresses misconceptions related to volcanoes and the formation of magma and lava. The intention is that students learn that the shape of the volcano depends on the viscosity of the lava and that volcanoes are not perforated mountains.

In the following (sixth) lesson, groups of student examine the volcanoes in Chile and the World. The Pacific Ring of Fire is outlined by the teacher. In the next lesson, a field trip guided by the question "What evidence of tectonic plate movements can we found in the mountains? The students traveled by bus from the school to "Lo Valdés", in San José de Maipo, located in the Andes mountain range at an altitude of 900 m. In this area it is possible to observe different layers of accumulated lava and marine and plant fossils. All this allows students to establish relationship between the landscape and the movement of tectonic plates (See also Table 1). The last session was only for the administration of the post-test of the questionnaire.

Variables and instruments

To assess the change in students' knowledge about Earth dynamics, a questionnaire was administered to students before and after the intervention (six lessons). The questionnaire consisted of seven open-ended questions about three specific topics within geoscience: Earth layers, Earth dynamics and continental drift. The questionnaire was validated through a two-year pilot process that included the following steps: 1) The generation of questions by two science teachers and two science educators participating in the main project; 2) A review of the questions by two geologists (content validity) and two elementary science teachers (face validity); 3) The survey instrument was first piloted with two classes, a fifth grade class (42 students) and an eighth grade class (41 students) from the same public school. An interview with a sample of five students was also conducted to assure construct validity; 4) A second pilot administration of the survey instrument with another two fifth and eighth grade school classes from the same private school; 5) A pilot with a class of 25 undergraduate students in their final year of geology education program to verify the content validity; and 6) A final analysis of reliability performed by comparing two seventh grade classes, one from a public school and another from a private school. The means of the classes did not differ from each other and the Cronbach's alpha was 0.62 and 0.63 respectively. The final version of the instrument is shown in Table 2.

The student answers to the survey instrument by the two courses that participated in this study (control and experimental) were analyzed separately by two researchers using a rubric for each question (see supplementary materials). The similarity of the answers was then compared. For this analysis, a Kohen Kappa was calculated for each of the seven questions, whose values ranged between 0.7 and 0.95, which demonstrates a high coherence between the evaluation of both researchers.

Statistical analysis

Because the score data of both classes were normally distributed, a parametric dependent t-test was performed. In addition, the effect size of the intervention was calculated for each group as Pearson' correlation coefficient (Field, 2011). Finally, an independent t-test was also performed with the gain score of each group. All these analyses were conducted with SPSS, version 21.

Results

Before the intervention, most students shared many geoscience misconceptions (Table 3). A list of 26 misconceptions was identified and many of them were not described

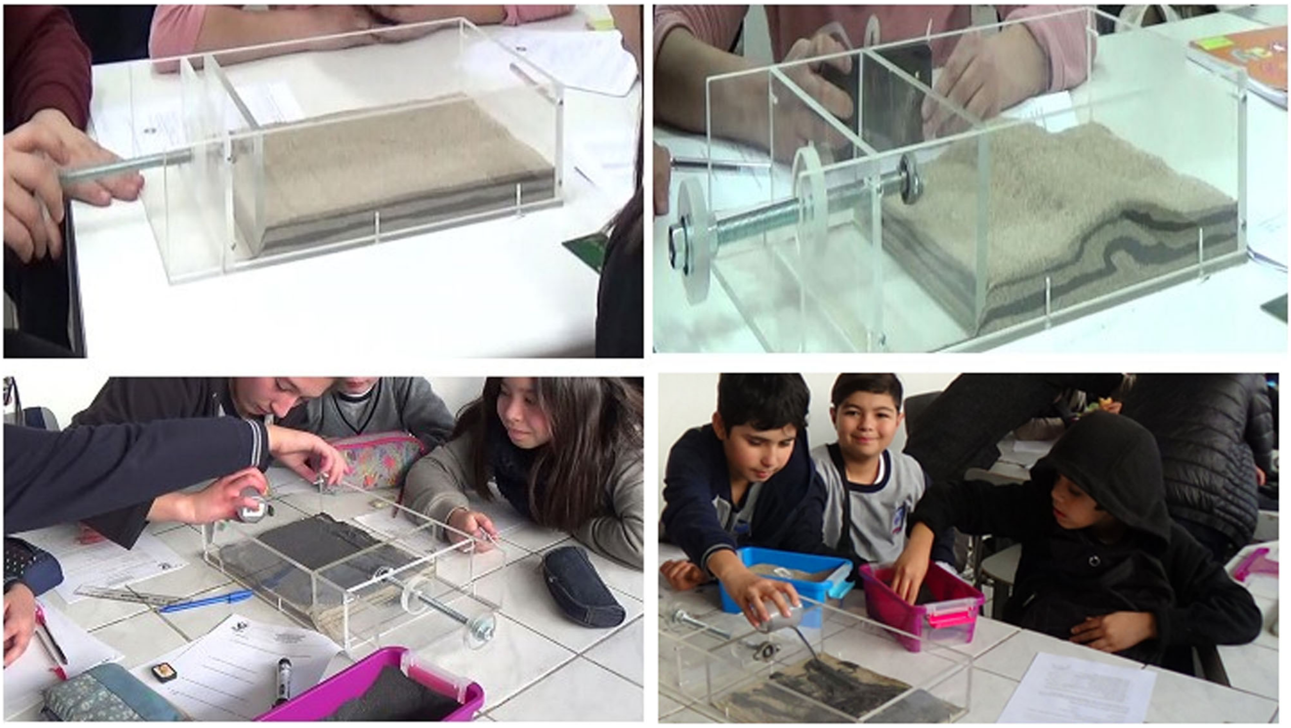

Figure 2. Students working with the analog model to build a "cake" with white and black sand and then compress it.

Figure 3. Analog model of volcanoes. Mixtures with different viscosities are pushed out and through the top of the volcano. It is possible to compare, how the slightly viscous and very viscous mixtures descend from the top.

previously (e.g., Francek, 2013). Most of the misconceptions are related to continental drift (12), volcanoes (7) and earthquakes (6). In general, the frequency of misconceptions diminishes after instruction, both in the control and experimental groups. However, the knowledge improvement in the experimental group was more substantial. The most challenging preconceptions are those related to the layers of the Earth (Table 3). Before the intervention many students responded that they did not know the answer. After the intervention, misconceptions decreased and the quality of

Table 2. Final version of the open-ended questionnaire completed by the seventh-grade students in the control class and experimental class.

How much do you know about Earth Science?

Instructions:
1. We want to know what do you think and know about the internal structure of the Earth and its dynamics
2. These questions do not correspond to an evaluation
3. Respond calmly and freely
4. If there is something you do not understand, you can ask
5. It is important that you answer ALL QUESTIONS

Answer the questions in the assigned spaces!
1. a. Draw a picture of how do you think the inside of the Earth looks like? In the same drawing indicate the name of the parts of the Earth.
   b. Indicate the presence of magma in your drawing,
2. a. In the history of the Earth, have the mountains always been there?
   I. YES (or)
   II. NO

b. If your answer is YES (they have been there): Why do you think they do not change?
c. If your answer is NO (the mountains have changed): How did this change happen?
3. How do you think volcanoes are formed?
4. Why do earthquakes occur?
5. There are more earthquakes occurring in Chile than in any other part of the world. Why do you think that earthquakes are more frequent in some places on Earth compared to other?
6. Two climbers climbing a mountain in the Andes found the remains of ancient marine animals (fossils). How could you explain these findings?
7. Claudia is a scientist who studies the remains of very old plants and animals (fossils) in different parts of the world. She currently works in Antarctica, where she has found fossils of a tree species. Her colleague Hernan works in India and found fossils of the same tree species. How could Claudia and Hernan have found fossils of the same tree species?

the explanations improved. In Figure 4, each student's score on the questionnaire is shown before and after the intervention, both for the control and for the experimental group.

The results obtained from the analysis of answers to the questionnaire showed a general improvement in the explanations of concepts related to geoscience in both groups, with improvement being significantly greater in the experimental group compared to the control group. At the beginning of the intervention, there was no significant difference between the means of both groups (experimental: $N = 26$, mean $= 11.9$; control: $N = 33$, mean $= 12.8$; $t = 1.3$; $p = 0.22$). These values suggest that the groups had comparable knowledge about the content before the intervention. Both distributions are normally distributed ($S\text{-}W = 0.96$, $p = 0.33$, $S\text{-}W = 0.98$, $p = 0.91$).

After the intervention, both groups had improved their knowledge of the geoscience topics taught in the lessons, but the magnitude of the effect was greater in the experimental group ($N = 26$, mean $= 26.8$, $DS = 5.8$, $r = 0.81$, $t = -10.24$, $p < 0.001$) compared to the control group ($N = 33$, mean $= 22.4$, $DS = 6.0$, $r = 0.65$, $t = -8.3$, $p < 0.001$). However, this difference is not statistically significant when the gain scores of each group are compared (control mean $= 8.1$; treatment mean $= 10.2$; $t = -1.35$; $p = 0.18$).

The performance by the classes on the three specific topics within the questionnaire (Earth layers, Earth dynamics and continental drift) yielded very similar results: *Earth layers*: control mean, pre = 3.1, and post = 4.2; experimental mean pre =4.0, and post = 5.2; *Earth dynamics:* control mean, pre = 7.8, and post = 14.2; experimental mean pre =8.0, and post = 15). For the topic *Continental drift,* the difference between pre- and post-intervention is greater for the experimental group (control mean pre = 1.0, and post = 1.6; experimental mean pre =0.8, and post = 2.8). Table 4 provides examples of students' responses from the experimental group. These responses highlight some of the most common misconceptions, for example, that "earthquakes occur because of global warming" or that "mountains have been formed as a result of earthquakes". After the intervention, many students could generate more scientifically accurate responses.

Discussion

This study describes for the first time in a Chilean context the misconceptions of a group of elementary students about well-known geological phenomena and their explanations in scientific theories. Much of the students' initial knowledge echoed previously reported findings. For example, some misconceptions related to the number and thickness of the Earth's layers, including the location of magma in the center of the Earth (Capps et al., 2013; Francek, 2013; King, 2008). Other misconceptions held by the students in this study, also related earthquakes to warm environments (Francek, 2013; Mejías & Morcillo, 2006; McDonald et al., 2019). In regards to the plate tectonics model, prior to the intervention several students referred to tectonic plates as static and rigid objects and attributed the frequency of earthquakes to the number of plates. This and other responses are very similar to previously reported misconceptions, and are evidence about the difficulties students have in understanding the elastic and dynamic properties of the Earth's crust (Dolphin & Benoit, 2016; Hubenthal, 2018; McDonald et al., 2019). Seventh grade students in Chile had been exposed, in the fourth grade, to some of the concepts and phenomena taught in these six lessons (the intervention). Nevertheless, most expressed misconceptions prior to the intervention. After the lessons, at least some of the students in the control group, and more students in the experimental group, improved their understanding of plate tectonics theory. This improvement is similar to the learning progression proposed by McDonald et al. (2019), in which advanced students are able to recognize plate tectonics as a causal, system-level explanatory model for a dynamic Earth. In our study, those students who were able to correctly describe the theory are

Table 3. Number of students that held geosciences misconceptions by treatment (control and experimental) before/after the intervention.

Theme		Misconception	PRE/POST Control	PRE/POST Experimental
Earth structure	1.	Magma is in the Earth's core	15/5	15/9
Volcanoes	2.	Magma supply for volcanoes comes from inner core	2/5	5/3
	3.	*Volcanoes are created by mountains*	*10/7*	*6/0*
	4.	*Volcanoes are created by impacts of meteorites.*	*1/0*	*0/0*
	5.	*Volcanoes are created by global warming*	*2/0*	*1/0*
	6.	*Volcanoes are formed by landslides*	*1/0*	*0/0*
	7.	*Volcanoes are created by man*	*0/0*	*1/0*
Earthquakes	8.	Weather triggers earthquakes	1/0	1/1
	9.	Earthquakes occur because of supernatural forces	*0/0*	*1/0*
	10.	Earthquakes occur because of global warming	*0/1*	*0/0*
	11.	*Earthquakes occur in Chile because there are more tectonic plates than in other countries.*	*12/5*	*11/0*
	12.	*Earthquakes occur in Chile because there are bigger tectonic plates than in other countries*	*4/2*	*2/0*
	13.	*Earthquakes occur in Chile because there are stronger tectonic plates than in other countries*	*2/2*	*0/0*
Plate tectonic	14.	Mountains form by the piling up of pieces of rock	1/5	1/0
	15.	Mountains are created by God or man	0/0	1/0
	16.	Mountains grow from stones, molded from dirt	2/6	2/1
	17.	*The mountains were below the sea and appear when the sea level drops*	*3/2*	*2/2*
	18.	*Mountains appeared due to the translation axis*	*1/0*	*0/0*
	19.	*Mountains appeared because of natural disasters, such as rain*	*3/1*	*1/0*
	20.	*Mountains appeared due to the erosion of the Earth*	*0/0*	*2/0*
	21.	*Mountains appeared due to a meteorite*	*0/1*	*0/0*
	22.	Mountains have always been there	*15/8*	*10/4*
Continental Drift	23.	*Marine fossils in the mountains are the result of a tsunami or a lake*	*10/6*	*10/2*
	24.	*Marine fossils in the mountains are the product of human action, wind, or animal migration.*	*4/4*	*3/1*
	25.	*Fossils on different continents are the result of the action of man or animals*	*9/6*	*17/3*
	26.	*Fossils on different continents can be found because these plants grow everywhere*	*13/10*	*16/4*

Misconceptions identified by Francek (2013) are shown in regular font. Misconceptions in italics have not been identified by Francek (2013).

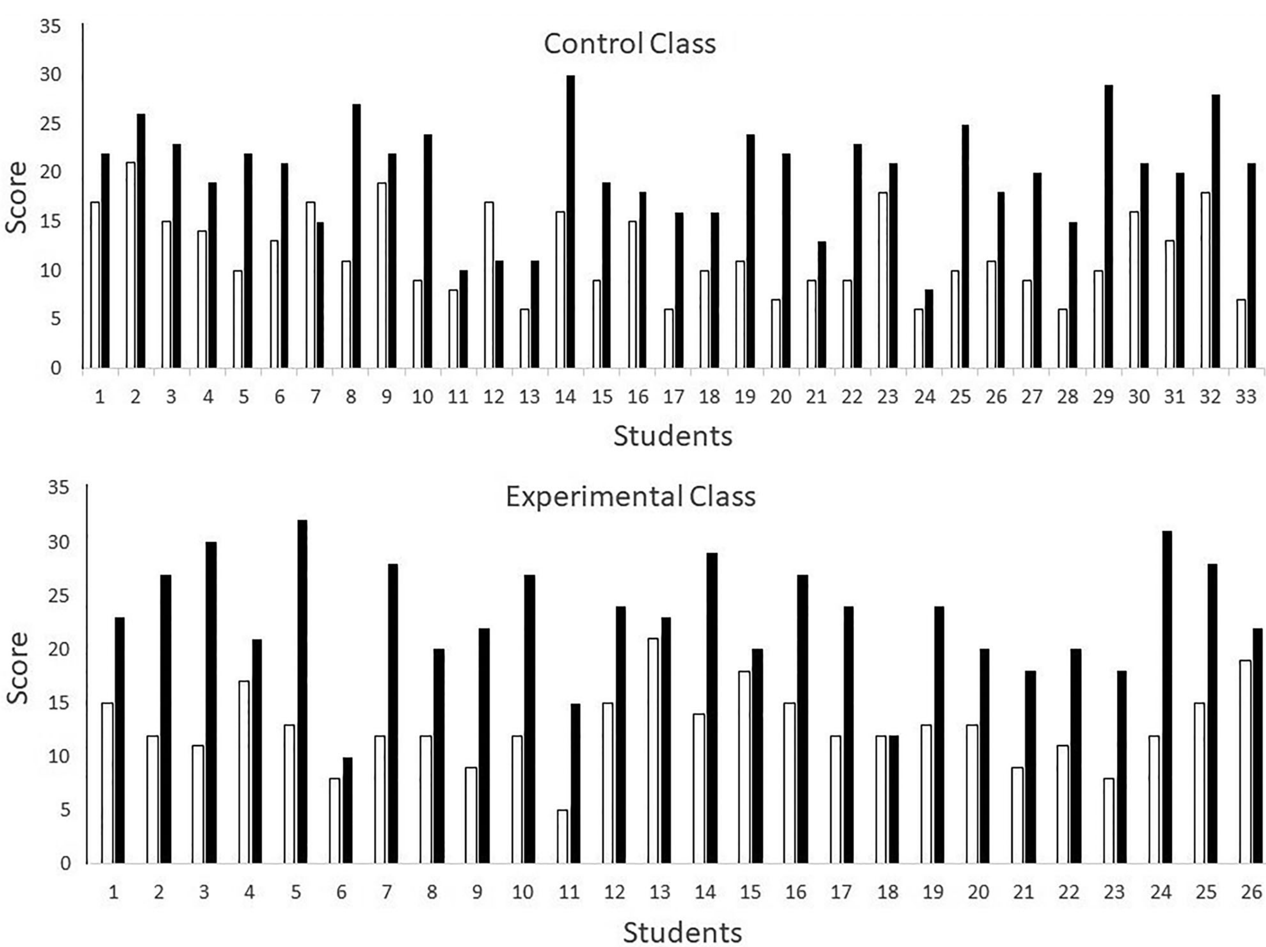

Figure 4. Student' score value in the questionnaire about geoscience content in each treatment (control and experimental) before and after the instruction.

those who also were able to explain different particular phenomena (earthquakes, volcanoes, mountain ranges) through the movement of the plates inside the Earth. This result suggests that strategies carried out in the experimental group were successful in improving student comprehension. The teaching strategy employed in the intervention was highly

Table 4. Example of responses by the same student before and after the intervention in the experimental group (responses have been translated from Spanish).

Question	Pretest answer	Post-test answer
1.a.	The drawing includes numerous concentric layers, but the names of these layers are not indicated (student 20).	The drawing includes the 3 layers of the Earth with their respective names. (student 20)
1.b.	Magma is placed in the center of the drawing (student 32).	Magma is placed inside the second layer called the mantle. (student 32)
2.a. 2.b.	*"Yes. They have always been there, but they were covered for different reasons."* (student 15)	*"No. Previously, there were no mountains, and they were produced because the plates exerted a pressure, which then was released and the mountains were created."* (student 15)
3.	*"It is a mountain, and sometimes there is lava on Earth, and maybe that's why there are volcanoes; they are like a combination of mountain and lava."* (student 13)	*"The crust has a crack, and the magma comes out to the surface, [where] it dries and forms the cone of the volcano."* (student 13)
4.	*"Earthquakes occur due to low temperatures, due to global warming or the axis changes its position through borders, etc."* (student 18)	*"Earthquakes occur because the tectonic plates are colliding, that is, they are making a convergent movement, and that is why earthquakes occur."* (student 18)
5.	*"Because there are more plates or these are less substantial than in other places."* (student 31)	*"Because they are in the Ring of Fire or are on the edge of some plates."* (student 31)
6.	*"I believe that before, there was a giant tsunami that covered the mountain range and left the fossils there."* (student 6)	*"Before, the hills did not exist, but then, over time and with the earthquakes, the hills accumulated [matter] to finally became high altitude mountains with marine fossils."* (student 6)
7.	*"It could have been a species that was everywhere."* (student 8)	*"Many years ago, there was only one continent, and trees of the same species grew everywhere, but then, the continent separated, and that is why you can find [the same] tree species in very distant places."* (student 8)

effective, achieving an average knowledge gain that nearly doubled the initial values. This knowledge improvement about geoscience is greater than expected, because elementary school teachers are generally not well prepared to teach this subject (Cofré et al., 2012; Vergara & Cofré, 2008). Notably, answers to the geoscience questionnaire from eighth grade students, and even from elementary pre-service teachers, indicated a lower level of understanding than achieved by both classes in this study after instruction (Vergara et al., 2019).

The significant improvement of the control group may be explained by the limitations of a quasi-experimental study in a school setting, in which not all variables can be controlled (Fischer, Boone, & Neumann, 2014). The poor performance manifested by both classes prior to the intervention increases the probability of improving their knowledge significantly at the end of intervention. Furthermore, the background of the teacher who taught the classes in both groups differs from that of teachers typically called upon to instruct primary school students in geoscience concepts. The teacher in this study has experience in teaching geoscience and geological research (primary teacher with a Master's degree in Science Education, which is rare in Chilean context) and has participated in our Development Program about geoscience instruction. There are examples in the literature of quasi-experimental studies, in which control groups obtain improvements, likely because the teaching manner is less traditional than under average conditions (Kim & Irving, 2010). Importantly, the control group in this study still engaged in some interactive activities. They were not just passive listeners. Finally, the field trip was a significant learning experience for all students, during which both groups were able to learn and apply their acquired knowledge.

Based on the results from the experimental group, our findings corroborate that a strategy that includes inquiry, addresses the nature of science, and uses analog models, can generate significantly improve student knowledge (Dolphin & Benoit, 2016; Dolphin et al., 2018). The greatest difference in performance between the control group and the experimental group was observed for the topic of plate tectonics. This topic presents several obstacles to student learning stemming from their prior misconceptions about Earth concepts in general as well as from the difficulty in understanding the nature of the hidden evidence for plate motions and structures. In our study, inquiry-based instruction and introduction to the nature of science proved more effective than textbook-oriented, didactic strategies for teaching seventh grade Chilean students the concepts of plate tectonics.

Limitations, instructional implications and future work

This study has several limitations that should be noted. First, the study was conducted at a single school involving only one control and one experimental group. Therefore, caution must be taken in generalizing from the results and conclusions. That being said, the participating school was quite representative of the urban region of Santiago de Chile. Second, the final evaluation (post-test) was only carried out immediately at the conclusion of the intervention, and the study did not examine long-term retention of geoscientific understandings. Finally, the intervention was carried out by the same teacher in the same school; therefore, the possibility existed that the students from both groups (control and experimental) could communicate and thus share their knowledge outside of classroom contexts.

Despite these limitations, our results suggest that the activities created and tested in this experiment promise deeper and more effective learning. Understanding a theoretical and systemic explanation of isolated and apparently unrelated phenomena is naturally quite challenging for students (Dolphin & Benoit, 2016; Hubenthal, 2018; McDonald et al., 2019). The plate tectonics theory joins together a diverse array of data-coastline geography, earthquake distribution, seafloor paleomagnetism and fossil distributions, for example. Within the framework of plate tectonics these phenomena become connected and related. This scientific achievement taxed the best minds of the globe for decades; that children can now learn these ideas in typical Chilean classrooms is a wonderful accomplishment. Models organize empirical evidence in support of the theory and connect theoretical explanations to phenomena of special interest to Chileans. Applying an instructional strategy based on geological models and inquiry activity appears to be particularly effective in addressing the challenge of learning plate tectonics meaningfully.

Future work should include the longitudinal impact of student-centered instructional strategies, such as inquiry and models, on the level of interest and engagement of the students. These types of strategies should also be applied to 9th grade students, who encounter the subject of geoscience for the last time during their high school experience in Chile. Finally, the current challenge exists in continuing to work with elementary school teachers on the implementation and improvement of strategies and activities employed in this study. This focus is crucial, as primary school teachers are responsible for teaching and the application of new strategies to achieve geoscience literacy to large numbers of students in one of the most seismically prone regions of the world. Educating students who live in a seismically active region of the world to think about the need to create resilient communities is one of their most important responsibilities.

Acknowledgments

We thank to Charles (Kip) Ault for his suggestions that improved the quality of the final version of this manuscript.

Funding

This work was supported by the National Fund for Scientific and Technological Development (Fondo Nacional de Desarrollo Científico y Tecnológico de Chile, FONDECYT) N°1161812 of CV.

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