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Mental models of the earth's internal structure among primary, middle and secondary school students in Chile

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Mental models are internal representations or conceptions that students construct as they make sense of their everyday interactions with the natural world. The layers of the Earth are topics covered in the Chilean national curriculum for primary and middle school education. Studies have shown that primary and middle school students hold many preconceptions about earthquakes, mountain formation, and volcanoes. In this study, we analyzed 785 drawings by students from six Chilean schools at six school levels. We developed and validated a rubric to analyze the students' drawings of the Earth's internal layers and identify the location of magma within the Earth. Among the main results, most students were found to draw concentric layers without distinguishing their thickness, number, or name. Fifth-grade and eleven-grade students were the most likely to create drawings that reflected the internal structures, albeit without differentiating the thickness of the layers. Most students placed magma in the center or core of the Earth. The study concludes that a possible learning progression begins with a framework theory in which students recognize aspects of their daily lives within the Earth, then continues with a mixed model in which scientific knowledge of concentric layers within the Earth is combined with the location of magma at the center, and ends with a model similar to that proposed by scientists.

KEYWORDS

alternative conceptions, drawings, earth's internal structure, magma location, mental model

1 Introduction

In the field of science education, Earth science education is less well represented in research (e.g., Odden et al., 2022; O'Toole et al., 2018; Skamp, 2020) and has a lower presence in science curricula worldwide than other disciplines, such as biology, chemistry, or physics (e.g., King et al., 2021; Orion and Libarkin, 2023). Furthermore, secondary and elementary school teachers feel less confident in their ability to teach Earth sciences, and much evidence indicates that teachers who teach these subjects at both the primary and secondary levels are often not specialists in Earth sciences (e.g., Cofré et al., 2012; King et al., 2021; Orion and Libarkin, 2023). This may help explain why many students globally, from elementary to college levels, hold many alternative conceptions about various Earth science topics (Dove, 1998; Francek, 2013; King, 2000, 2008), including climate change (e.g., Libarkin et al., 2018; Rousell and Cutter-Mackenzie-Knowles, 2020), plate tectonics (e.g., Vergara-Díaz et al., 2020; McLure et al., 2021,

2022), earthquakes and tsunamis (e.g., Vergara-Diaz et al., 2020; Cabello et al., 2021; Cabello, 2022; Kurdziel et al., 2003), and the layers of the Earth (e.g., Vergara-Diaz et al., 2020; Cardoso et al., 2018; Kurdziel et al., 2003; McAllister, 2015; Steer et al., 2005; Vosniadou et al., 2008). Similarly, alternative conceptions have been identified among science teachers (e.g., Dahl et al., 2005; Francek, 2013; King, 2000), and many science textbooks contain conceptual errors related to plate tectonics and other Earth science topics (e.g., King, 2008, 2010).

On the other hand, empirical studies in the fields of cognitive sciences, science education, and educational psychology have demonstrated that intuitive ideas are not isolated elements but rather complex structures that often coexist with scientific theories (Cofré et al., 2023; Parraguez et al., 2023; Nehm, 2018; Vosniadou and Brewer, 1992; Vosniadou and Skopeliti, 2017). In their classic work, Vosniadou and Brewer (1992) distinguish between fragmented conceptions, which consist of a combination of alternative conceptions and scientific knowledge that are pieced together without regard for explanatory power or coherence, and synthetic conceptions, which, although scientifically incorrect, exhibit internal consistency and some explanatory power (see also Vosniadou et al., 2008; Vosniadou, 2019).

These alternative conceptions and mental models that students generate to explain natural phenomena have historically been studied using drawings (e.g., Andersson et al., 2020; Cabello et al., 2021; Cabello, 2022; Chang et al., 2020; McLure et al., 2021, 2022; Reiss and Tunnicliffe, 2001; Rivera et al., 2025; Vosniadou and Brewer, 1992; Vosniadou and Skopeliti, 2017). Chang et al. (2020) reviewed 76 journal articles and concluded that drawings have been used to assess students' mental models and conceptual understanding in four main science topics: chemical reactions (e.g., Chang et al., 2014), the human body (e.g., Reiss and Tunnicliffe, 2001), astronomy (Vosniadou and Skopeliti, 2017), and geology (e.g., Jee et al., 2014).

With respect to understanding the interior of the Earth and the layers that compose it according to scientific knowledge, few studies have been carried out over several decades (e.g., Capps et al., 2013; Cardoso et al., 2018; Dove, 1998; Gobert and Clement, 1999; Libarkin et al., 2003; Steer et al., 2005; Vosniadou et al., 2008). For example, in one of the earliest reviews about mental models and alternative conceptions in Earth science, Dove (1998) described alternative conceptions such as "Magma flows from the center of the Earth" and "A magnet is found at the center of the Earth". Citing a previous study with Spanish students between 11 and 15 years of age, Dove (1998) reported that although most students correctly portrayed the internal structure of the Earth as a series of concentric layers, some children depicted a hot, melted center from which magma flowed out to volcanoes on the surface. Dove (1998) also described results from another study with younger students (9–10 years old) who believed that the center of the earth was colder than the surface because the sun's rays could not warm it up. In a contemporary study, Gobert and Clement (1999) described the conceptual understanding of the structure and dynamics of the Earth through diagrams and summaries. In a work that included fifty-eight Grade 5 students (10–11 years old), the researchers reported that the diagram group outperformed both the summary and text-only groups in terms of understanding both the spatial/static (layers of the earth) and causal/dynamic aspects (movement in layers producing mountain formation and volcanic eruption) of Earth science topics. At the beginning of this century, some studies focused on describing the mental models of university students before and after teaching (e.g., Libarkin et al., 2003; Steer et al., 2005). For

example, Libarkin et al. (2003) applied both open-ended questionnaires (including drawings) and interviews to study the comprehension of 265 students. This study revealed that most responses about the Earth's interior involved a drawing or description of spherical layers, with a few students who conceived of flat layers, as Dove (1998) reviewed. Although many students used scientific terms, such as core, mantle, or magma, the answers show confusion between the two models of the Earth's interior (static and dynamic). In another study including 97 university students, Steer et al. (2005) reported that, using a model-based, conceptual change approach to teaching earth science, students improved their knowledge about the interior structure of the earth after instruction. In analyzing the drawings made by the students, the researchers recognized 5 levels of complexity: 1) students with an alternative conception of the interior of the earth; 2) students who recognized only that the earth interior consists of multiple concentric spheres; 3) students who drew only three or four concentric spheres indicating that they held either the chemical or physical view; 4) students who drew multiple concentric spheres and boundaries were correctly labeled; 5) students whose diagram showed correctly labeled concentric spheres and indicated that the crust was much thinner than other boundaries; and 6) students who met all previous criteria and designated the line marked the outer circle as the crust.

With respect to school-level students, Vosniadou et al. (2008) reported that, in a sample of 72 students from the first, sixth and eleventh grades, most first grade students believed that the earth interior contains only solid materials arranged in flat layers. The study also revealed that the drawings of sixth-grade and eleventh-grade students appeared in circular layers, with the magma placed in the center of the spherical earth; even the eleventh-grade students believed that the magma is located very deep in the center of the earth rather than relatively close to its surface. This study reported students present seven mental models of the layer and composition of the earth. The three simplest models were more frequent among first-grade students; in sixth grade, some students present the flat layer model, and others present the spherical layer model with magma in the center, while most 11th-grade students present the last spherical model. In a similar study, Capps et al. (2013) studied drawings made by 105 fifth and sixth-grade students in Honduras (ages 9–14 years). The researchers categorized the drawings into one of five levels of conceptual understanding: Level 1 displayed major alternative conceptions (e.g., mythical creatures inside the Earth); Level 2 displayed only concentric layers; Level 3 displayed concentric layers including zones such as the core, mantle, and crust; Level 4 displayed concentric layers and included materials such as lava and rock and included zones such as the core, mantle, and crust or demonstrated that the Earth's interior was not static; and Level 5 displayed all the previous correct elements. In the results, 50% of the students were scored at level 1, while only 30% reached levels 2 and 3. Only 20% of the drawings were categorized as level 4. Finally, in a recent study, Cardoso et al. (2018) studied the drawings of 67 schoolchildren from elementary schools, with ages ranging from 6 to 11 years (average = 7.9 years). Some elements present in the internal composition of the earth according to the drawings were magma/lava, metals, rocks, water, soil, astronomical elements, and life.

Although these studies have generated a good diagnosis of what mental models are most frequently met with among students, especially among younger students and those who are in college, there is still no clear learning progression concerning how students generate

their representations over time. There have been no more in-depth studies where mental models of the layers of the earth are studied in a larger sample (500 or more) or where more grades within the range of grade 1 through grade 12 are included (3 >). The purpose of this study was to fill this gap by characterizing the mental models that elementary and middle school students have about what the Earth is like inside and where they believe magma is located.

2 Materials and methods

2.1 Context and participants

Compulsory schooling in Chile comprises 8 years of basic or elementary education (ages 6–13 years) 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%) (Cofré et al., 2015). In the Chilean national curriculum, Earth science is incorporated into both the 4th and 7th grades. In this context, we have worked with students from the 4th to 11th grades (128 from the 4th; 151 from the 5th; 242 from the 6th; 213 from the 7th, and 51 from the 11th, for a total of 785 students) from six state-subsidized private schools in urban areas and serving middle-income families. On average, the schools have 35 students per class (four from Santiago and two from Valparaíso).

The whole sample of students belong to the Gen Z, who have been exposed a lot with digital information. The student sample that participated in this study was non-probabilistic and based on convenience sampling. The questionnaire was administered to the students of science teachers who participated in a professional development program focused on pedagogical content knowledge in Earth science. Only those teachers who taught Earth science were subsequently observed in their classrooms. All of these teachers worked in state-subsidized private schools. Therefore, the sample does not include students from public schools or wholly private schools. All the students participated voluntarily, and they and their parents signed an informed consent form approved by the ethics committee of the University of the Researcher responsible for the project.

2.2 Data collection

As in previous studies (e.g., Cabello et al., 2021; Cabello, 2022; Libarkin et al., 2003; McLure et al., 2021, 2022; Reiss and Tunnicliffe, 2001; Rivera et al., 2025; Vosniadou et al., 2008; Vosniadou and Skopeliti, 2017), in this research, the drawings and explanations of students constitute a window into their mental models about the natural world. The students responded to a previously validated instrument on knowledge in the Earth sciences (Vergara-Diaz et al., 2020), whose first question explicitly asks them to draw the layers of the Earth and indicate the location of the magma, as has been done in previous studies (e.g., Capps et al., 2013; Libarkin et al., 2003; Steer et al., 2005). With respect to the youngest students (4th grade), we also supplemented the students' drawings with an interview used to encourage them to explain their responses, as in prior studies (e.g., Capps et al., 2013; Libarkin et al., 2003). The interviews generally consisted of open-ended questions based on the students' drawings and lasted between 5 and 10 min. The interviewees were selected on the basis of their drawings. The drawings were randomly selected

from the codes represented by the youngest students (4th grade, $N = 36$; codes present: 6, 5, 4, 3, and 1). The interviews helped us better understand the characteristics of the students' drawings, as they gave the students the opportunity to use their own words to explain the ideas represented in the drawings and identify the possible origins of those ideas. All the student interviews were conducted by two researchers (KN and CP) and were audio-recorded, transcribed, and analyzed.

2.3 Data analysis

For the analysis of the drawings, a rubric was developed on the basis of the work of Vosniadou et al. (2004, 2008) and Capps et al. (2013), which allows for the identification of the different mental models that students have about what the layers of the Earth are and how and where it is located (Table 1) and where students locate magma in the Earth's interior (Table 2). With respect to the location of the earth layers, 7 mental models were recognized, from the most sophisticated to the least scientific (scored from 7 to 1). For the location of the magma, 4 mental models were recognized, from the most correct to the least correct (scored from 3 to 0). This rubric was validated by three researchers in science education working in the Earth sciences and one geologist. For the analysis, each drawing was analyzed with rubric by two researchers independently, and the differences in the coding were settled by a third researcher. For the first question about the Earth's layers, the kappa was 0.85 ($p < 0.05$), and for the second question about the magma location on Earth, the kappa was 0.88 ($p < 0.05$).

The interview data were compared with the original tentative categorization of the students' drawings to verify the validity of the classification and indexing systems using the rubrics. The construct validity of the rubric was determined by the consistency observed between a student's interview and their drawing. To this end, once the students completed the questionnaire, which asked them to highlight a drawing of what they believed the Earth looked like inside, identify its parts, and indicate the location of the magma, the drawings were analyzed by two researchers separately. Later, during the interview, the student was asked to explain the drawing in their own words, along with where they obtained those ideas. These data were compared with the classified data, verifying consistency in 100% of the cases.

2.4 Statistical analysis

With respect to the statistical analyses, the following tests were conducted to compare mental models of earth science among students. First, the distribution of the data was evaluated using the Shapiro–Wilk test, which indicated a no normal distribution for all the data groups. A comparison of the degree of sophistication in mental models for Earth layers across the five grades was subsequently conducted using the Kruskal–Wallis test (Field, 2009). After that, *post hoc* tests were conducted to verify the difference between pairs of groups (Bonferroni correction). With respect to the analysis of mental models related to the location of the magma, a Pearson chi-square statistical analysis was conducted to determine whether the distribution of the level of sophistication was the same across grade levels. Finally, a Spearman correlation test was performed between the two variables. For all analyses, differences for which $p < 0.05$ were considered significant (Field, 2009). All the statistical tests were conducted using SPSS software, version 22.0.

TABLE 1 Rubric for mental models of the layers and composition of the Earth, based on previous research (Capps et al., 2013, Torres et al., 2013, Vosniadou et al., 2008).

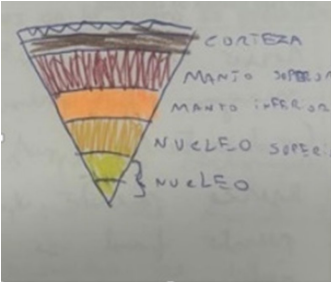
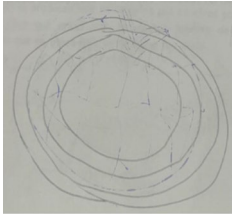


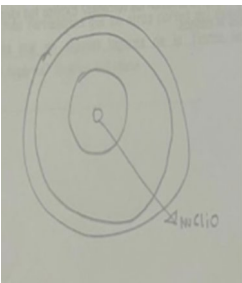
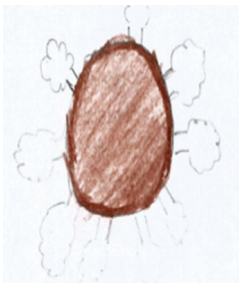




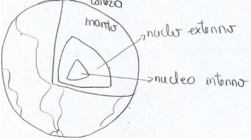
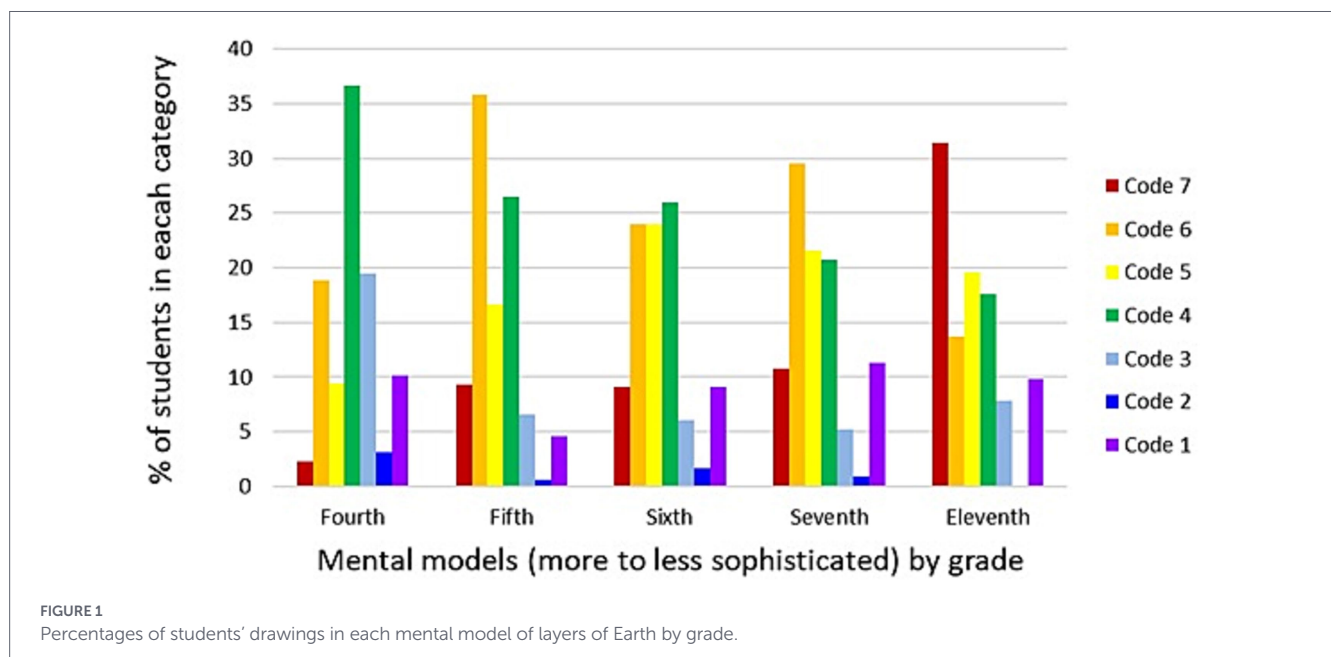
Explanation	Example of drawing	Coding	Explanation	Example of drawing	Coding
Draw the concentric layers within a spherical structure. Draw the layers in proportion to their density (thinner crust). Indicate the order and correct names. Core (inner-outer)—mantle—crust.		7	Draws the layers concentrically, within a spherical structure. Does not draw them proportionally (no thinner crust). Does not identify any layer.		4
Draws the concentric layers, within a spherical structure. Does not draw them proportionally (no thinner crust). Does not differentiate between inner core and outer core. Identify correctly core—mantle—crust. Identify at least two correct concentric layers.		6	Fictional models (unreal). Draws a spherical structure, but with structures inside that do not correspond to reality.		3
Draws the concentric layers, within a spherical structure. Does not draw them proportionally (no thinner crust). Does not differentiate between inner core and outer core (confuses some of the names of these layers or does not include at most 1 of the corresponding layers). Only identifies 1 layer correctly.		5	Draws a concentric structure with structures outside (e.g., buildings, continents).		2
			Nonconcentric layers		1

TABLE 2 Rubric about the location of magma within Earth, including drawings.

Magma location description	Example drawing	Coding
Locates the magma in the mantle.		3
Locates the magma in the crust.		2
Locates the magma in the core or in the center.		1
No magma location at all.		0



3 Results

The analysis of a mental model drawings of the Earth's layers reveals that eleventh grade students have the highest percentage (31%) of the most scientifically accurate model (7); that is, these students drew concentric layers within a spherical structure and recognized the order and correct names of the core (inner-outer), mantle, and crust, and their drawings also show the layers proportional to their density, with the crust being thinner than the mantle. The percentage of students who produce this type of drawing was similar in the seventh, sixth, and fifth grades (near 10%), followed by the fourth grade, which had the lowest value (2.3%) (Figure 1). An opposite pattern to that shown by level 7 is presented by level 4, as it decreases from the fourth grade (36.7%) to the

eleventh grade (17.6%), passing through intermediate values in the fifth, sixth, and seventh grades (Figure 1). These visual patterns of differences were corroborated by the results of the Kruskal–Wallis test, which compared the sophistication values of the drawings between grades [H(4) = 22.63, $p < 0.001$]. When the degree of sophistication of fourth grade was compared with the degree of sophistication of all other grades, a significant difference arises according to a *post hoc* test. However, no differences were found between the rest of the grades and each other.

On the other hand, the analysis of mental model drawings of the Magma locations revealed that they place it in the core or in the center of the Earth most of the time, regardless of their grade level (Figure 2). However, similar to the previous analysis, students' drawings from fourth grade have more simpler' mental models than the other grades

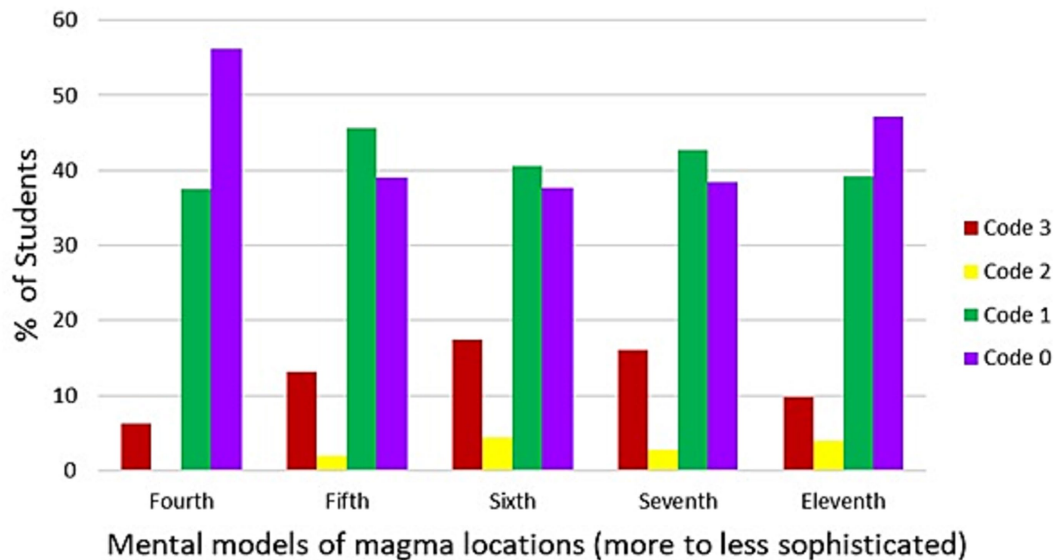


FIGURE 2
Percentage of students in each mental model of magma locations by grade.

do ($\chi^2 = 33.635$, $p < 0.001$). In a final quantitative analysis, we found a positive and statistically significant correlation between the earth layer and magma models ($r = 0.34$; $p < 0.01$); therefore, students with more sophisticated models of earth layers tended to perform better with respect to the location of the magma.

Table 3 shows examples of drawings and the explanations given by the students who made them. In general, students provided descriptions of their drawings that were consistent with the categories established in the rubric for both the layers of the Earth and the location of the magma. For example, in the case of the drawings in code 6, students recognized concentric layers, identifying the core and mantle (students 4,511 and 4,526), but they confused the crust with the earth. Representing students whose drawings were rated at code 3, student 4,064, said, “these little black things what is it is the interior sharp rocks, as far as they go They go as far as the center in the core I think there is lava in the center which is magma it is a black thing it is in the center.” Students whose drawings were rated code 1 drew, for example, a spherical structure, with a seed in the center whose roots extend to the surface; student 4,051 said, “I think they have a seed inside and roots were created and at the center of the earth there is a large seed and roots were generated the water would be a little on the outside but more on the inside the magma would be something like balls I would place it where the seed is on the outside in the whole earth”. Others asserted that below the surface there is earth, then more earth, water, and earth. Finally, it is also evident that most students could not identify the magma, regardless of their classification of the Earth’s layers. Usually, they considered that magma is lava with rocks, and when they did identify it, they placed it at the center of the Earth or beneath volcanoes (Table 3).

4 Discussion

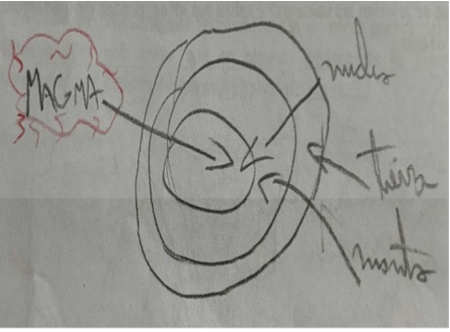


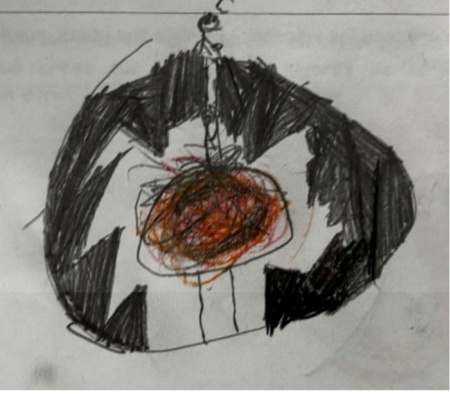
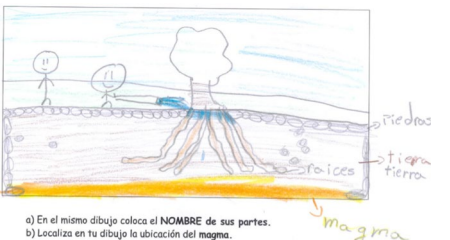
In the present study, we recorded a low level of understanding of the interior structure of the Earth, as has been frequently described in

previous studies in Chile (Vergara-Diaz et al., 2020; Davis and Cabello, 2024), as well as in different countries around the globe, including Greece (Vosniadou et al., 2008), Honduras (Capps et al., 2013), Portugal (Cardoso et al., 2018), and the USA (Libarkin et al., 2003; Steer et al., 2005) and even among older students, such as those in their first years of university or people in general (Cardoso et al., 2018). Numerous alternative conceptions were identified regarding the composition and structure of the interior of the Earth and the location of magma. Elements that only exist on the surface of the Earth were usually included in the drawings, which may be explained by an analogy with what students observe in the world in their daily lives (Cardoso et al., 2018).

This study also reports for the first time on mental models of the Earth’s interior at five different educational levels in a similar educational context and with a sample of students several times larger than those previously studied. This allows us to have a more holistic view of how students can acquire and develop their knowledge about these aspects of nature that are foreign to our daily lives (Orion and Libarkin, 2023). This study reveals that one-third of fourth-grade students hold very simple views of the Earth’s interior, including for example, horizontal layers of soil or living organisms, perhaps alluding to a view of an Earth like a hollow sphere, as described above (Vosniadou and Brewer, 1992; Vosniadou et al., 2008). Common alternative conceptions of the contents of the interior of the Earth, such as water, fire, lava, living organisms (e.g., trees or animals), and even people have been described (Dahl et al., 2005; King et al., 2021; Capps et al., 2013; Cardoso et al., 2018). Some students also include mystical elements such as hell and the underworld related to biblical representations (Cardoso et al., 2018). This proportion of students with simple views coincides with those reported by Vosniadou et al. (2008) (approximately 60% in first grade and 50% in sixth grade) and Capps et al. (2013) (approximately 50% in fifth and sixth grade), but in our case, these simple mental models decrease in representation when the drawings of fifth and sixth-grade students are analyzed (only between 10% and 20%).

On the other hand, the proportions of drawings with different levels of sophistication at the eleventh-grade level found in our study also coincide with those reported by Vosniadou et al. (2008) at the

TABLE 3 Examples of student drawings of and explanations from interviews about different layers of the earth and magma locations.

Student' drawing explanation	Drawing	Number of students interviewed	Coding
<p>Here I drew how the earth is split in half and its layers are indicated with arrows. What I labeled as earth is the surface of the Earth. The core and magma are in the center, meaning that magma is in the core. In Minecraft, it appears at the bottom of locations (student 4,511).</p>		<p>2</p>	<p>Earth's layers at level = 6 Location of magma = 1</p>
<p>I drew the layers in circles, because the Earth is round. I thought that, in this part, this green one, it's like the surface, where the trees and all that are. Inside the Earth, there are circles, and one of them is the core and magma (student 4,052).</p>		<p>6</p>	<p>Earth's layers at level 5 Location of magma at level 1</p>
<p>So, I'm going to describe what was inside the Earth. It's like when we split the Earth in two and want to see what's inside it. I wanted to represent what the Earth looks like inside. This is supposed to be the center of the Earth. in the center, when you see that yellow color, it's like lava. I do not remember the other names. The colors represent the layers of the Earth, and each of these colors is a different layer. So, if we remove all the other three layers, we'll be left with just lava. I do not know where magma is, and I do not know what it is (student 4,538).</p>		<p>12</p>	<p>Layers at level 4 location of magma 0.</p>
<p>The black bits are like the interior, like sharp rocks. The person at the top is digging downward and in the center is the core, which is orange because I think there is lava there. And the magma is like a black thing in the center mixed with the lava (orange color). and there is a connection between one end and the other (student 4,064).</p>		<p>9</p>	<p>Layers at level 3 location of magma 1</p>
<p>I drew layers that are like lines in the earth itself. I tell you they are lines, like earth, earth, and then earth. In the end, underneath it all. magma (student 4,050).</p>	 <p>a) En el mismo dibujo coloca el NOMBRE de sus partes. b) Localiza en tu dibujo la ubicación del magma.</p>	<p>7</p>	<p>Layers at level 1 location of magma 1</p>

same educational level and partially by Steer et al. (2005) for university students. However, although these students develop a mental model that includes concentric layers and some scientific concepts such as the core, mantle, and crust, there is a preconception that seems to arise from teaching, namely, the persistent location of magma at the center of the Earth (Vosniadou et al., 2008; Capps et al., 2013; Cardoso et al., 2018; Libarkin et al., 2003; Steer et al., 2005). It is interesting to note that this preconception, according to the historical review of the development of scientific models created to explain the interior of the Earth carried out by Cardoso et al. (2018), matches the Kircher model, which proposed in 1665 that because the Earth had been a sun that had cooled down in the meantime, large fires that blew in its interior escaped to the surface through several channels and originated as volcanoes.

On the basis of these results and previous literature (e.g., Vosniadou et al., 2008; Steer et al., 2005; Capps et al., 2013), a possible learning progression can be recognized (Vosniadou, 2019), in which synthetic models regarding the internal structure of planet Earth evolve. Thus, before being explicitly taught the subject at school (in Chile, this occurs in fourth grade), students seem to maintain the belief that earth contains solid materials or even life inside without recognizing an organization or the presence of different layers with several components, and only flat layering is assumed to exist in Earth's interior (framework theory *sensu* Vosniadou, 2019). Once the first learning opportunity and teaching strategies are introduced, many students incorporate the knowledge that the Earth's interior is not homogeneous but contains layers that are not suitable for life. However, it is only after a new learning opportunity (which in Chile occurs in seventh grade) that students retain slightly more of the names and characteristics of these layers, with the correct location of magma being the greatest challenge to achieve, with most students thinking that the magma is placed at the bottom or the center of the spherical earth (coexistence of intuitive understandings and scientific concepts *sensu* Vosniadou, 2019). According to the results, it is likely that a scientifically accurate mental model of the Earth's interior can be achieved only at the end of school or even during university education.

On the other hand, this study also confirms that drawings provide a useful window into human cognition, not only because of the inherent opportunity to build connections between concepts without potential verbal barriers but also because of the opportunity to blend scientific and nonscientific aspects of students' mental models (Libarkin et al., 2003, 2018; Chan et al., 2020). The interviews conducted show how accurately the drawings reflect the students' mental models and provide us with information about the possible origin of certain alternative conceptions. In summary, when comparing the findings for younger students with those for older students, we identified some similarities, such as both groups locating magma at the center of the Earth. However, we also observed several differences, most notably a more scientifically accurate layered model of the Earth among students in higher grade levels.

5 Limitations, further direction and conclusions

As with any study conducted with student participants, several limitations must be considered when the results are analyzed. This

study is pseudo-longitudinal, meaning that we do not know if this learning trajectory actually occurs for each student; thus, studies with this type of follow-up would be very important in the future. Interviews were not conducted at each of the educational levels studied; therefore, conclusions drawn from drawings made by older students should be treated with caution (Chan et al., 2020).

Our results have implications for teaching the internal structure of the Earth and are consistent with previous findings (Steer et al., 2005). For example, a model-based conceptual change approach to teaching Earth's interior could be useful for improving students' understanding of earth structure (Steer et al., 2005; Vergara-Diaz et al., 2020), especially when the focus is on the location of magma in Earth's interior. Another possibly effective strategy for working on the preconception of magma located at the center of the Earth may be to review historical models of the Earth's interior so that students can realize the relationship between their mental model and the scientific model (mostly the Kircher model, 1665) proposed in the past (e.g., Rudge and Howe, 2009; Cardoso et al., 2018).

Therefore, future research should focus on conducting true longitudinal studies, as well as testing interventions that take into account the different preconceptions identified in this study. Additionally, more research should examine how science teachers, who are responsible for teaching these topics, develop strategies and create opportunities for students to better understand these core concepts. In other words, further work is needed on pedagogical content knowledge related to Earth's dynamics.

In conclusion, although they live in a country with high geological risk, the mental representations of the younger Chilean students analyzed are similar to those reported in other international studies. A possible learning progression based on the drawings begins with a framework theory in which students recognize aspects of their daily lives within the Earth. A mixed model in which scientific knowledge of concentric layers within the Earth is combined with the location of magma at the center and ends with a model similar to that proposed by scientists is proposed. Finally, the large sample size and the development of clear rubrics in English (the original study by Vosniadou et al., 2008, is in Greek) are also methodological contributions of this study.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Alberto Hurtado University Ethics committee VRIP_CE 39/2023. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the minor(s)' legal guardian/next of kin for the publication of any potentially identifiable images or data included in this article.

Author contributions

CV-D: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing, Funding acquisition. KN: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Validation, Writing – original draft. CP: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Writing – original draft. HC: Data curation, Investigation, Validation, Writing – original draft, Writing – review & editing.

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References

- Andersson, J., Löfgren, R., and Tibell, L. A. E. (2020). What's in the body? Children's annotated drawings. *J. Biol. Educ.* 54, 176–190. doi: 10.1080/00219266.2019.1569082
- Cabello, V. M. (2022). Students understanding of earthquakes and tsunamis in high risk areas. *Front. Earth Sci.* 10:841251. doi: 10.3389/feart.2022.841251
- Cabello, V. M., Moreira, P. M., and Griñó Morales, P. (2021). Elementary students' reasoning in drawn explanations based on a scientific theory. *Educ. Sci.* 11:581. doi: 10.3390/educsci11100581
- Capps, D., McAllister, M., and Boone, W. (2013). Alternative conceptions concerning the earth's interior exhibited by Honduran students. *J. Geosci. Educ.* 61, 231–239. doi: 10.5408/12-317.1
- Cardoso, A., Ribeiro, T., and Vasconcelos, C. (2018). What is inside the earth? Children's and senior citizens' conceptions and the need for a lifelong. *Sci. Educ.* 27, 715–736. doi: 10.1007/s11191-018-0003-y
- Chang, H. Y., Lin, T. J., Lee, M. H., Lee, S. W. Y., Lin, T. C., Tan, A. L., et al. (2020). A systematic review of trends and findings in research employing drawing assessment in science education. *Stud. Sci. Educ.* 56, 77–110. doi: 10.1080/03057267.2020.1735822
- Chang, H.-Y., Quintana, C., and Krajcik, J. (2014). Using drawing technology to assess 25 students' visualizations of chemical reaction processes. *J. Sci. Educ. Technol.* 23, 355–369. doi: 10.1007/s10956-013-9468-2
- Cofré, H., González-Weil, C., Vergara, C., Santibáñez, D., Ahumada, G., Furman, M., et al. (2015). Science teacher education in South America: the case of Argentina, Colombia and Chile. *J. Sci. Teacher Educ.* 26, 45–63. doi: 10.1007/s10972-015-9420-9
- Cofré, H. L., Vergara, C., Jiménez, J., Santibáñez, D., Camacho, J., and Galaz, A. (2012). Future challenges of science teacher education in Chile. *Sci. Teach. Educ.* 63, 8–18.
- Cofré, H. L., Vergara, C., Santibáñez, D., Núñez, P., and McComas, W. (2023). "Biology education: what research says," in *Handbook of Research on Science Education*, eds. N. G. Lederman, D. L. Zeidler and J. Lederman (New York: Taylor and Francis).
- Dahl, J., Anderson, S. W., and Libarkin, J. C. (2005). Digging into earth science: alternative conceptions held by K-12 teachers. *J. Sci. Edu. Bogota* 6, 65–68.
- Davis, N., and Cabello, V. (2024). Modelos científicos escolares sobre placas tectónicas y terremotos en educación primaria (School scientific models about tectonic plates and earthquakes in primary education). *Estudios Pedagógicos* 50, 265–280. doi: 10.4067/S0718-07052024000200265

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- Dove, J. E. (1998). Students' alternative conceptions in earth science: a review of research and implications for teaching and learning. *Res. Pap. Educ.* 13, 183–201. doi: 10.1080/0267152980130205
- Field, A. (2009). *Discovering statistics using SPSS*. 3rd Edn. London: Sage Publications Ltd.
- Francek, M. (2013). A compilation and review of over 500 geoscience misconceptions. *Int. J. Sci. Educ.* 35, 31–64. doi: 10.1080/09500693.2012.736644
- Gobert, J., and Clement, J. (1999). Effects of student generated diagrams versus student-generated summaries on conceptual understanding of causal and dynamic knowledge in plate tectonics. *J. Res. Sci. Teach.* 36, 39–53. doi: 10.1002/(SICI)1098-2736(199901)36:1<39::AID-TEA4>3.0.CO;2-
- Jee, B. D., Gentner, D., Uttal, D. H., Sageman, B., Forbus, K., Manduca, C. A., et al. (2014). Drawing on experience: how domain knowledge is reflected in sketches of scientific structures and processes. *Res. Sci. Educ.* 44, 859–883. doi: 10.1007/s11165-014-9405-2
- Kind, V. (2009). Pedagogical content knowledge in science education: perspectives and potential for progress. *Stud. Sci. Educ.* 45, 169–204. doi: 10.1080/03057260903142285
- King, C. (2000). The earth's mantle is solid: teachers' misconceptions about the earth and plate tectonics. *Sch. Sci. Rev.* 82, 57–64.
- King, C. (2006). Enseñar geología a los profesores de ciencias: La experiencia de la Earth Science Education Unit (ESEU). *Enseñanza de las Ciencias de la Tierra* 12, 142–149.
- King, C. (2008). Geoscience education: an overview. *Stud. Sci. Educ.* 44, 187–222. doi: 10.1080/03057260802264289
- King, C. (2010). An analysis of misconceptions in science textbooks: earth science in England and Wales. *Int. J. Sci. Educ.* 32, 565–601. doi: 10.1080/09500690902721681
- King, C., Gorfinkel, D., and Frick, M. (2021). International comparisons of school-level geoscience education– the UNESCO/IGEO expert opinion survey. *Int. J. Sci. Educ.* 43, 56–78. doi: 10.1080/09500693.2020.1854894
- Kurdziel, J. P., Beilfuss, M., and Libarkin, J. C. (2003). Research methodologies in science education: mental models and cognition in education. *J. Geosci. Educ.* 51, 121–126. doi: 10.1080/10899995.2003.12028056
- Libarkin, J. C., Anderson, S., Dahl, J., Beilfuss, M., Boone, W., and Kurdziel, J. (2003). Qualitative analysis of college students' ideas about earth: interviews and open-ended questionnaires. *J. Geosci. Educ.* 53, 17–26. doi: 10.5408/1089-9995-53.1.17

- Libarkin, J. C., Gold, A. U., Harris, S. E., McNeal, K. S., and Bowles, R. P. (2018). A new, valid measure of climate change understanding: associations with risk perception. *Clim. Chang.* 150, 403–416. doi: 10.1007/s10584-018-2279-y
- McAllister, M. L. (2015). A study of undergraduate students alternative conceptions of earths interior using drawing tasks. *Journal of Astronomy & Earth Sciences Education (JAESE)* 1, 23–36.
- McDonald, S., Bateman, K., Gall, H., Tanis-Ozcelik, A., Webb, A., and Furman, T. (2019). Mapping the increasing sophistication of students' understandings of plate tectonics: a learning progressions approach. *J. Geosci. Educ.* 67, 83–96. doi: 10.1080/10899995.2018.1550972
- McLure, F., Won, M., and Treagust, D. F. (2021). What students' diagrams reveal about their sense making of plate tectonics in lower secondary science. *Int. J. Sci. Educ.* 43, 2684–2705. doi: 10.1080/09500693.2021.1983922
- McLure, F., Won, M., and Treagust, D. F. (2022). Analysis of students' diagrams explaining scientific phenomena. *Res. Sci. Educ.* 52, 1225–1241. doi: 10.1007/s11165-021-10004-y
- Nehm, R. H. (2018). "Evolution" in *K. Kampourakis, and M. Reiss (Eds.). Teaching biology in schools. Global research, issues, and trends* (New York: Routledge), 164–177.
- O'Toole, J., Freestone, M., McKoy, K., and Duckworth, B. (2018). Types, topics, and trends: a ten-year review of research journals in science education. *Edu. Sci.* 8, 1–19. doi: 10.3390/educsci8020073
- Odden, T., Marin, A., and Rudolph, J. L. (2022). How has science education changed over the last 100 years? An analysis using natural language processing. *Sci. Educ.* 105, 653–680. doi: 10.1002/sce.21623
- Orion, N., and Libarkin, J. (2023). "Earth science education," in *Handbook of Research on Science Education*, eds. N. G. Lederman, D. L. Zeidler and J. S. Lederman (Taylor and Francis).
- Parraguez, C., Núñez, P., Krüger, D., and Cofré, H. L. (2023). Describing changes in student thinking about evolution in response to instruction: the case of a group of Chilean ninth-grade students. *J. Biol. Educ.* 57, 1022–1038. doi: 10.1080/00219266.2021.2009006
- Reiss, M. J., and Tunnicliffe, S. D. (2001). Students' understandings of human organs and organ systems. *Res. Sci. Educ.* 31, 383–399. doi: 10.1023/A:1013116228261
- Rivera, M., Cortés, W., Pino, S., Meza, M., Solis, J., and Merino, C. (2025). Climate change perceptions among Andean schoolchildren in Chile. *Front. Edu.* 10:1536271. doi: 10.3389/feduc.2025.1536271
- Rousell, D., and Cutter-Mackenzie-Knowles, A. (2020). A systematic review of climate change education: giving children and young people a "voice" and a "hand" in redressing climate change. *Children's Geographies* 18, 191–208. doi: 10.1080/14733285.2019.1614532
- Rudge, D. W., and Howe, E. (2009). An explicit and reflective approach to the use of history to promote understanding of the nature of science. *Sci. & Educ.* 18, 561–580.
- Skamp, K. (2020). Research in science education (RISE): a review (and story) of research in RISE articles (1994–2018). *Res. Sci. Educ.* 52, 205–237. doi: 10.1007/s11165-020-09934-w
- Steer, D. N., Knight, C. C., Owens, K. D., and McConnell, D. A. (2005). Challenging students ideas about earth's interior structure using a model-based, conceptual change approach in a large class setting. *J. Geosci. Educ.* 53, 415–421. doi: 10.5408/1089-9995-53.4.415
- Torres, J., Moutinho, S., Almeida, A., Pereira, C., and Vasconcelos, C. (2013). "Pupil's mental models of earth internal structure" in *ICERI2013 proceedings (IATED)*, 6368–6376.
- Vergara-Diaz, C., Bustamante, K., Pinto, L., and Cofre, H. (2020). Exploring Chilean seventh grade students' conceptions of earth dynamics before and after model and inquiry-based instruction. *J. Geosci. Educ.* 68, 360–370. doi: 10.1080/10899995.2020.1725406
- Vosniadou, S. (2019). *The development of students' understanding of science*. Front: Edu doi: 10.3389/feduc.2019.00032.
- Vosniadou, S., and Brewer, W. F. (1992). Mental models of the earth: a study of conceptual change in childhood. *Cogn. Psychol.* 24, 535–585. doi: 10.1016/0010-0285(92)90018-W
- Vosniadou, S., and Skopeliti, I. (2017). Is it the earth that turns or the sun that goes behind the mountains? Students' misconceptions about the day/night cycle after reading a science text. *Int. J. Sci. Educ.* 39, 2027–2051. doi: 10.1080/09500693.2017.1361557
- Vosniadou, S., Skopeliti, I., and Ikospentaki, K. (2004). Modes of knowing and ways of reasoning in elementary astronomy. *Cogn. Dev.* 19, 203–222. doi: 10.1016/j.cogdev.2003.12.002
- Vosniadou, S., Vamvakoussi, X., and Skopeliti, I. (2008). "The framework theory approach to the problem of conceptual change," in *International Handbook of Research on Conceptual Change*, ed. S. Vosniadou (London: Routledge).