Conceptions of Moroccan secondary school students in relation to the "Integrative Concept" of plate tectonics

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ABSTRACT

The study of learners' conceptions of geological concepts has been the subject of several studies in the field of earth science didactics. The majority of these studies show that learners have misconceptions that can be an obstacle to learning Earth sciences. The present work aimed to identify the views of second year undergraduate students on plate tectonics to identify some of the barriers to teaching this unifying scientific theory across the different disciplines of the Earth sciences. The data was gathered with questionnaire administered to students in the second year of the Baccalaureate before teaching about plate tectonics. The results of our study confirmed that student learners do indeed have conceptions of plate tectonics and associated phenomena but have great difficulty in mobilizing their knowledge to explain geological phenomena related to plate tectonics. These difficulties may have several origins: the nature of the geological knowledge transposed, and the very limited knowledge of teachers with a bachelor's degree in Biology.

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1. INTRODUCTION

Geology is a diachronic science, relating to phenomena that occur over time [1]. It aims to define both the present functioning of the planet and the reconstitution of its history. Geology is both a historical and functionalist science: functionalist geology studies current geological phenomena, both external (erosion and sedimentation) and internal (volcanoes and earthquakes), which are explained by the model of plate tectonics; whereas historical geology reconstructs the Earth's past; this past is interpreted based on field evidence of geological phenomena in geological formations [2], [3].

The earth sciences (ES) have experienced the emergence of the well-known and major theory called 'plate tectonics' which was accepted by the scientific community in 1968, and introduced for the first time into the Moroccan curriculum in 1994. The theory of plate tectonics has not only contributed to the comprehension of the dynamics, functioning and history of the Earth, but has also unified several fields of study in the Earth sciences (petrography, volcanology, sedimentology, paleontology, stratigraphy, and tectonics) and has given rise to new sciences such as geodesy, geostatic, geophysics, and geochemistry [2].

The acquisition of information and knowledge is not a simple passive process, but is a very complex process through which the learner learns and acquires new knowledge. A simple mechanical repetition of knowledge could not ensure its acquisition by the learner; it requires mental operations that take place spontaneously [4]. Explaining how the learning process occurs and evolves in the learner has been the subject of several research studies in science didactics [5]–[8].

the previous state of the learner's structure as the primary factor influencing new learning [9]. Good learning is a dynamic process that associates any new knowledge with cognitive structure. The learner's cognitive structure already holds an initial conception of the concept, and through the contribution of new knowledge undergoes modifications and specific changes, responsible for meaningful learning. Research in science didactics has focused on the learners' conceptions from a constructivist perspective [7], [10]. Many studies have shown the importance of considering the individual's conceptions of a given subject in the context of his or her training [7], [11] because they often constitute real obstacles to the improvement of teaching-learning processes and the professional development of teachers.

Understanding these conceptions, their origins and their analyses is an indispensable step towards the effective designing of both teacher training program and curricula. The didactic approach underlines that effective teaching must take into account the identified conceptions, analyze how they hinder the acquisition of a scientific concept, and invent teaching strategies focused on these obstacles to overcome them. Indeed, learners' conceptions guide us in giving answers (finding solutions) to the problems posed by learners, and we cannot neglect them when learning any subject [7]. It should be noted that 12th grade students have been introduced to the theory of plate tectonics in the eighth grade.

Plate tectonics is a major theory that is central to the Earth sciences and, therefore, constitutes an important part of teaching and learning at the secondary and university levels. Like other geological concepts, the theory of plate tectonics seems problematic for teachers and learners alike for a variety of reasons. However, the issue of science teaching and learning in general, is not new; it has been the subject of much debate over the past several decades. Difficulties in the teaching and learning of Earth sciences are related to its interdisciplinary nature. This is supported by its interaction with physics, chemistry and mathematics, which provide a pathway to the understanding of geological phenomena. Moreover Earth sciences are broadly related to both space, where learners have difficulty moving between a 2D plane to volume (3D), and also the notion of time, which is measured in millions of years [12], [13]. Furthermore, such difficulties are related, among other things, to the academic career path and teaching practices [14]. Some of these characteristics specific to science teachers have contributed to the devaluation of this discipline among learners and teachers, as the works of several researchers confirms [2], [15]–[17].

For us, being interested in learners' means being particularly interested in knowing their conceptions in order to adapt teaching and learning. Conceptions correspond to an individual's organized and structured knowledge, which will be mobilized in a given situation; this is also a way of conceiving reality by mobilizing previous knowledge [8], [9]. In recent decades, there has been a proliferation of work in Earth science didactics that focuses on the study of learners' conceptions and their didactic consideration in teaching and learning [18]–[25]. In Morocco, little research has been published on learners' conceptions of geological concepts and phenomena [18], [23]. This work focused on the study of earthquake-related conceptions among students in the 7th grade, and those related to volcanoes among both Moroccan students in the 2nd year of high school (11th grade) and future teachers of life and earth sciences (SVT). Students, teachers and future teachers may have the same conceptions of earthquakes and volcanoes. Consistent with the previous work and aware of the importance of taking into account learners' conceptions when considering learning, we have chosen this topic through which we seek to identify the conceptions of learners in the 12th grade (2nd year Bac) about plate tectonics and concepts linked to it as shown in Table 1, by looking for their underlying sources. Therefore, two main questions guided our study: i) What are the views of twelfth grade students (second year Baccalaureate) on the 'integrative concept' of plate tectonics?; ii) How do these learners explain geological phenomena related to plate tectonics?

Table 1. Contents of internal geodynamics in the SVT-middle school program (Edition 2009)

Unit title	Contents to be taught	Hourly volume
Internal geological phenomena.	Theory of plate tectonics: Proofs of continental drift; Plate concept	4h (4/28)
	The relationship between plate tectonics and internal geological phenomena: Earthquakes, volcanism, tectonic deformations	4h (4/28)
	Formation of magmatic rocks, and contact metamorphism	6h (6/28)
	Formation of mountain ranges: General tectonics	4h (4/28)
	Structure of the globe	2h (2/28)

2. RESEARCH METHOD

To identify learners' conceptions of plate tectonics, we chose an anonymous questionnaire (Appendix) as an investigative tool as presented in Table 2. It should be noted that some items (items 2, 5, and 7) in our questionnaire are based on validated questionnaires [12], [21]. The other items (items 1, 3, 4, 6, 8, 9) were developed by us based on the objectives of the SVT program on the unit of internal geodynamics (Table 2). The proposed items are varied (open-ended questions and multiple-choice questions). Some items correspond or intersect with each other, which will allow us to cross-check the information collected. The items are formulated in Arabic and at a scientific and linguistic level that is accessible to the learners. Our questionnaire was validated by didactic specialists, educational inspectors, trainers from the Ecoles Normales Supérieures (ENS), Regional Centers for Education and Training Trades (CRMEF), and secondary school teachers from the SVT Department.

We tested this questionnaire among 11 learners by asking them to answer the questions and to let us know if they did not understand certain questions so that they could be reworded or removed. The sample is composed of 165 participants (male and female students) in the second year of the Baccalaureate, aged between 17 and 18. These students are spread over five classes in four public high schools in the directorate of Chtouka Ait Baha Academy in Sous Massa-Agadir, Morocco. The choice of establishments was related to ease of access. The questionnaire was administered during the practical sessions (reduced number of students), under the supervision of the SVT teachers of the chosen classes, and the students answered as soon as the copies of the questionnaire were distributed by the teacher. The statistical analysis of the responses was performed using IBM statistical package for the social sciences (SPSS) 22. The percentages that appear in the tables are expressed according to the number of people questioned.

Table 2. Objectives of the questionnaire questions

Questions	Objectives of the questions
Q1: Open question	To gain an idea of what learners think about plate tectonics.
Q2: Multiple choice closed-ended question	To know the drivers of plate tectonics.
Q3: Open question	To distinguish between a continent and a lithospheric plate.
Q4: Multiple choice closed-ended question	To know the sources of heat inside the Earth.
Q5: Open question	To have an idea about the volume variation of the globe.
Q6: Open question	To know the causes of earthquakes.
Q7: Multiple choice closed-ended question	To establish the relationship between magma formation and plate tectonics.
Q8: Multiple choice closed-ended question	To master the conditions of mountain range formation.

3. RESULTS AND DISCUSSION

3.1. Learner's conception of plate tectonics

The first question, which asked the students 'What words do you think of when you hear the term Plate Tectonics?', focuses on concepts and phenomena that learners can mobilize and enunciate spontaneously. After reading all the students' answers, we tried to group them into categories, some answers were assigned into one or more categories. The categorization of learners' responses was carried out according to the main themes and axes of the teaching unit. Table 3 summarizes all the categories under which we classified learners' responses, and the frequencies of the different words generated by the learners.

Analysis of the students' responses (Table 3) reveals that 65% of them associated plate tectonics with earthquakes, and 62% to volcanism. This is normal, since these concepts represent major parts of the curriculum taught at secondary college level (8h/28h), in addition to the fact that these concepts are more widely covered by the various media. 22% of learners mentioned continental drift, while 16% of learners thought of mountain range formation and plate subduction (15%), these concepts represent (8h/28h) the middle school curriculum.

On the other hand, some learners thought about tectonic deformations (10%) and concepts related to the structure of the Earth (16%), continents (15%), and lithosphere (9%). From this quantitative analysis of the first open-ended question, we deduced, in general, that the learners were able to mobilize and think about the essential geological concepts, notions and phenomena related to the integrative concept of plate tectonics. These concepts and notions mobilized by the learners in our sample represent the key elements of the remaining items in our questionnaire.

Table 3. Learners' conceptions of the concept of plate tectonics

Category	Words	Word frequency (%)
Category 1: Geological phenomena	Earthquakes (earthquake, earthquake focus, tsunami)	65
	Magmatism (volcano/magma)	62
	Mountain ranges	16
	Tectonic deformations (Fault, Fold)	10
Category 2: Plates/Platter Boundaries	Plate Subduction	15
	Collision	5
	Oceanic and continental plate	4
Category 3: Structure of the earth	Earth globe/Earth	16
	Continents	15
	Lithosphere	9
	Oceans/Sea/Ocean floor	4
	Oceanic crust	2
	Earth core	2
	Hills	1
	Islands	1
Category 4: Movement and causes of movement	Continental drift	22
	Removal of the plates	11
	Mobility	8
	link of the plates	5
	Ebb and flow	2
	Convection currents	2
Category 5: Rocks	Rocks	10
	Magmatic rocks (Basalt, Granite)	4
	Geological layers	3
	Sedimentary rocks (Clay, Silt)	2
Category 6: Climatic phenomena	Thunderstorms	1
	Greenhouse effect	1
Category 7: Names of persons and countries/General words	Geology	9
	Africa/America	1
	Wegener	1

3.2. Theory of plate tectonics

3.2.1. Plate tectonic engines

Most of the learners mobilized tectonic causes responsible for plate tectonics that were incorrect, such as seismic activity (67%) and volcanic activity (33%). Almost 40% of the learners surveyed identified incorrect non-tectonic causes, such as the ebb and flow of the oceans and seas. While, 27% of the learners consider convection currents to be the driving force behind the mobility of lithospheric plates as presented in Table 4. This was the driving force adopted by the scientific community in 1970, and one still found in life and Earth science curricula and textbooks.

We also noted that none of the learners mentioned subduction as a factor responsible for plate tectonics. Learners' responses to this question were truly surprising. Most misconceptions can be linked to several reasons, on the one hand to geological knowledge transposed at the textbook level, and on the other hand to the very limited knowledge and the misconceptions of life and Earth science teachers.

Table 4. Learners' conceptions of the drivers of plate tectonics

Factors responsible for TPQ (Responsible factors)	Percentages (%)
Other factors	6
Convection currents	27
Volcanoes	33
Earthquakes	67
The ebb and flow of the oceans (The tide)	16

3.2.2. Difference between a continent and a lithospheric plate

Three-quarters of the learners identified that there is a difference between the continent and the lithospheric plate, while one quarter of respondent learners think that it is the same as can be seen in Figure 1. From this it can be deduced that the latter have associations between continental drift and plate tectonics. Subsequently, we asked learners in the first category to clarify this difference between the continent and the plate. We classified their answers as displayed in Table 5. Even though they identified that there is a difference between the continent and the plate, 60% of these learners were unable to clarify this difference; while 29% of the responding learners mentioned misconceptions about the two concepts. Only 11% were able to distinguish and describe the differences between these two notions.

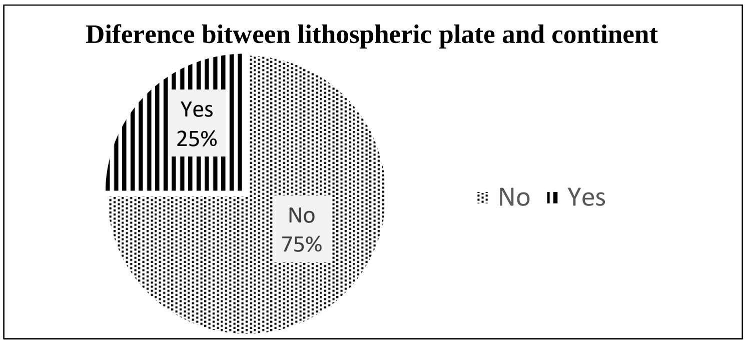

Figure 1. Conceptions of the difference between lithospheric plate and continent

Table 5. Learners' conceptions of the difference between continent and lithospheric plate

	Effectives	Percentages (%)
Non-respondent	74	60
Confusion between continent and plate	36	29
Distinction between continent and plate	13	11

3.2.3. Sources of temperature increase with depth

In question 4, we asked the responding learners to write down the sources and origins of the increase in temperature in the Earth's interior. Learners' responses were very diverse. Table 6 summarizes the different categories obtained. Where an answer contained more than one or two conceptions, they were classified under several categories.

Table 6. Categorization of learners' responses regarding sources of temperature

Categories	Percentages (%)
Category 1: Magma (Magma/volcano/lava)	27
Category 3: Core of the earth, center of the earth	7
Category 4: Climate change/greenhouse gases/pollution/ sunlight/ozone hole/atmospheric pressure	7
Category 5: Plate tectonics/Plate collision/Convection currents/Subduction	5
Category 6: Depth/pressure	5
Category9: Disintegration of radioactive elements	1

There were 27% of the responding learners say that the origin of the temperature increase is related to magmatism (volcanoes and magmas located in the interior of the Earth). While, 7% of them link the rise in temperature to the thermal energy released by the Earth's core. A minority of learners (5%) make use of the contact zones of lithospheric plates (collision, subduction) and the variation in depth (lithostatic pressure). However, 7% of the responding learners link this increase in temperature to external factors such as climate change, the greenhouse effect, the sun.

On the other hand, only 1% of learners reported the decay of radioactive elements within the Earth's interior, which is considered by the scientific community to be the primary source of heat within the globe. These conceptions are purely of media origin or knowledge learned in ecology and environmental sciences. These representations call into question the relationship that the teaching of geological phenomena has with time and space.

3.2.4. Variation in the volume of the globe

It is well known that there are geological phenomena that reduce the surface of the Earth, such as subduction, and other geological phenomena that compensate for this reduction, the extension at the level of the oceanic ridges, which causes the stability of the volume of the terrestrial globe as a function of time. According to the results in Figure 2, the majority of learners (88%) identify that the volume of the Earth remains stable, and few (4%-5%) think that the volume of the Earth increases or decreases with time. No learner checked off all three choices at the same time.

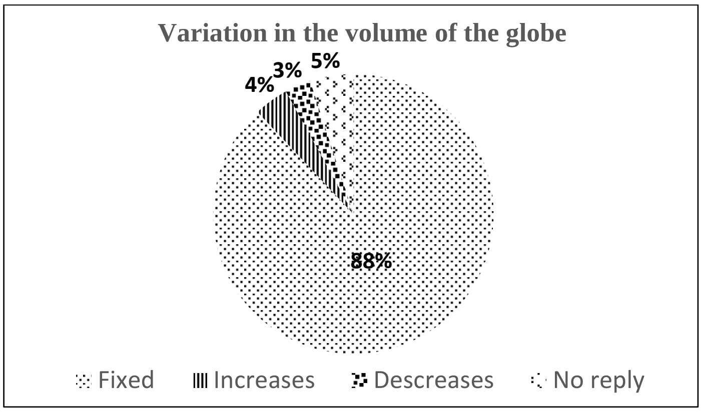

Figure 2. Learners' conceptions of the variation in the volume of the globe

3.3. Geological phenomena associated with plate tectonics
3.3.1. Origin of earthquakes

This question deals with the factors that trigger earthquakes; the results are presented in the Table 7. More than 80% of the learners surveyed were able to explain how earthquakes occur within the framework of plate tectonic theory. However, 19% linked earthquakes to volcanic flows. And a minority of learners thought that earthquakes are due to the rotation of the Earth (3%), military bombs (1%), and convection currents. Around 11% of learners linked the functioning of earthquakes to other factors without specifying them. We also found that the learners did not mention tectonic deformations (faults, overlapping, folding) as factors triggering earthquakes.

Table 7. Learners' conceptions of the origin of earthquakes

What are the factors that trigger an earthquake?	Effectives	Percentages
Other factors	18	11
Plate Tectonics	140	85
Bombs used in war	02	1
The rotation of the globe	05	3
Volcanic flows	31	19

3.3.2. Magmatism and plate tectonics

Regarding item (a) on the distribution of volcanism on a global scale, the majority of responding learners (96%) identified that volcanoes are not distributed all over the globe as seen in Figure 3, i.e., there is a distribution in specific locations of the Earth, which is consistent with the interpretive theories adopted by scientists. Table 8 summarizes their very diverse responses, which we have classified into several categories.

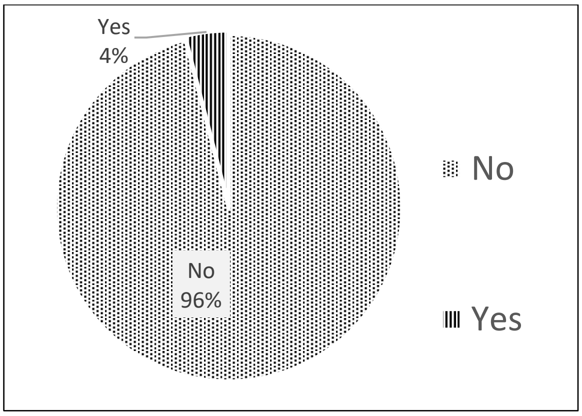

Figure 3. Learners' conceptions of the distribution of volcanoes

Table 8. Categorization of learner responses from the explanation distribution of volcanoes

Categories	Staff	Percentages
Category1: Mountain areas/mountain peaks/Himalayas	46	27%
Category 2: Names of geographical areas (continents, countries)	27	16%
Category 3: Extension Zone (mid-oceanic ridge)	20	12%
Category 5: Coastal areas/Equatorial areas/Warmer areas.	10	6%
Category 6: Subduction Zone	7	4%
Category 7: earthquake zone	1	1%
Category 8: No reply	The rest	38%

3.3.3. The process of mountain range formation

The aim of this question is to identify the learners' conceptions of mountain range formation. The Table 9 summarizes the different explanations given by the learners about orogeny. There were 30% of the students started with plate tectonics as the main factor in the formation of mountain ranges (orogenesis), with a few geological phenomena contributing to its formation, mentioning, for example, the coming together of plates, collision between them, subduction, yet the majority failed to produce scientific interpretations and explanations of the processes causing the formation of mountain ranges. The other 12% of the learners mentioned volcanic activity as the cause of orogenesis and 8% of the learners linked the formation of mountain ranges to external geological phenomena (sedimentation, wind erosion). Another two learners considered the areas of divergence between plates (oceanic ridges) as areas characterized by the formation of mountain ranges. Most of the learners tried to mobilize their knowledge and skills to explain the genesis of mountain ranges, but the content of their answers shows that they were unable to explain the mechanisms of this geological phenomenon.

Table 9. Explanation of the formation of mountain ranges (Orogenesis)

Categories	Learners' conceptions of mountain range Formation	Effectives	Percentages
Category 1	Plate Rapprochement/Lithospheric Plate Collision, Compressive Stresses, Subduction of one lithospheric plate under another	50	30%
Category 2	Volcanic activity, accumulation of volcanic lava	20	12%
Category 3	Accumulation of soils and rocks on top of each other, over millions of years, Accumulation of sedimentary layers, Erosion (wind), sedimentation, compaction,	13	8%
Category 4	Earthquakes (Earthquakes)	12	7%
Category 5	The ebb and flow of the oceans and seas.	9	5%
Category 6	Distension/Removal of lithospheric plates.	2	1%
Category 7	Answer difficult to classify	20	12%
Category 8	No answer	61	36%

3.4. Discussion

Several research studies have examined learners' conceptions of notions related to plate tectonics; we will discuss the results obtained in our study in the light of these studies. Our survey showed that the learners did not report subduction as the main driving force of plate tectonics, especially since a great deal of geological research shows that the lithosphere is the proper driving force of its mobility and tectonics. And it is especially the density of older lithospheres plunging into the asthenosphere that is the cause of the movement of lithospheric plates. The 1970 version of the plate tectonic model tended to overestimate the role of oceanic ridges in relation to subduction. But currently ridges are considered to be mostly passive, and only compensate for subduction [26], [27]. During the first years of the construction of the theory of plate tectonics, geologists believed that the plunging lithosphere did not exceed 670 km in depth, either by disappearing by acquiring a temperature equal to that of the surrounding asthenosphere, or by sliding horizontally on the surface of the discontinuity at 670 km. Seismic tomography, which was absent prior to 1970, has shown that submerging oceanic lithospheres often cross the 670 km limit and can reach the mantle-core boundary [26].

Of course, these elements of interpretation have not been introduced into life and Earth science curricula and textbooks to date. Indeed, the early version of the plate tectonic model overestimated the role of magmatism in the action of ocean ridges. Magmatism, which results from the partial melting of the mantle that rises beneath an oceanic ridge, is the consequence of the functioning of ridges, not its cause. This finding is reinforced by the discovery of ridges functioning without magmatism and ocean bottoms without the crust [26]. The same is true for earthquakes, which are one of the consequences of plate tectonics and not its cause. As for the origin of earthquakes, a study by Chalak and El Hage in Lebanon [21] also showed that a significant number of students (77% of first and Terminal years) referred to the theory of plate tectonics to explain the functioning of earthquakes. And that the earlier model of Fixism, considered as an epistemological obstacle, appears to have influenced the majority of learners.

The same research stressed the need to be cautious in interpreting these results, and the value of properly measuring the level at which learners use this theory to explain earthquakes. For our part, we confirm this observation, especially since these same learners (67%) considered seismic activity as a factor responsible for plate tectonics (analysis of the sixth question); hence, the need to deepen these results to clearly identify the conditions under which learners use plate tectonics theory to explain the geological phenomena associated with them.

Several research studies have been carried out on learners' conceptions of the origin of lava [18], [20], [21], [28]–[30] which have also shown the inability of learners to relate volcanic activity to plate tectonics. Boughanmi's study, which focused on the learners' conceptions of the formation of subduction chains, showed that each learner mobilized part of the knowledge acquired concerning the formation of subduction mountain ranges, the explanation of the phenomenon was never globalizing, and that the learners encountered enormous difficulties in understanding this geological phenomenon that is not perceptible to human apprehension. Only 10/58 were able to mobilize notions that go back to the mechanisms of mountain chain formation. The diversity of explanations for mountain range formation poses problems in understanding the processes of mountain range formation [12].

4. CONCLUSION

Conceptions correspond to the organized and structured knowledge of an individual, which are mobilized in a given situation. It is also a way of conceiving reality by mobilizing previous knowledge. Scientific research in the fields of teaching-learning agrees on the importance of teachers taking into consideration the learner's conceptions, on the one hand, because the learner has become the center of teaching-learning processes and the main actor in the construction of his or her own knowledge. And on the other hand, these conceptions offer the teacher a multitude of procedures that would facilitate learning. However, the use and exploitation of learners' conceptions has become complex and difficult because they are influenced by other factors, in addition to classroom instruction, such as the media and all the tools that enrich their own cultures and contribute to changes on the level of their cognitive structures.

The results of our study confirm that high school students, who already have previously acquired knowledge related to plate tectonics (content already started in a unit in the second year of secondary school: the theory of plate tectonics, its relationship with internal geological phenomena, the formation of magmatic rocks, and the formation of mountain ranges), do indeed have misconceptions about plate tectonics and the phenomena associated with them. They also find it very difficult to mobilize their knowledge to explain geological phenomena related to plate tectonics. These difficulties could be related to several reasons, namely to the nature of the geological knowledge taught especially in relation to problems of time and space, to the methods and approaches adopted in the teaching of chapters and units related to internal geodynamics which are often analytical and non-systemic, and also to the very limited knowledge of the teachers, especially those specialized in life sciences. Furthermore, the curriculum has been slow to adopt the modifications already validated by the scientific community on the theory of plate tectonics, especially as the evolution of technology has made it possible to overcome and evolve the analogical theories of the 1960s (1960-1970). Based on the results obtained from our research, we were able to identify several benchmarks that can help teachers to overcome difficulties in the construction of knowledge: i) Diversifying the didactic situations and pedagogical approaches adopted by teachers which allows to change their frames of reference and correct any misconceptions about the scientific concepts and phenomena taught; ii) Adopting a systematic approach that allows the relationships between the different elements of the internal geological phenomena that are related to plate tectonics to be identified and the reactions between them to be recognized. This approach emphasizes the global perspective when studying these phenomena and makes it possible to study several variants at the same time, with theories that are simple to use even though they are not often precise. The adoption of this type of approach is made easier by the presence of a unifying and integrating concept, which is "plate tectonics"; iii) Exploiting various didactic situations concerning/explaining the causal relationship between plate tectonics and earthquakes/volcanoes; iv) Using theories about the relationship of Earth sciences to time and space; v) Using ICT in the teaching-learning of complex geological phenomena; vi) Taking into consideration the abstraction capacity of the learners (psychogenetic obstacles), although the popularization of science sometimes omits the scientific basis for the geological concepts and phenomena taught.

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APPENDIX

Questionnaire

Establishment: ……………………………………			**City or town:** ……………
Age:	Gender: Male ☐	Female ☐	

1. ***What words do you think of when you hear the phrase 'Plate Tectonics'?***

....

2. ***What drives the mobility of lithospheric plates?***
   - Ebb and flow movement ☐
   - Earthquakes ☐
   - Convection currents ☐
   - Volcanoes ☐
   - Other factors ☐

3. ***a. Are there differences between the continent and the lithospheric plate?***
   Yes ☐ No ☐
   b. If so, please specify these differences:
   ....

4. ***What is (or are) the source(s) of the temperature increase inside the Earth.***

....

5. ***The volume of the globe***
   Increases ☐ Decreases ☐ Is fixed ☐

6. ***Earthquakes are caused by:***
   - Volcanic flows ☐
   - Rotation of the globe ☐
   - Military bombs ☐
   - Movement of lithospheric plates ☐

   Other sources: ……

7. ***a. Do volcanoes exist all over the globe?***
   Yes ☐ No ☐
   b. If the answer is 'No', specify the geological zones characterized by volcanic activity:
   ....

8. ***Cite the processes of mountain range formation (orogenesis)***

....