Bilingual Students' Ideas and Conceptual Change About Slow Geomorphological Changes Caused by Water

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ABSTRACT

This paper presents the results of an experiment investigating the development of elementary-school dual-language learners' conceptual knowledge about processes of erosion, deposition, and transportation caused by water movement. To elicit students' ideas, researchers asked students to answer four open-ended questions using written answers and/or drawings. Students' responses were analyzed, and misconceptions were organized in a systemic network. A semiquantitative analysis was conducted to investigate changes in students' number of misconceptions as a result of a science and reading instructional sequence. Forty-nine fourth-grade students participated in this investigation. Eleven misconceptions were identified in relation to erosion processes. The science and reading intervention, which focused on the use of cognitive strategies, was effective at reducing the number of misconceptions students held. Changes in the number of misconceptions were significant for four misconceptions explaining slow geomorphological changes based on (1) unnatural explanations, such as magical or man-made explanations; (2) accumulation rather than erosion; (3) forces other than gravity cause water to move; and (4) nonlandform interpretation of terms. Particular aspects of the intervention that could explain these changes are discussed.
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Key words: science, reading, earth science, bilingual, conceptual change, misconceptions

INTRODUCTION

The purpose of this paper is to investigate the development of dual-language learners' conceptual knowledge about the processes of erosion, deposition, and transportation caused by water movement. We are interested in understanding children's initial knowledge about erosion and in finding out how this knowledge changes as a result of an inquiry-based science and reading intervention (Instruction on Science and Reading [*INSCIREAD*]).

Children's Earth Science Conceptions

Several studies have been conducted that investigate students' ideas in different areas. For example, there have been studies about Earth's shape and gravity (e.g., Vosniadou, 1992), and lunar phases (e.g., Happs, 1985). However, a breadth of research in the area of students' conceptions about geosciences concepts is lacking (Manduca et al., 2002). More specifically, as Table I shows, prior work has covered a variety of topics in earth science, such as Earth's structure (e.g., Blake, 2005), groundwater (e.g., Dickerson et al., 2005), or watersheds (Shepardson et al., 2007). Some studies have identified misconceptions about specific landforms such as mountains (e.g., Happs, 1982).

Between 1982 and 2009, there have been several studies dealing with research specifically addressing conceptions about Earth processes. The studies have investigated students' understanding of the hydrologic cycle (Bar, 1989; Shepardson et al., 2009), the water cycle (Taiwo et al., 2001; Ben-zvi-Asarf and Orion, 2005), rock, water, and carbon cycles (Sibley et al., 2007), and complex Earth systems (Sell et al., 2006). The findings for these studies are summarized on Table I.

Only a few works have directly addressed erosion and weathering (Russell et al., 1993; Dove, 1997). Dove (1997) used a survey on 236 students, aged 16–19, to ascertain details of their ideas about these two terms. He found that the main idea these students used to discriminate between weathering and erosion is movement. A majority of students in this study appreciated that weathering occurs in situ, whereas erosion involves transport. Many participating students regarded weathering as solely related to atmospheric elements. Human actions were perceived by these learners as types of accelerated erosion, but uncertainty surrounded whether animal activities are bioerosion or biological weathering.

Blake in his 2005 study investigated students' conceptions in relation to Earth structure, including the processes of erosion and weathering. Using drawings, questionnaires, and semistructured interviews, he looked at the concepts of 115 students between 7–11 y of age from a primary school in England. His findings indicated that in weathering, when shown the picture of a weathered gravestone, most students' responses were protoscientific (beginning to develop some understanding but still limited), indicating that they were able to recognize that it was a natural process, which also occurred to mountains and cliffs, but inconsistently understood that the process would continue to operate in the future, and sometimes were able to cite a cause. Some of these children incorrectly thought "age" was a causal agent.

In relation to erosion, Blake (2005) found that these young children showed a good understanding of the concept, with half the interviewees (non-age-related) showing a scientific understanding (scientifically consistent).

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TABLE I: Prior work in children's Earth processes conceptions.

Study Population	Relevant Findings	Reference
Earth's Structure		
115 students (7–11 years)	-Underground drawings were mostly Non-Scientific or Proto-Scientific -Volcanoes: Every child interviewed demonstrated a Proto-Scientific level -Mountain building: Most children showed a Proto-Scientific understanding -Rock formation: Non- or Proto-Scientific responses, latter increasing with age	Blake, 2005
Groundwater		
29 secondary and 44 postsecondary	-Many people held inappropriate conceptions of hydrogeologic principles -Groundwater storage described using multiple structures other than pores and crack -Wide range of ideas concerning scale	Dickerson, et al., 2005
Watersheds		
915 students from the Midwest, United States	-Different conceptions of a watershed -Literal representation of the words "water" and "shed" in combination -The watershed concept not connected to their everyday world -Lack of understanding of humans as part of a watershed -Poor watersheds conceptions retained from elementary through high school	Shepardson, et al., 2007
Mountains		
37 students	-Views about the two mountains likely to be different from scientific ideas -63% not aware that Mount Egmont has the potential to erupt again -Most students had not attained an appreciation of plate tectonics	Happs, 1982
Hydrologic Cycle		
1,298 students, grades 4–12 from the Midwest, USA	-Portrayed the hydrologic cycle in the context of mountain or coastal landscapes that are common in textbooks but that were not representative of the environments where students lived	Shepardson, et al., 2009
Water Cycle		
1,000 junior high school students from six urban schools, in Israel	-Understanding of various hydro-bio-geological processes, but lacking the dynamic, cyclic, and systemic perceptions of the system -Incomplete picture of the water -Most ignored the groundwater part of the water cycle -When underground system was included, it was perceived as static	Ben-zvi-Asarf and Orion, 2005
255 Botswana students (4 to 7)	-Perception of water cycle was positively influenced by schooling but negatively impacted by the 'untutored' ideas the children brought to school	Taiwo, et al., 2001
Rock, Water, Carbon Cycles		
240 students in university geology course	-Many students lacked the critical ability to recognize parts of a system that are not readily apparent or visible	Sibley et al., 2007
Complex Earth Systems		
15 juniors & seniors enrolled at University	-Conceptual model expressions could be used as a predictor of inquiry-based learning modules -Students had difficulties reasoning about multivariable causality	Sell et al., 2006

However, the author was able to only evaluate this concept in terms of causation. During the evaluation, children were able to explain that an eroded pebble had once been larger and more angular, and some of them recognized a natural cause (e.g., wind or running water), but not the more scientific reason of abrasion with other rocks.

In a similar vein, Sexton (2008) explored the conceptions of rivers held by 24 college students via in-depth interviews. She collected demographic data and analyzed the results looking at ethnicity. Her work yielded several findings indicating that students held mostly scientific and incomplete scientific conceptions of the nine river topics covered in the study, and that these conceptions were complex. Students had more alternative conceptions for processes, causes, and difficult-to-observe features. She also observed that Hispanic students held incomplete scientific-alternative and alternative conceptions more frequently than did Caucasian students.

As shown by the research just presented, the misconceptions in relation to the term erosion held by young students who come from diverse backgrounds and who are learning English remain unclear. Part of the issue with the concept of erosion is caused by the fact that it is concerned with the lowering of the land surface and involves processes that operate over a long time period. A recent geoscience research review (Cheek, 2010) revealed that students have a poor conception of scale when something is outside their ability to observe it directly. It has also been shown that students have the idea that things do not change (Kortz and Murray, 2009). Duration in geologic time deals with the ability to conceive processes that occur at very slow rates and therefore require very long periods of time, such as the process of erosion. Most research into students' conceptions of geologic time has dealt with temporal succession, rather than duration in geologic time.

Language has an important role in learning in geoscience. The research in relation to language issues is presented in the next section.

Language and Conceptual Learning in the Geosciences

When working with bilingual diverse populations, we not only must recognize that students' misconceptions are rather persistent, but we also must explore ways in which teachers can stimulate a contextually driven dialogue between the individual's personal-, sociocultural-, and physical-driven concepts, and those aligned with accepted scientific explanations (Falk and Dierking, 2000).

Some studies have looked at children's perceptions of landforms by asking them to provide definitions of a wide range of geographical terms (Lunnon, 1969; Milburn, 1972; Platten, 1995). In her literature review, Cheek (2010) also found that misapplication of terminology is a factor in Earth processes. In the previously mentioned study investigating college students' understanding of the distinction between weathering and erosion conducted by Dove (1997), he found that erosion was seen as a physical process not related to weather elements, and that students appeared to be reasoning on the basis of the common etymology of weather and weathering. Other investigators have identified the use of everyday language as a problem (Kusnick, 2002; Kortz and Murray, 2009).

Kortz and Murray (2009) noticed in their investigation with eight college-level students that reasonable statements made by students may actually be hiding incorrect mental models. They also explained that teachers often make statements thinking that they are extremely clear and obvious. However, because of the underlying conceptual barriers the students may hold, these statements could be misinterpreted. For example, their investigation showed that when the teacher states that "it takes a long time for rocks to form," the students will think in terms of their own lives, and most will place the time scale to be hundreds to thousands of years, which makes it impossible for students to understand slow processes.

Kusnick (2002) conducted an investigation in which 24 college students planning to become elementary-school teachers wrote stories explaining how rocks form. Twenty-five percent of the students spoke English as their second language. Kusnick found that a startling number of students described rocks forming by processes no geologist would recognize. The researcher identified four proposed prisms that explained the range of misconceptions as interactions of belief systems with instruction. According to the author, prisms are generated as the individual's world view interacts with meaningful experiences to produce belief. The first of such identified prisms referred to a mismatch in communication between teacher and student, in which the instructor assumes that the student always uses the technical meaning of a term. Kusnick explained that when we use words that have both a common meaning (e.g., rock) and a technical meaning, we must be very clear which meaning we intend.

In conclusion, there is indication from the literature that when educating bilingual individuals, attention must be paid to the development of scientific vocabulary, with special emphasis on the transferring of terms across students' languages, particularly when working with students who speak romance languages (Cummins, 2001; Lambert and Whelan Ariza, 2008), and in negotiating meaning (Faltis and Coulter, 2008). Additionally, it is essential for teachers to utilize students' funds of knowledge (Moll, 1992) and allow the use of any linguistic resource they might have in order to facilitate conceptual and language development.

THEORETICAL FRAMEWORK

The work presented in this research paper is examined under the light of theories of conceptual change from a constructivist perspective. An assessment of students' prior knowledge of scientific concepts is necessary for teachers to design quality, meaningful lessons. Research has shown that learning includes changing how students think about a concept, rather than simply accumulating knowledge (Shiland, 2002). Instead of teachers pouring new knowledge into the minds of their students, constructivists believe that students already have ideas about how the world works (Piaget, 1965/1969). Based on this understanding, scientific knowledge is a result of a progression of movement from everyday knowledge to new ideas, and finally to student understanding of those ideas. This construction of knowledge is shaped through social interactions with members of the community and culture (Vygotsky, 1986).

Students tend to retain a misconception that makes sense rather than accept scientific explanations that are in conflict with their common sense beliefs (Stepans et al.,

1986). Because students, particularly dual-language learners, come to science classrooms with different cultural, educational, and personal experiences, they come with different mental models (Glynn and Duit, 1995). Learning science requires students to reflect on their existing mental models and build new conceptual models (Glynn and Duit, 1995; Greca and Moreira, 2000).

In this research report, we use the term misconceptions to refer to prior concepts that individuals use to explain concepts and processes in the physical world (Kendeou and van den Broek, 2005) that have been found to hinder learning (Alvermann et al., 1985) because they are markedly different from the concepts of the teaching program.

RESEARCH QUESTIONS

Based on this review and framework, the present study aims to contribute to the field of earth science by addressing the following research questions:

(1) What are students' ideas about the processes of erosion, deposition, and transportation caused by water movement?
(2) In what ways might students' ideas about erosion change as a result of the *INSCIREAD* intervention?

METHOD

This section describes the participants and setting, and the design and procedure for this investigation.

Participants and Setting

The research study was conducted in a suburban elementary school in the eastern United States, serving children in kindergarten through fifth grade. At the time of this investigation, enrollment was 609 students, 187 of whom were English-language learners, and 52 of whom received special education services. The school follows a language immersion program in which all students learn math, science, and language arts in Spanish. All students are learning a second language, either English or Spanish.

The primary researcher worked at the school as a special education teacher, and she had been working as a bilingual teacher there for over 10 y. She acted as a teacher–researcher during the investigation. She was a graduate student specializing in special education for bilingual students and had been teaching science for 10 y at the time of the investigation.

Forty-nine fourth-grade students, ages 9 to 10, participated in the instructional sequence. The reason for choosing this particular grade level is that fourth grade is where students start encountering informational texts that present a real challenge for English-language learners. In addition, the Standards of Learning for upper elementary science curriculum in the state where the school was located included slow changes and the processes of weathering and erosion. Specifically, the fifth-grade Standard 5.7 for Earth Patterns, Cycles, and Change stated, "the student will investigate and understand how the Earth's surface is constantly changing" (Commonwealth of Virginia Board of Education, 1995, p. 16). Furthermore, it is specified under the same Standard 5.7 that one of the key concepts to investigate is weathering and erosion. Students were exposed to this fifth-grade material in fourth grade.

The distribution of students to their three respective classes tended toward a balance of girls and boys and of other general students' characteristics within the same class in this school. Due to the prerequisite for conducting this research in this school, the researcher did not alter these existing groups for the intervention. Each group included approximately 20 students, ranging from classrooms with 18 to 21 students.

Thirty-one percent of the participants in the study came from Spanish-speaking households, whereas 69% came from English-speaking homes. Qualification for the free and reduced lunch program was used to determine the socioeconomic level of participants' families. The families of students coming from Spanish-speaking households came from Central America, and all of these students were in the free and reduced lunch program. In general, the English-speaking students came from middle-level socioeconomic families (did not qualify for the free and reduced lunch program).

Design and Procedure

The research design of this study consisted of three phases: preinstruction elicitation of students' ideas; *INSCIREAD* intervention; and postinstruction elicitation of students' ideas.

Preinstruction Elicitation

In order to identify and measure students' misconceptions, the teacher–researcher who conducted the intervention, in cooperation with another researcher in the project, created four open-ended general questions to stimulate the participants' generation of prior ideas. The questions were based on the content objectives related to slow changes in geomorphology at the elementary level in Virginia (Table II). The teacher researcher read all questions to the participants, and then asked them to write (in English or Spanish) and/or draw on four blank pieces of paper, one per question, to show their thinking. Drawings have been used before as a technique for exploring science ideas (e.g., Dove et al., 1999). Drawing taps holistic understanding (White and Gunstone, 1992) and is a useful alternative form of expression for children who have difficulty expressing their thoughts verbally (Rennie and Jarvis, 1995).

The researcher then analyzed the data and identified the misconceptions, which were then organized into a systemic network (Bliss et al., 1983). A systemic network is a way of organizing information into categories that can then be used to analyze available data (see Fig. 1). More information about the systemic network is included later in this manuscript.

INSCIREAD Intervention

The *INSCIREAD* intervention consisted of six consecutive sessions, during which students worked always either in groups or pairs. Three of the sessions focused on science and three on reading comprehension. The instructional sessions presented students with activities focusing on science or reading on alternative days. For the three sessions that focused on collaborative inquiry-based science, students used a Web-based system called *GoInquire* (GoInquire, 2006). The *GoInquire* system was designed and developed

TABLE II: Questions to stimulate generation of prior ideas.

Open-ended Questions
1. Explain how the Grand Canyon was formed (visual provided)
2. Explain what water erosion is
3. Explain why the water in rivers doesn't move in straight lines, but curves as it moves
4. Explain the relationship among erosion, deposition, and transportation caused by water

by Dr. Brenda Bannan-Ritland and a team of researchers at George Mason University in 2006. The *GoInquire* system aims to develop students' prior knowledge on slow geomorphologic processes and improve their reading comprehension, using a collaborative inquiry-based science approach.

The *GoInquire* system supports the development of students' knowledge of slow geomorphologic processes and the improvement of their reading comprehension skills. The system encourages collective rather than individual construction of meaning from texts while activating strong student motivation as they construct their own meaning of the content and the texts. The strategies used throughout the *GoInquire* system parallel those used in reciprocal teaching (Palincsar and Brown, 1984). The reading/science strategies emphasized in the *INSCIREAD* intervention are questioning and self-monitoring. In *GoInquire*, students observe and analyze the geomorphological features of school grounds photographs, generate and try to answer questions, monitor their understanding while answering metacognitive prompts and reading other students' ideas, and identify unfamiliar words. As part of the three science lessons, students engaged in a field experience during which they were asked to compare the photographs they had analyzed in the *GoInquire* system with the actual place where the photograph was taken.

The remaining three sessions of *INSCIREAD* focused on reading and provided students with explicit instruction in the questioning and self-monitoring reading strategies, based on the method of reciprocal teaching (Palincsar and Brown, 1984). Instruction was in the form of initial modeling and gradual removal of the assistance as students attempted to implement their new knowledge first in the whole group and then in small groups. Students' use of bilingual strategies, such as transferring, translating, and the use of cognates (Jiménez et al., 1996) was emphasized throughout

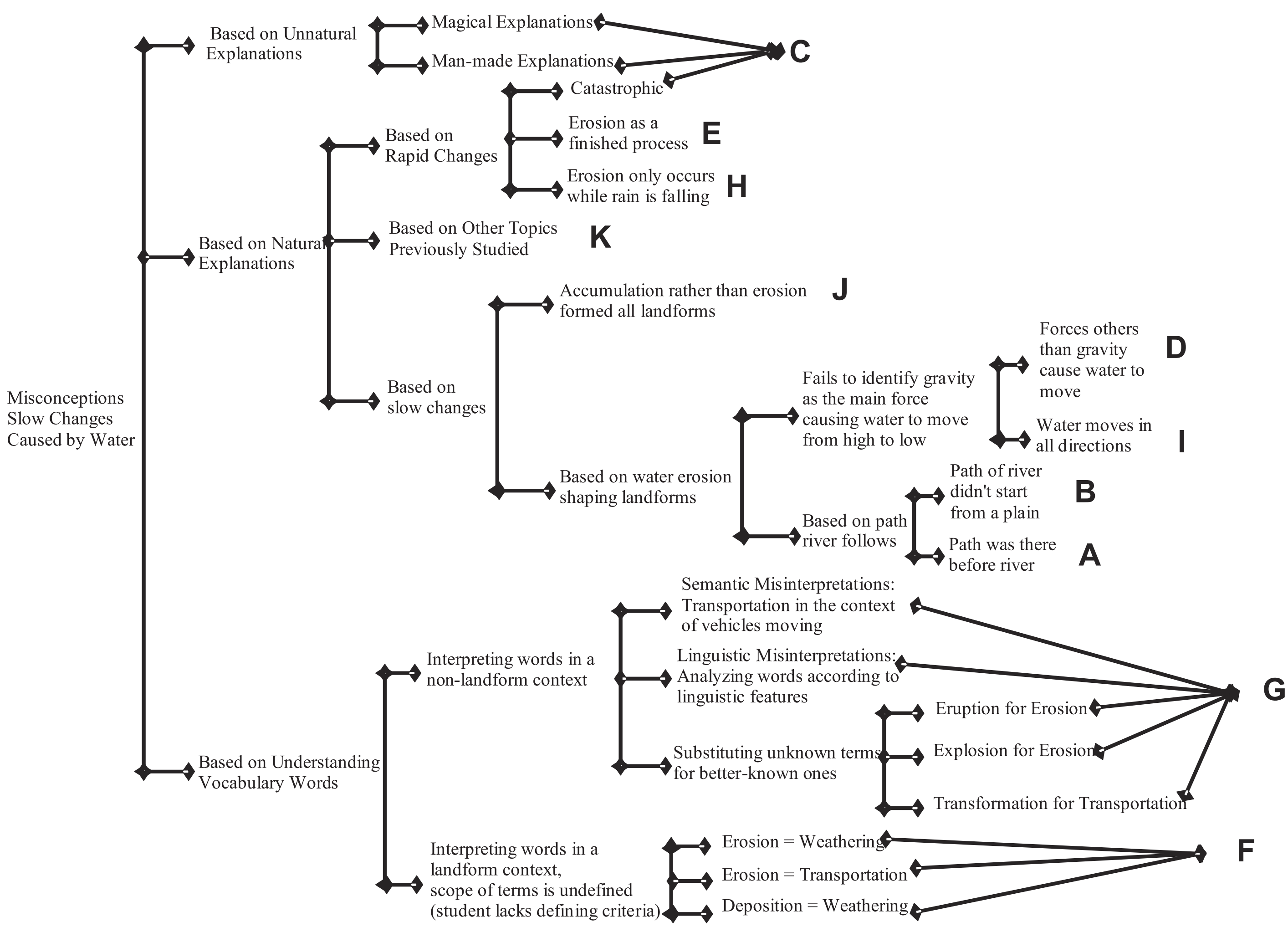


FIGURE 1: Systemic network of students' misconceptions about slow geomorphological changes caused by water movement.

the instructional sequence. The intervention was conducted in Spanish, but students were encouraged to formulate their understanding and thinking using any linguistic resource (English or Spanish) they had available.

Postinstruction Elicitation

After the 6-d instructional sequence, the researchers carried out another phase of elicitation using the same questions used previously. The researcher then analyzed these data and identified the misconceptions (see Fig. 1). The data collected were quantified in the same way as those collected during the preinstruction analysis and were analyzed for statistical significance using proportions.

Semiquantitative Measure

The semiquantitative measure used in this study focused on identifying and analyzing students' number of misconceptions and was adapted from Osborne and Black (1993). One of the goals of the Web-based intervention was to use the information collected to help students develop concepts and processes closer to those held by geomorphologists.

After collecting students' drawings and writing to answer the four open-ended questions shown on Table II, the misconceptions were identified and quantified by the teacher–researcher, with the help of a research assistant. The teacher–researcher had previously conducted classroom inquiry in science and had participated in an intensive 1-y program to generate ideas on teaching the topic of changes caused by the slow movement of water. As part of this program, a geomorphologist and a representative from the American Association for the Advancement of Science (AAAS, were invited to teach a total of three 2-h classes to the teacher–researcher and the other researchers and participants in the project. Students' answers to the set of four open-ended questions were analyzed before and after the Web-based intervention according to the following procedure.

Data Analysis

The data obtained were the actual drawings of the students and the writing they did on them. There were a total of eight pieces of data per student, two per question (see Table II). In order to analyze the assessments and obtain a score for students' misconceptions, the researcher used a scoring method adapted from Carey and Smith (1993). According to this method, the most common misconceptions can be identified by reviewing students' answers. Once a list of misconceptions was generated from a review of students' initial work, the information was organized in a systemic network (Bliss et al., 1983). Then the researchers used the systemic network as a classification tool for misconceptions and to facilitate the semiquantitative analysis of all pieces of data.

In the present study, the data were analyzed using methods of inductive analysis (Patton, 1987, 1990). All data were coded by the first author, who is bilingual. The analysis of the initial four representations each student had generated started by looking at all the work and reading the text on students' drawings and representations. The data were searched for patterns or themes versus imposition of predetermined codes onto the data (Patton, 1987, 1990), and thus codes and categories emerged from the drawings and explanations.

From the first reading of the data, initial codes (emergent misconceptions) were constructed reflecting the students' ideas about erosion. This initial coding allowed us to conduct an initial interpretation of the students' work and to create an emergent list of misconceptions. Revision of the emergent codes (misconceptions) occurred during a second reading.

Next, all the analyzed data were organized into a booklet by question being addressed (see Table II for the four questions), showing a minimized version of students' work for reference. We have included one of these organizing pages in the Appendix A. Then, the teacher–researcher looked at each one of the answers and found commonalities among the themes in the misconceptions. It was relatively easy to group students' ideas around the initially identified misconceptions (and the final branches, which we called terminals). The systemic network was created based on this initial student work by grouping the misconceptions in bigger themes according to the conceptual relationships among them. For example, the ideas related to the interpretation of words were all grouped under the theme "misconceptions based on understanding vocabulary words," and then from there, the teacher–researcher further reclassified the misconceptions into two branches, one being "interpreting words in a nonlandform context," and the second one being "interpreting words in a landform context" (see Fig. 1 for final network).

Finally, using the systemic network, the number of misconceptions from both the pre- and the postassessment was tallied. At this point, the raw data were analyzed by a bilingual graduate student, with limited science background, who acted as a research assistant. The teacher–researcher trained the research assistant on using the systemic network. They together went over each misconception and its branches and discussed the meaning of the misconceptions (verbal examples were provided to better illustrate the ideas). Once the bilingual assistant had been familiarized with the language in each misconception, and she felt she understood the concept, she worked on classifying the raw data students had produced.

This way of analyzing the information was used effectively by Osborne and Black (1993) to organize students' responses to questions about the nature of seeing. The researcher then assigned each assessment a final score according to the number of the identified misconceptions represented in each student's responses to the pre– and post–open-ended questions (Carey and Smith, 1993).

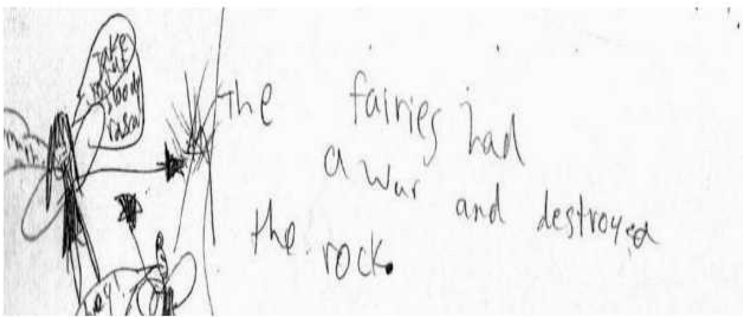
The number of students who held each misconception was computed as a proportion of all participants. Changes were defined as increases or decreases in the proportion of students in each dependent sample who held each misconception before and after the intervention. This analysis was conducted at the misconception level.

RESULTS

The results are discussed under three sections: Themes and branches of the misconceptions; description of the misconceptions; and conceptual changes in the misconceptions.

Themes and Branches of the Misconceptions

Next, we describe in detail the identification of themes and branches for each identified misconception.



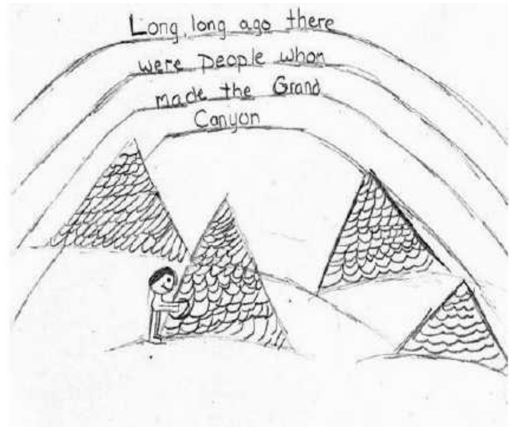


FIGURE 2: Students' ideas on how the Grand Canyon was formed based on unnatural explanations.

As mentioned earlier, in order to develop the systemic network, the identified misconceptions were classified in general groups or themes. The three initial identified themes were (1) misconceptions based on natural explanations, (2) misconceptions based on unnatural explanations, and (3) misconceptions based on understanding vocabulary words. The misconceptions under each of these initial themes were then further classified in the form of branches of a tree diagram until all misconceptions were represented in the systemic network in the form of a final branch called a terminal.

For example, under the general theme of misconceptions based on natural explanations, there were ideas such as one student whose drawings and words indicated that she believed the Grand Canyon was formed by a rock from space that fell on Earth (after drawing the rock flying from outer space toward Earth, the student wrote "yo creo que una roca del espacio" *I think that a rock from space*). The original drawing is included as part of Appendix A. This misconception was classified as natural, so it fell under this first category, and within that category, it was further classified as a misconception based on rapid changes, and assigned to the terminal catastrophic (misconception C).

The work from two students whose misconceptions were classified under the general branch of unnatural explanations is shown on Figure 2. The first drawing shows two living beings with wings and wands who are arguing with each other ("take that bloody rascal" is written in a bubble coming out of one of the being's mouth, while the second being is saying "hey!"), and the student wrote "the fairies had a war and destroyed the rock." This interesting drawing may be pointing to embedded cultural ideas and experiences outside of school of war and superstition. The drawing was classified under the branch of unnatural explanations. The second drawing also included in this branch shows a person building up mountain-like structures with stones. The student wrote "long, long ago there were people *whom* made the Grand Canyon" in lines that form semicircles. Once again, this illustration points out interesting sociocultural aspects of this child that come out in the form of science concepts. These two examples and other similar ones served to create two branches rooted under the theme of misconceptions based on unnatural explanations. The two branches were labeled (1) magical explanations (Fig. 2, first illustration), and (2) man-made explanations (Fig. 2, second illustration). Since these two branches were at the end of the diagram, and no more branches emanated from them, they were terminals.

The teacher–researcher then reviewed students' responses looking for those ideas falling under these terminals and counted them (Carey and Smith, 1993). The initial list of misconceptions from data from the preassessments contained 11 misconceptions.

An example of the way in which the responses were coded from this point on can be understood by analyzing Figure 1, in combination with Figures 3 and 4. Figure 3 shows a misconception that was first categorized as "based on natural explanations," and then it was assigned the terminal "based on other topics previously studied," which corresponds to misconception K. Figure 4, on the other hand, fell under the misconception "based on understanding vocabulary words" and then "interpreting words in a nonlandform context," and finally "semantic interpretations: transportation in the context of vehicles moving," which corresponds misconception G.

The first author scored all pieces of work, while a second reviewer used the network to classify 56% of the data. According to Kennedy (2005), the current convention is that 20% of observations is a minimal percentage and 33% is preferable to adequately assess the consistency of measurement. Ideally, we would have liked to review 100% of the data together; however, the nature of these kinds of data is very time consuming, and we only had the research assistant for a limited period of time. Consequently, once the interobserver agreement was over 80%, 56% of the data were deemed sufficient based on the interobserver agreement. An 82% interobserver agreement was achieved.

Description of the Misconceptions

In the following, we present a verbal description of each misconception, which, in conjunction with Figure 1, allowed for the classification of students' ideas. One of the identified misconceptions was related to explanations about why rivers do not always move following a straight path. Two examples of these misconceptions are: (1) The path the river follows was there before there was water (and the water filled it up taking that shape); and (2) the path the river follows did not start from a plain (there were different kinds of objects in the

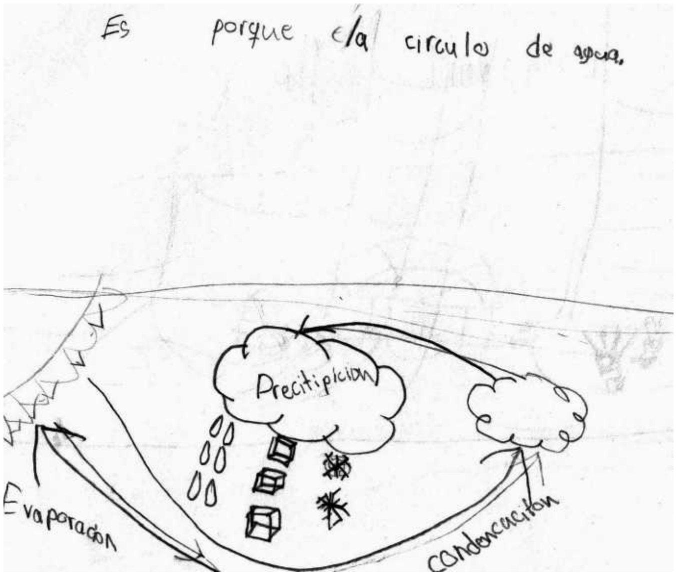


FIGURE 3: Student's explanation of water erosion: "It is because of the circle of water."

rivers' path). Other misconceptions were found in students' attempts to explain how a landform was formed. For example, students' explanations of the formation of the Grand Canyon included: (1) processes of accumulation rather than erosion; and (2) catastrophic and magical reasons. Students' misconceptions included the misinterpretation of the vocabulary words of erosion, deposition, and transportation in terms of: (1) a nonlandform context (e.g., transportation as a car transporting people); (2) substitution by a similar word having a completely different meaning (e.g., erosion as explosion); and (3) a lack of defining criteria (e.g., erosion is any type of change rather than associating erosion with the movement/removal of solids).

In relation to the slow and ongoing processes related to erosion, students generally referred to erosion as something that is over. Some students' work showed that unless it was raining, they did not think erosion was taking place. In relation to water movement, not all students understood that water moves from high to low attracted by gravity, but rather their work indicated misconceptions related to the direction in which water moves and the forces that caused it to move. Some of the misconceptions that were identified came in the form of students relying on water cycle (expressed as water *circle* in one stance), rock cycle, water pressure from top to

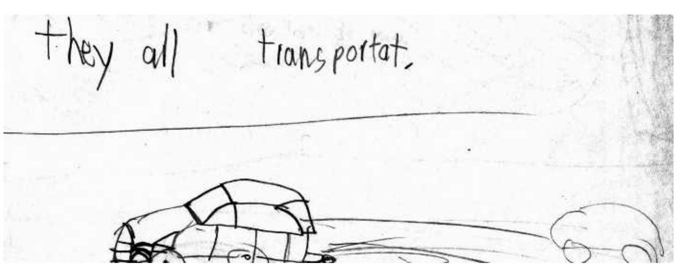


FIGURE 4: Student's explanation when asked about the relationships among erosion, deposition, and transportation.

bottom, states of matter, plate tectonics, or other topics they had learned about, and not necessarily on erosion. Figure 1 shows the resulting systemic network, which should be examined by commencing with the three main branches. Each final element of the branch or terminal (e.g., erosion as a finished process) represents misconceptions identified during the initial analysis of the data. Several terminals might represent one single misconception. Once the systemic network was developed, students' work was analyzed using the network, and their misconceptions, before and after the instructional sequence, were tallied.

Conceptual Changes in the Misconceptions

Due to the nature of the data collected, which led to frequencies, proportions (nonparametric tests) were used to analyze the data. To calculate the confidence intervals for the proportions analyses, the researcher first selected the desired confidence level of the results. For the purposes of our analyses, a confidence level of 95% was used. Using the sample size and the frequency or percent of occurrence, a confidence interval (using upper and lower boundaries) was obtained for each misconception. Using proportions, the frequency of occurrence was divided by the total number of subjects during both pre- and postintervention measures (e.g., misconception C will be $P1 = 29/49$ and $P2 = 4/49$). Then, the proportion using both frequencies was calculated by adding the frequencies and dividing by the total number of participants in both waves (e.g., $29 + 4/49 + 49$). The Cochran q statistic was then calculated by subtracting this proportion from 1 and used to obtain the lower and upper boundaries. The positive/negative combination of signs of the resulting interval was used to determine significance.

The proportions analysis with the percent of students who held each misconception before and after the instructional sequence revealed that there were significant differences in four of the misconceptions (see Table III). The four misconceptions that were significant at the $p < 0.05$ level were C, J, D, and G. Misconception C refers to the work of students who explain slow geomorphological changes based on unnatural explanations such as magical or man-made explanations. For example, during the preassessment, one student wrote in English "long, long ago there were people whom made the Grand Canyon," while a postassessment example read in Spanish "por un río. El río se erosionó las rocas blandas por muchos, muchos años y formó el cañón *(because of a river. The river eroded the soft rocks for many, many years and formed the canyon.)*"

Misconception J is related to ideas in which the student explains slow geomorphological changes based on natural explanations, but in relation to accumulation rather than erosion for all landforms. In the preassessment, one student wrote, for example, "one day, well over the years, the Grand Canyon has been transforming, and well if you had been there well back, in say two years, something will be different about it…The Grand Canyon started off, and added rock and grew," while a student wrote the following in Spanish during the postassessment "yo creo que el Gran Cañón del Colorado formó de erosion, porque yo veo una v. *(I think the Grand Canyon of the Colorado formed from erosion, because I see a v.)*"

Misconception D refers to the idea that forces other than gravity cause water to move. Students identified as having this misconception either mentioned the fish or the wind as

TABLE III: Network of misconceptions with students' scores.

Misconception Terminals	Preintervention		Postintervention	
	Frequency $n = 49$	Percent $n = 49$	Frequency $n = 49$	Percent $n = 49$
C. Magical, man-made explanations, and catastrophic	14	29%	2*	4%*
E. Erosion as a finished process	5	10%	2	4%
H. Erosion only occurs while rain is falling	12	24%	7	14%
K. Based on other topics previously studied	2	4%	2	4%
J. Accumulation rather than erosion formed all landforms	9	18%	4*	8%*
D. Forces others than gravity cause water to move	6	12%	0*	0%*
I. Water moves in all directions	0	0%	0	0%
B. Path of river did notstart from a plain	6	12%	3	6%
A. Path was there before river	1	2%	2	4%
G. Interpreting words in a nonlandform context	18	37%	8*	16%*
F. Interpreting words in a landform context, scope of terms is undefined	7	14%	5	10%

[1]* = Changes from pre- to postelicitation stages that are significant at $p < 0.05$.

the main and only causes for the movement of water. For example, at the preassessment, one student wrote in Spanish "cuando todos los peces mueven su cola al mismo tiempo, crea una corriente *(when all the fish move their tail at the same time, it creates a current.)*" During the postassessment students' answers referred to other causes. For example, one student wrote "steep and flat surfaces, and objects in the way."

Finally misconception G refers to students' work showing a nonlandform interpretation of the terms. There were different types of nonlandform interpretation answers from the students. For example, when asked what do the terms transportation, deposition, and sedimentation have in common, one student wrote in Spanish "todos tienen –ion *(all of them have –ion)*," and another student substituted the word for transformation, and wrote "transportation is when it is different." Answers from the postassessment show more of a landform interpretation, such as "erosion is when rocks erode, transportation caused by water carries sediment and rocks. Deposition the same thing. They all have things to do with rocks and dirt."

As shown by the examples just presented, students significantly demonstrated they had acquired concepts that were closer to those held by scientists after the intervention in these four areas of misconception. The frequencies and percentages for each misconception before and after the intervention are shown in Table III.

There were no differences in the frequency of misconception K (from 4% to 4%), which is related to students using other topics they had learned about in the science class to explain changes caused by water movement. For example, students drew a diagram showing the water cycle, or mentioned the states of matter. At the end of the intervention, two students continued to use water cycle or states of matter to explain slow geomorphological changes. No students in the intervention revealed they held misconception I (from 0% to 0%), showing that they knew water moves from high to low attracted by gravity; therefore, this misconception was not statistically analyzed.

Finally, misconception A, thinking a river is filling out a previously existing path was still present after the intervention (from 2% to 4%). This could be related to the challenge of using retrodiction instead of prediction in the processes being studied. Exposing students to simulations showing how the water can actually carve a new path and create a river could help to challenge this idea.

DISCUSSION

Based on the results, it is clear that the *INSCIREAD* intervention lowered the total number of misconceptions. The data suggest that students acquired concepts closer to those held by scientists. The fact that this 6-d intervention was effective at helping students understand some of their inaccurate ideas or move toward a more geomorphological way to explain processes suggests that rather than a lack of knowledge, some of these misconceptions are likely not deeply ingrained and therefore are easier to change, since students appear to just not have any scientific information on which to fall back. This finding points to the importance for teachers to be knowledgeable of students' funds of knowledge (Moll, 1992) and prior ideas. The following discussion is organized in two sections: conceptual changes; and language and conceptual learning in the geosciences.

Conceptual Changes

Apart from helping students develop a landform interpretation of terms (discussed under the language section), the intervention was particularly effective at reducing students' misconceptions in three areas. Two of them were related to understanding the process of erosion based on natural explanations and as a result of lowering of the land, rather than accumulation.

The fact that students held misconceptions in these areas has been documented in the literature. It is not uncommon for young children to attribute nonnatural or magical causality in earth science. Piaget in 1929 found that children aged 7 to 8 believed that stones were created by men or by God, or that the stones grew from seeds planted in the soil. In this case, given the diversity of the participants, these types of misconceptions related to war, magic, or men with superpowers demonstrate the extent to which one's

beliefs and customs outside of school influence learning. Other researchers have found belief in nonnatural causes for the hydrologic cycle (Taiwo et al., 2001).

A third misconception that was successfully addressed by the *INSCIREAD* intervention was understanding the nature of forces that causes water to move (gravity). It is interesting that most students stated that gravity causes water to move, but when prompted with a real application of the concept (e.g., explain why the water in rivers does not move in a straight line), they demonstrate that they still hold an underlying conceptual structure based on their observations and everyday experiences. This finding has been previously documented. For example, Piaget (1930) asked children to explain what caused the water in the river to move and found that among the answers children aged 5 gave were men rowing, people swimming, or God. Nussbaum and Novak (1976) showed that second-grade children say that Earth is round, but under more detailed questioning, they give answers consistent with other alternative views.

It seems that the combination of text, drawings, pictures, and field exploration helped students form rich mental model representations from which greater inferencing about the domain could be done. A process called "drawing to learn" (text to diagram) has been used in plate tectonics to facilitate understanding of the spatial/static as well as causal/dynamic aspects, and the integration of this information into a mental model (Gobert and Clement, 1999). As part of the *INSCIREAD* intervention, the combination of the analysis of erosion using still pictures with field explorations in which students had an opportunity to discuss their observations was helpful at assisting students in revising their ideas. The pictures students analyzed in the computer were taken months before the intervention took place. This analysis of pictures permitted students to directly observe the differences that had occurred and encouraged the exploration of hypotheses. In addition, water was provided so that students could investigate the movement of the water on the land, as well as related agents (such as amount of water or types of solids). The groups' online and in-the-field discussion around a series of essential understandings and questions (see GSA Data Repository[1]) proved to be necessary for providing information about the children's underlying conceptual structures. The questions were of a generative nature in that they asked children to explain phenomena that they could not directly observe (Vosniadou and Brewer, 1992). It has been documented that students need opportunities to explore their existing ideas in an effort to build more scientifically accepted models (Shepardson et al., 2005). The presented experiences and discussions seemed to provide an opportunity for conceptual change in that they provided opportunities for the reinterpretation of students' presuppositions (Vosniadou and Brewer, 1992).

The *INSCIREAD* intervention was least effective at addressing two misconceptions. The first one is students using other topics they have learned about in the science class to explain changes caused by water movement (e.g., the water cycle and states of matter). The fact that water is essential in the content we addressed, together with the understanding that words are used across science contexts in different ways, such as solids (that water carries material, and solid as a state of matter) or compact and loose, might explain why students kept trying to explain the process of erosion in terms of the water cycle or the states of matter. Ciechanowski (2009) in a study with third graders in a Spanish/English immersion school found similar connections across topics in the academic curriculum and everyday resources. The researcher explained that students utilized these connections to gain deeper meaning about natural and social phenomena. In fact, she noticed that these intersections may have contained untapped potential for students to learn more deeply about content and to negotiate multiple resources. Teachers should explore ways in which instruction can bridge content knowledge, which, although substantially connected, is traditionally learned as completely separate topics.

The second misconception that was still evident at the end of the intervention was thinking that a river is filling out a previously existing path. Other researchers have found that children believed that bridges were constructed before rivers so that people could cross over the empty channels which only later were filled with rainwater (Piaget, 1930). This prior idea seems to be connected to the fact that students have a poor conception of scale when something is outside their ability to observe it directly (Cheek, 2010). In order to fully understand this concept, students must first acquire an understanding of the agents involved in water erosion (steepness, quality of the soil, size of solids). In addition, students are frequently asked to observe in order to make predictions of what would happen next; however, understanding the process of erosion relies more on "retrodiction" than in "prediction." That is, students must observe to make predictions about the past. Specific experiments, such as conducting an experiment starting on flat ground and adding water while making observations and drawing, could create a conflict between what students have said and what they observe, and it could stimulate the generation of students' explanations of this conflict.

Language and Conceptual Learning

The *INSCIREAD* intervention helped children develop a landform interpretation of the terms. Taking into account that we were working with dual-language learners, the finding that the intervention helped children develop a landform interpretation of the terms is very relevant. The analysis of students' work in the form of drawings and writing revealed misconceptions and alternative ideas based on students' sociocultural background, but it also demonstrated the connection between language proficiency and conceptual learning. Students were interpreting the content-related terminology in contexts other than geomorphology. The role of the misapplication of terminology in Earth processes has been explored in the literature (Dove, 1997; Shepardson et al., 2005; Cheek, 2010). The fact that some children explained transportation by drawing a car is not surprising. As explained in the literature review, the use of everyday language in a scientific context in earth science has been identified in several other studies as a potential source of students' misconceptions (e.g., Happs, 1982; Kortz and Murray, 2009).

[1]Detailed description of the *INSCIREAD* intervention, a GSA Data Repository item and Supplementary Material to this *JGE* article, is available online at http://dx.doi.org/10.5408/09-145.1, or on request from editing@geosociety.org or Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301, USA.

As part of the *INSCIREAD* intervention, teachers provided scaffold for students' use of cognitive strategies during science text reading. An emphasis was placed on self-monitoring ones' understanding of the terms. Specifically, students asked questions prompting for clarification while reading and were given the opportunity to engage in online discussions about unknown terms. The questioning about terms was done through an online dictionary tool that students used to enter words they wanted to explore. The system generated a discussion board and students were encouraged to provide their explanations for the term and to add to other's descriptions as well. This coconstruction of knowledge clearly facilitated students' more contextualized reinterpretation of terms. Others have indeed found that through sociocognitive interaction, which creates a collective product, students have the opportunity to also advance their learning on an individual basis (Mason and Santi, 1998).

Additionally, teachers enhanced students' awareness of words that are cognates in English and Spanish (erosion, deposition, and transportation are all cognates), and encouraged students to use all the linguistic resources available to them (both their languages) to make sense of the information. This practice is supported by the literature, as shown in this quote by Milk (1993) "bilingual children engaged in cognitively demanding academic learning must be allowed to access their entire score of linguistic resources in order to achieve full potential…particularly when the primary focus of an activity is cognitively oriented" (p. 102). These practices had a role in helping students acquire an interpretation of the terms in a more scientific manner, but as they are usually mandated to use their two languages separately, allowing them to use their different linguistic resources also helped students feel more relaxed. This difference was evident during the instructional intervention in the form of motivation and lively discussions.

It is clear in the data that language creates different images for different students. Teachers need to first explore students' interpretation of words, and then help them bridge everyday language to scientific discourse (Torres-Guzman and Howes, 2009). Furthermore, educators need to confront everyday language in the classroom to ensure they use the words in scientific contexts (Dove, 1998).

CONCLUSIONS AND IMPLICATIONS

The present study supports the literature on student conceptions in that we observed that student conceptions were: (1) based on their observations, social interactions, and language, (2) similar across age, ability, gender, and culture, and (3) not easily changed (Wansersee et al., 1994).

Following the proposed research question, this study provided information on students' ideas about the processes of erosion, deposition, and transportation caused by water movement. Furthermore, the findings indicate that bilingual elementary students hold many prior ideas, which, unless addressed through instruction, could potentially hinder learning because they are different from the concepts of the teaching program. Specifically, 11 general misconceptions were detected. Students created their own alternative explanations for natural phenomena based on their prior experience and observations. They connected with topics previously studied and made meaning of the terminology in unexpected ways.

Although we know that thinking about a subject becomes more sophisticated with age, learning about students' early ideas in relation to the process of erosion provides guidance on the learning progressions of students (Hmelo-Silver and Duncan, 2009). Teachers can use this information to effectively plan for instruction.

Addressing the second research question, the combination of the open-ended *GoInquire* Web-based system with more traditional direct instruction in science reading comprehension strategies was effective at helping students acquire geomorphological concepts more closely connected to those held by scientists.[1] Students using other topics they had learned about in science to explain the process of erosion actually shows that students are making connections among topics that are actually related (such as erosion and the water cycle). Teachers could utilize this information to help students negotiate meaning.

Finally, thinking a river is filling out a previously existing path appeared to be the most persistent alternative conception for students in this intervention. This idea is related to the skill of retrodicting (thinking what has happened) in an educated manner. Questions remain as to what type of simulations or field experiences could help diverse elementary students better understand this particular concept.

FUTURE WORK

The systemic network generated as part of this study should be used with a larger sample of students from diverse backgrounds. It would be of interest to explore the semantic interpretations of students who speak a nonromance language. Finally, investigations looking into other forms of erosion (ice, wind) as well as weathering would help create a clearer picture of students' prior ideas.

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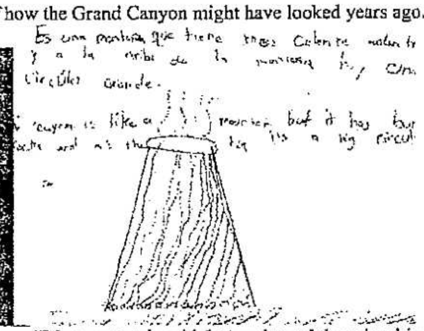
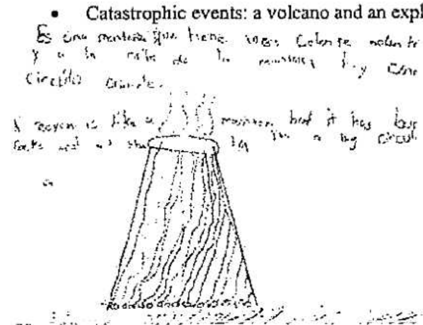
- Students think of a mountain and the river running under it. They don't see that the river was running through a plain:
  - Teachers must show pictures of how the Grand Canyon might have looked years ago.

"It is a mountain and it has a river below the mountain, and it also has rocks below the mountain"



"It's a mountain with hot rocks and there is a big circle on top. A canyon is like a mountain, but it has rocks and at the top there is a circle."

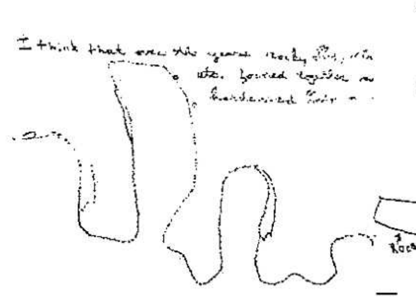
- Catastrophic events: a volcano and an explosion:

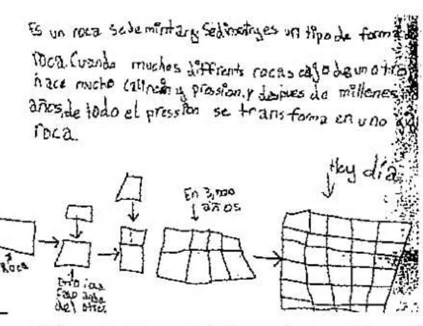


"It is a mountain with hot rocks and there is a big circle on top. A canyon is like a mountain, but it has rocks and at the top there is a circle."

"I think a rock from space."

- Students relate to the rock cycle because they study that topic through elementary school:





"It is a *sedemintary* rock. *Sedimentry* is a type of shape of a rock. When many different rocks fell from one to another, it makes much heat and pressure and after millions of years, it transforms into a rock from all the pressure"

APPENDIX A. ORGANIZING DATA PAGE.