Third Misconceptions Seminar Proceedings (1993)

Paper Title: Children's understanding of Earth systems phenomena in Taiwan
Author: Broadstock, Maan Jiang

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Keywords: Concept Formation,Research Methodology,Educational Methods,Misconceptions,Cognitive Development,Cognitive Ability,Qualitative Research,Curriculum Design,
General School Subject: Earth Science
Specific School Subject:
Students: Elementary School

Macintosh File Name: Broadstock - Earth Systems
Release Date: 12-15-1993 C, 11-4-1994 I

Publisher: Misconceptions Trust
Publisher Location: Ithaca, NBroadstockf the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics
Publication Year: 1993
Conference Date: August 1-4, 1993
Contact Information (correct as of 12-23-2010):
Web: www.mlrg.org
Email: info@mlrg.org

A Correct Reference Format: Author, Paper Title in The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Misconceptions Trust: Ithaca, NY (1993).

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Children's understanding of Earth systems phenomena in Taiwan

Maan Jiang Broadstock, Tainan Teachers College, Taiwan, Republic of China

INTRODUCTION

In the early 1970s, research in science education began to focus on the conceptual learning process that lies behind students' thinking in particular science domains. Much research has been done and is still being done in understanding students' science ideas. These studies show that students coming into a learning environment bring their own conceptions of the world (Osborne, 1984; Engel & Driver, 1986; Solomon, 1985; Gil-Perez & Carrascosa, 1990). Despite what teachers teach about science, many students maintain their early and alternative conceptions of the natural world for several years and even into adulthood. These ideas are constructed by children through their perceptive experiences in daily life. These concepts that children use to explain natural events with respect to their own experiences make sense to them and are therefore difficult for a teacher to change. The ideas students possess prior to formal instruction are considered the single most important factor influencing learning (Ausubel, 1968). Concept learning studies can aid curriculum developers in designing curricula and instructional materials that begin with what students already know and explicitly contrast children's ideas with scientific explanations (Eaton, Anderson, & Smith, 1983).

Students' alternative conceptions in earth science have been investigated since the 1970's. Although the number of studies dealing with earth science is dramatically less than the numbers of studies in other fields, such as physics, chemistry, and biology, the findings from these studies have provided information to help science educators understand children's ideas about Earth systems. Nussbaum and Novak (1976), Nussbaum (1979), Mali and Howe (1979), Klein (1982), Sneider and Pulos (1982), Vosniadou (1989), and Crews (1990) investigated children's ideas about the shape of the Earth, gravity, and the relationship between the Earth and the Sun. The results of these studies, some of which were cross-cultural and cross-age, showed that many children hold alternative conceptions about the Earth and its gravity. The concept of the Earth develops with age within an individual by a series of transitions from the most egocentric notions to a scientifically compatible one. Jones, Lynch, and Reesink (1987), Sadler (1987), Treagust and Smith (1989), Schoon (1989), Baxter (1989), Dai

(1990), and Vosniadou and Brewer (1990) identified students' misconceptions about the Earth, day and night, seasons, and the phases of the Moon. Baxter (1991) also developed an astronomy curriculum and teaching strategy to overcome students' alternative conceptions. Jones, Lynch, and Reesink (1987) also stated that elementary students' ideas about the relationship of the Earth and the Moon closely match the historical development of the scientific explanations. Piaget (1972a, b), Za'Rour (1976), and Stepans and Kuehn (1985) used interviews to investigate children's ideas about wind, rain, and weather phenomena. They claimed that children's explanations of these natural phenomena developed through stages from more animistic, egocentric views to true causality. The findings of concept learning research related to natural phenomena can be of extreme value to science educators. Taking account of children's prior experiences can provide teaching strategies better adapted to students (Driver, 1983).

The focus of this study is an exploration of the conceptions about the Earth systems held by elementary students in Taiwan. The purposes of this research are (1) to identify children's ideas about selected Earth systems phenomena, (2) to investigate the origins of children's beliefs about these natural phenomena, and (3) to describe the characteristics of children's explanations. In this study children's alternative conceptions about three Earth system domains were investigated:

(1) astronomy (day and night, the phases of the Moon, and seasons),
(2) meteorology (rain and wind), and
(3) geology (mountains and rivers).

These topics are all taught in the elementary science curriculum in Taiwan.

METHOD

Twelve elementary school students (one boy and one girl from each of grades one through six) were chosen to find out how they explain selected Earth systems phenomena. To establish trust and gain rich information, the sampling method used in this research was purposive sampling. The subjects were to be children who could easily express their ideas. Having good rapport with them, especially for the younger children, was the priority. Thus, the source of subjects was the children whom the researcher already knew well or school children recommended by elementary teachers.

Each subject was individually interviewed twice with a week between

interviews. The interviews took place in school playgrounds, libraries, or subjects' homes. After establishing rapport, an open-ended conversation about interview topics was conducted with each child in an unthreatening atmosphere. The sequence of questions for each interview was changed according to the unique responses of the child. Each interview took thirty to forty minutes. The interviews were tape recorded, and field notes including subjects' drawings were taken. A reflective journal was completed after each interview. Interview strategies changed as the study proceeded to establish better rapport with students and to obtain broader and more in-depth data.

All the interview data were transcribed in Chinese. Three researchers independently checked the transcriptions and coded the data. After consensus discussion between researchers, a final coding list was established from the transcriptions and children's drawings for data analysis.

RESULTS

Based on the purposes of this research, three major categories were used in data analysis: (1) the origin of children's ideas, (2) the types of children's alternative conceptions, and (3) the characteristics of children's explanations. Each category contains a list of subcategories presenting different attributes of the category. The list of subcategories was initially derived from literature review and evolved during data collection. A summarized list of the coding categories is shown in Table 1.

Table 1: The coding list for data analysis

A: The origins of children's ideas.

A1: immediate physical experiences
A2: language, metaphor, and cultural sayings
A3: beliefs and opinions of peers or parents
A4: formal instruction
A5: reading children's books
A6: religious background
A7: television
A8: science museums

T: The types of children's alternative conceptions.

T1: animism--endows objects with feeling, will, or purpose
T2: artificialism--feels everything is intentional and created for the good of man
T3: finalism--possesses a compulsion to explain things
T4: human-made
T5: God-made or supernatural
T6: mechanism--explains things using mechanical processes
T7: scientific ideas

C: The characteristics of children's explanations.

C1: personal
C2: inconsistent
C3: stable
C4: uses logical thinking; the ideas make sense to subject
C5: confuses causes and effects
C6: uses illogical thinking; the ideas are unrelated
C7: subject confuses the information
C8: explanation begins correctly but ends incorrectly
C9: explanation begins incorrectly but ends correctly
C10: incoherent
C11: gives two kinds of explanations simultaneously
C12: uses description as causality

The first major category concerns the origins of children's ideas. The subcategories were drawn from the interview data. Five of the origins, i.e., immediate physical experience, everyday language, metaphor and cultural sayings, beliefs of peers or parents, formal instruction, and religious background, were also stated in earlier studies (Sutton, 1980; Louisa & Veiga, 1989; Hewson & Hamlyn, 1985; Driver & Erickson, 1983; Solomon, 1987). During data collection in this study, children's books, television programs, and science museums emerged as three additional subcategories.

The second major category concerns the types of children's alternative conceptions. The following subcategories, which were found in the interviews, came primarily from the studies by Piaget and his followers (Piaget, 1972a; Fuson, 1976; Stepans & Kuehn, 1985). The definition and an example of each type of explanation are listed below.

1. Animism: Children endow natural objects with feeling, consciousness, and emotion. For example, the first grade girl claimed, "The rain is because clouds are hurt and feel sad, so they cry."
2. Artificialism: Children feel that everything is intentional and created for the good of humans. For example, the second grade girl claimed, "Wind is because it wants to make humans feel cool and comfortable."
3. Finalism: Children possess a compulsion to explain natural events, or children believe that a natural phenomenon is a simple finality in accordance with ordinary common sense, giving little regard to the origins or the consequences of this phenomenon. For example, the first grade boy said, "Spring, summer, autumn, and winter are names of seasons to have different climate. It just changes. "
4. Human-made: Children think that natural phenomena are caused by human powers. For example, the fourth grade girl said, "There are two kinds of mountains. One is made by humans, like you can see these amusement parks in the mountains; those are human-made. The other kind is formed by nature."
5. God-made: Children believe that natural phenomena are caused by God. For example, the fifth grade girl stated, "The King of Ocean manages the rain. Every spring he releases water to the ground to help crops to grow."
6. Mechanism: Children use mechanical processes to explain natural phenomena without involving human qualities. For example, the sixth grade boy said, "When the Earth goes around the Sun, it blocks the sunlight to the Moon. Thus, the shape of the Moon changes."
7. Scientific ideas: Children hold ideas that are accepted by scientists and by their teachers.

The subcategories for characteristics primarily arose during data collection. The findings support the statement in the book by Driver, Guesne, and Tiberghien (1985) that the characteristics of children's ideas are (1) personal--some children's ideas arise from very personal experiences; (2) incoherent--children's ideas are inconsistent and lack relevance; and (3) stable--children's alternative conceptions

exist consistently and are difficult to change. During the interviews, nine other attributes of children's explanations emerged (see Table 1).

About the topics

A summary of subjects' descriptions of each topic is listed in Table 2. The interview topics were chosen from events in daily life with which children are familiar. Most of the subjects had learned these concepts in school. Among the interview topics, the concepts of day and night, rivers, and rain were easier for subjects to understand than other topics. This may be because children can directly observe these natural events. They explained that they had watched heavy rains form small streams on the ground and erode topsoil, and they had seen steam come out of a teapot and condense into water droplets on a cool surface. Although children cannot physically sense the rotation of the Earth, they indicated that they can apply the experience of facing toward and facing away from a source of light to help explain this phenomenon.

The phases of the Moon, seasons, mountains, and wind were too abstract for subjects to comprehend completely. None of the subjects held scientific ideas about the phases of the Moon or the seasons. Even though some children had been taught these concepts in science classes, they misinterpreted what their teachers had taught. Although they used the right terms and correct models, these terms did not correlate with the ideas they had already constructed deep inside their minds. Everyday experiences had also misled subjects' ideas about wind and the formation of mountains.

Table 2. Summary of subjects' descriptions of interview topics

Topic	Brief descriptions	Subjects
Day/ Night	1. The Earth rotates every 24 hours, causing day and night.	6FM,5M, 4M,3F,2M
	2. The Sun goes around the Earth.	5F,4F,3M,2F,1FM
	3. The Sun and the Moon are alive.	5F,3M,2F,1F
Phases of the Moon	1. The Earth blocks the sunlight to the Moon.	6FM,5M,4F,2M
	2. The clouds block the Moon.	4F,3F,1F
	3. The Moon or Sun moves, shifting the shiny part.	5F,4M
	4. The Moon is alive can change its body shape.	3M,2F,1M
Seasons	1. Earth's revolution causes differences in sunlight.	6F
	2. Angle of sunlight to X-axis of Earth's revolution.	5M
	3. Earth is closer to Sun in summer, farther in winter.	6M,4FM,3F
	4. Winds cause the change of the seasons.	5F,3M,2M
	5. The clouds block the Sun and cause the seasons.	1F
	6. Seasons are controlled by ghosts or Gods.	5F,1F
	7. The Sun takes a rest in winter.	2F
	8. Seasons are natural events; no need for reasons.	1M
Mountains	1. The Earth's crust movement makes mountains.	6FM,5M
	2. Mountains are formed through erosion by rain.	4FM,3F
	3. Mountains are pushed up by the current of oceans.	2M
	4. Mountains are human-made.	5F,4F,2F,1M
	5. Mountains are for impressing humans.	3M,1FM
Rivers	1. Water in rivers comes from rain, and rivers are caused by erosion.	6FM,5M,4F, 4M,3FM,2M,1F
	2. Rivers are God-made or human-made.	3M,2F,1M
	3. Rivers are tears of children whose mother died.	2F,1F
Wind	1. The convection of cold air and hot air.	6F,4M.
	2. Wind is caused by pressures from ocean and Earth.	6M,5M
	3. Wind is moving air caused by moving objects.	4F,3F,2M
	4. Wind is the breath of the clouds.	3M,2F,1F
	5. Wind is created and controlled by God.	5F
	6. Wind is strong and is related to rain and oceans.	1M
Rain	1. Water evaporates, condenses, and drops as rain.	6FM,5FM,4M,3F,2M
	2. Water evaporates; clouds and winds make it fall.	4F,2F,1M
	3. Rain is the tears of the clouds or of a mother.	2F,1F
	4. Rain is created and controlled by Gods.	5F
	5. Rain comes from oceans and has human emotion.	3M

The types of children's alternative conceptions

A summary of the types of explanations subjects held is shown in Table 3. Subjects' explanations suggested a variety of alternative conceptions. The results

show that the types of explanations used by subjects were more closely related to the characteristics of subjects' thinking rather than the interview questions. Younger subjects were more likely to display animism, artificialism, and finalism. They were more egocentric and defined concepts based on appearances.

Mechanistic ideas were held by older children or those who had reached the concrete operational stage. These ideas developed through logical reasoning and matched students' physical experiences. Because mechanistic ideas make sense to children, these ideas often are more difficult to change and may persist into adulthood.

The idea of "human-made" was found primarily in subjects' explanations about mountains and rivers. Students often confused human-made constructions as part of mountains and rivers, thus believing that mountains and rivers are formed by humans. The idea of "god-made" was held by students who had been strongly influenced by religion either at home or from reading. These supernatural ideas existed with other explanations simultaneously without conflict.

Subjects often used the same type of explanations to explain the causes of day and night, seasons, and the phases of the Moon. Each subject consistently used their own model to represent the relationships between the Sun, Earth, and Moon. While answering the questions, the subjects' alternative conceptions about their models became clearer and made more sense to them.

The origins of children's alternative conceptions

Children's alternative conceptions arise from many different sources. Physical environment appears to have the strongest influence. Subjects actively applied what they had experienced in daily life to explain natural phenomena. Sometimes they misused an analogy with which they were already familiar, as in the phases of the Moon changing like a silkworm's body.

Direct perception can strongly influence students' ideas that are more difficult

Table 3: Summary of the types of explanations

Topics / Subjects	Day / night	Moon	Seasons	Mountains	Rivers	Rain	Wind
6F	◕	○	○	◕	◒	◕	◕
6M	◕	○	○	◒	◕	◕	○
5F	♡○	○	⛺	△	○	◒⛺	⛺
5M	◕	○	○	◒	◕	◕	○
4F	○	○	○	△○	◕	◒	○
4M	◕	○	○	○	◕	◒	◕
3F	◕	○	○	○	◕	◒	○
3M	♡○	♡	♡	♡♡	◒⛺	♡	♡△
2F	○	♡	♡♡	△	△♡	○♡	♡
2M	◕	○	○	○	◕	◕	○
1F	♡○	○	○⛺	♡♡	○♡	♡⛺	♡
1M	○	♡	△	△	△	△	△

◕ Scientific idea ♡ Animism △ Finalism

◒ Partially scientific idea ♡ Artificialism △ Man-made

○ Mechanism ♡○ Two explanations ⛺ God-made

Shaded areas show the grade level at which concepts have been taught

F: Female M: Male

to change, such as the idea of the Sun going around the Earth. Unless students

are challenged by the conflict between their ideas and scientific ideas and rethink these problems, they will keep their alternative conceptions for a long time.

Children's alternative concepts also arise from formal instruction. This research showed that science instruction sometimes did not cultivate students' scientific concepts. One unit in the third grade science curriculum in Taiwan shows that mountains and rivers are eroded by rain and water. Thus, many subjects who had learned this unit thought that mountains are built through erosion by water. Often, students had only superficially learned the terminologies by rote without completely comprehending the ideas. The concept of seasons is taught in the fifth grade science curriculum, yet none of the four subjects in fifth grade or beyond truly understood what causes the seasons. Two of them had learned some of the terminology but did not know how to apply it. The fifth grade girl did not even mention any of the ideas she had supposedly learned about the seasons two weeks before her interview.

Some alternative conceptions held by the younger subjects arose from their formal instruction in subjects other than science. One unit in the first grade Chinese textbook describes how the Sun works hard to help the crops and fruits grow in different seasons. Another story characterizing the Sun and wind with human emotion portrays Uncle Wind competing with Grandpa Sun and blowing a strong wind to block the Sun's energy. These two characters appeared in many younger subjects' responses about wind, day and night, and seasons. These children had not reached the concrete operational stage and could not separate stories from reality. Thus, they usually agreed with what the textbooks said and believed that the Sun and wind have human qualities.

Daily language was also found to be a source of some of these subjects' alternative conceptions. Chinese language describes sunrise and sunset as the Sun coming up from behind the mountains and the Sun falling down into the mountains. Thus, many subjects used this description to explain the concept of day and night, even the fourth and fifth graders who had been exposed to more science instruction. They still believed that the Sun goes around the Earth. In many children's stories, paintings, and daily conversation, people always speak as if the Sun is a moving object, which may reinforce children's alternative conceptions.

Vosniadou and Brewer (1990) stated that the mountains and the sea in the Greek landscape seem related to the fact that Greek children preferred to explain the day and night cycle in terms of the disappearance of the Sun behind the

mountains or sea. American children preferred the explanation that the Sun goes down underneath the Earth. Mountains and oceans are also the major landscape features in Taiwan. Subjects in this study used similar expressions to explain day and night as did Greek children. This idea might come from their daily language as well as the direct experience of watching the Sun set beyond the mountains or sea.

Chinese expressions about wind also played an important role in subjects' alternative conceptions. Chinese language describes wind in many different ways. Spring wind is used to describe the wind in spring that is warm and comfortable. Summer wind is a softer breeze. Autumn wind is cool and howling and makes people feel sad. Winter wind is very strong and cold. People use these terms to describe the weather and even their moods in literature and daily conversation. Thus, subjects may have applied this language to the origin of the seasons. Three of the subjects thought that the seasons are caused by different winds.

Language may have also affected subjects in learning science concepts. The word "Earth" in Chinese literally means "ground ball", or a ball-shaped object that you stand on. Thus, every subject knew that the shape of the Earth is round like a ball. They may not have realized that language influenced their ideas about the shape of the Earth. They claimed that this idea came from reading science books, watching television, looking at a globe, or seeing pictures taken from space. One student said, "Of course the shape of the Earth is round; otherwise it would not be called the Earth."

The results also show that some subjects' alternative conceptions came from children's books, especially books for younger children. The authors of these books use stories or personification to motivate students' interests and get their attention. However, younger subjects sometimes could not distinguish stories from reality and accepted stories as fact. For example, the idea of a cold ghost and a hot ghost causing the change of the seasons appears in a series of Chinese children's books containing many stories and games to help preschool children understand the environment. However, after reading these books, the first grader actually believed that ghosts are the cause of the seasons.

Many subjects claimed that science books given to them by their parents or from libraries were the major source of their ideas, especially the students from cities whose parents were more concerned about education. Through reading constantly, some subjects comprehended many scientific concepts.

Sometimes they had just learned concepts by rote, but when they started to explain and apply the knowledge they remembered, their ideas became more clear and made sense to them. Subjects exposed to rich science resources showed a higher level of logical thinking.

Religion or family beliefs also seem to have affected subjects' views of the world. An obvious example of the influence of religion was shown by the responses of the fifth grade girl. Her strong belief that natural events are controlled by many different gods affected her ideas about the whole universe. She would usually give a mechanistic answer and then add a god-made notion. In her view, scientific concepts can coexist with supernatural powers without conflict.

Characteristics of children's alternative conceptions

Most subjects responded to the interview questions by thinking and then giving answers that made sense to them. These answers also existed consistently between the two interviews. In the second interview, subjects had more time to reflect upon these topics before answering, and they usually answered the questions more completely and clearly. Only two subjects gave inconsistent answers and used many different types of explanations to describe natural phenomena.

Children's cognitive development is an important factor influencing children's thinking. In this study, animism, artificialism, and human-made ideas appeared frequently in the answers of the younger subjects, in agreement with Piaget. Subjects defined concepts from the physical appearances of objects. The first grade boy used the description of natural phenomena as the cause of these events. Children in this preoperational stage use their direct physical experiences to misinterpret natural events (Piaget, 1972a). For example, in this study some subjects thought that the Sun goes around the Earth, that wind is caused by moving objects, and that black clouds block the Moon and cause the phases of the Moon.

Children in the concrete operational stage are more flexible, organized, and logical when dealing with concrete, tangible information that they can directly perceive. Thus, the phenomena that they can experience in their daily lives, such as rivers and rain, are easier to understand than more abstract topics like the phases of the Moon, seasons, and the movement of Earth's crust. Subjects in this stage primarily used mechanistic ideas to interpret the world

around them. The results show that children's cognitive levels are not necessarily related to children's ages. The second grade boy held more logical and objective ideas than some of the older children.

There were differences between the answers from subjects who had been taught science in school and those from subjects who had not had formal instruction in these topics. The former used more scientific terms (such as evaporation, erosion, and revolution) and interpreted them in more technical ways. The latter used everyday language to explain their ideas. For example, the third grade girl said, "Rivers are caused through erosion by water", but the first grader said, "When raindrops fall, they are usually very strong, and they hit the ground and dig a hole to become a very small stream."

While explaining their answers, subjects tried to clear up their ideas. Sometimes subjects would abandon their first responses to a question as alternative conceptions and shift to more scientific ideas. In these cases, they would adjust their ideas when faced with conflicts between different answers. In other cases, some subjects shifted away from the scientific concepts that they remembered toward mechanistic ideas. This shifting depended upon which ideas were stronger and made more sense to the student. Some subjects held more than two explanations simultaneously without hesitation. They accepted that these natural phenomena can have multiple causes.

Subjects' ideas were often the result of interaction between children's ideas derived from the perception of natural phenomena and current science knowledge presented by their teachers, textbooks, and children's books. This demonstrates what Ausubel (1968) proposed about the way children learn: a child assimilates new information into an existing cognitive structure, but in the process of assimilation, components of the intended meaning may become distorted. For example, the sixth grade boy had learned in school that mountains are formed by the movement of the Earth's crust, but in his response to the interview question about mountains, he claimed that typhoons comprise one of the dynamics that cause the Earth's crust to move and build mountains.

IMPLICATIONS FOR TEACHING

The recommendations made here are based upon the researcher's observation of the twelve subjects in this study. These recommendations were formulated through interpretations of the study findings. Due to the small size of the sample in this study, the findings may not be representative of all

elementary students in Taiwan. The reader is encouraged to personally evaluate these findings and form his or her own conclusions.

For researchers

The interview technique, with its use of follow-up questions, is helpful in revealing a great deal about what children understand about a concept. Although researchers can never truly know what subjects really think, interview still provides opportunities to obtain deep data that allow researchers to make adequate interpretations. The results from interviews can offer fundamental information for further investigation and for teachers to use in adjusting their teaching strategies.

For science teachers

Teachers play an important role in students' alternative conceptions. Children have their own ideas before they enter the classroom. Teachers must realize this and diagnose children's beliefs before teaching. Each teacher can act as a researcher and investigate what students already know by asking appropriate questions. They can then provide evidence to help students confront their own alternative conceptions. Unless teachers identify children's views and design their teaching strategies accordingly, some children's views will not change or may change in unanticipated ways. Teachers also must understand that each pupil is an individual learner who acquires knowledge from many different sources and challenge students' alternative conceptions to make them change their ideas. Thus, teacher training programs should encourage preservice and inservice teachers to be constructivists who see each student as an individual learner. Teacher educators also should enhance teachers' experiences in concept change strategies. Elementary teachers need to become familiar with using concept change strategy: eliciting students' ideas, reconstructing these ideas, applying these concepts, and reviewing changes in ideas (Driver, 1986; Posner, Strike, Hewson, & Gertzog, 1982)

Children's science learning

Providing abundant information and different resources to students is effective in stimulating children's science learning and promoting cognitive development. Many subjects in this study showed that they had learned scientific concepts through reading science books. These subjects learned science concepts just as well as students who had formal science schooling, sometimes even better. Children can learn science from many different sources as long as they are provided with appropriate information. Thus, teachers and parents

should expose children to science resources other than their textbooks. This may motivate students' interests and cultivate their science thinking. However, to promote children's science learning, children's science books should present science concepts in a way that is appropriate to the cognitive level of the child. Adults also need to choose children's books carefully and help children to distinguish between what is fantasy and what is reality so that children can understand the scientific concepts behind the stories.

For curriculum designers

Elementary science textbooks should be revised to make explanations of scientific concepts more clear and reasonable. Curriculum designers need to be more aware of children's alternative conceptions and design curriculum materials that explicitly contrast these alternative conceptions with scientific explanations. The concepts presented in textbooks from other subjects need to be carefully evaluated to avoid misleading students' science concepts.

Further research could be conducted in longitudinal studies to show the developmental trends in the subjects of this study to understand how these subjects change their alternative conceptions through time. More case studies should be completed to explore individual learning styles to better understand children's thinking. A diagnostic instrument could be designed according to the results of this study to evaluate students' understanding of Earth systems. Research in concept change strategy also needs to be developed to help students overcome alternative conceptions. The success of science learning will depend on uncovering children's beliefs that cause alternative conceptions and on discovering the appropriate instructional strategies for changing these alternative conceptions.

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