Teachers' & Students' Concepts of the Measurement of the Size of the Earth

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Abstract: The purpose of this study is to figure out how teachers conduct an experiment in measuring the size of the Earth and how students recognize it. For this study, an in-depth interview was conducted one week after the lesson on the experiment about measuring the size of the Earth. The participants were five secondary school teachers and five secondary school students. The in-depth interview was recorded and transcribed. The result of the interview was drawn through an inductive categorized analysis method. As a conclusion of this study, the teachers taught the students the lesson using alternate angles instead of using the altitude of the Sun. Their lessons were based on Eratosthene's story or some related illustrations suggested in the textbook and not based on an explanation of the principle. Also, students measured the Earth's size only by using alternate angles and didn't understand the meaning of the shadow in the experiment. The results of this study show that teachers need to reconstruct the textbook and understand the accurate experimental principle for the students to have a meaningful experience of the experiment on measuring the size of the Earth.

Key words: measuring the Earth's size, the Sun's altitude, alternate angle, Eratosthenes's measurement of the Earth's size.

Ⅰ. Introduction

It is difficult to directly observe the objects of Earth Science because they involve a great scale of time and space such as geological formation, the size of the Earth, and the composition of the universe(Kim, 2002; Kim, 2005; Lee & Kwon, 2010; Lim & Jeong, 1993). This makes it difficult to bring the objects into a laboratory and conduct inquiries through an actual manipulative activity(Gobert & Clement, 1999; Lee & Kwon, 2010). Therefore, the activity of making up models and researching them based on theory plays a significant role in Earth Science class compared to a manipulative activity(Engelhardt & Zimmermann, 1982; Giere, 1988). This teaching-learning method is useful for students to encourage their interests and acquire a scientific concept(Oh, 2007). The goal of Korean science curriculum is to improve the basic scientific inquiry ability and attitude through diverse activities like observation and experiment suited for the student's level(Ministry of Education & Human Resources Development, 2007). Especially, the experiment activity is key of science class because it can provide students, who have problems doing an abstract activity, with specific and direct experience of the process of Science(Kim, 1997).

Measuring the Earth's size in learning concepts of Earth Science through the modeling experiment suggested to students is Eratosthenes's actual example, it is important in science history. The experiment of Eratosthenes is meaningful in that it measured the Earth's size scientifically using the difference of solar altitudes(Chae, 2012). This method of measurement is more advantageous to students because they can experience it as scientists since the scientific principle is simple. But Chae(2012) pointed out several problems in the experimental process like emphasizing on the concept of alternate angles and suggested an improved experimental method. Woo and Cha(2006) also recognized the difficulty of doing the Earth's size measurement experiment and developed an

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experiment apparatus. Although conducting experiments is an important activity in Science education, like the experiment in measuring the size of the Earth, most experiments in school do not give students meaningful learning(Hart *et al.*, 2000). Therefore it needs to diagnose and improve it by a systematic and critical analysis how the experiment class is going on. Therefore, it needs to be re-assessed and improved by a systematic and critical analysis(Yang, 2006). Therefore, the purpose of this current study is to find out how science teachers conduct an experiment on the measurement of the size of the Earth and how students recognize and diagnose it. Also, this study aims to improve such method of experiments. For these purposes, the research problems are as follows.

First, how do science teachers recognize the experiment of measuring the Earth's size?

Second, how do students recognize the experiment of measuring the Earth's size?

Ⅱ. Research Method

1. Participants

For this research, five science teachers who teach second-year students from secondary schools, and five secondary school students were chosen as participants. These science teachers are working in a secondary school in a metropolitan city and consist of four females and one male. Their career in education is 9 to 11 years and they majored in Earth Science education in university. Students participating in this study are interested in science and they received high grades in science. The participants are selected by a convenience sampling method that extracts sample like field or person that the researcher can easily get access to and get material from(Creswell, 1998). They recognized the purpose of this study and voluntarily participated.

2. Data collection

A semi-structured interview method was used to gather data in order to find out how teachers and students recognize the experiment in measuring the size of the Earth. This method has the advantage of collecting a comparable material from several participants. The main questions of the semi-structured interview were as follows(Table 1).

The interview was done individually in the participant's school, one week after the related lesson. The interview was conducted in a quiet place. Before the interview, the researcher established a rapport with the participant and the interview took 20 to 30 minutes at most. For the students, the interview was conducted by writing the main questions in the questionnaire, in order to save time and to make them feel more comfortable. In the process of the interview, the researcher prepared the related experimental materials, such as a globe, a light

Table 1
The main questions of the semi-structured interview

Object	Main questions
Teachers	· How do you explain the contents of measuring the Earth's size? · How do you conduct the experiment of measuring the Earth's size?
Students	· Explain Eratosthenes' s measurement method by drawing some photos. · Explain the principle of Eratosthenes' s measurement of the Earth's size. · Explain how you conducted an experiment about the principle of Eratosthenes' s measurement of the Earth's size. · Explain the difficulty in the process of Eratosthenes' s measurement of the Earth's size.

bulb and a bar, and allowed the students to use such materials in explaining their answers. The interview was recorded and transcribed.

3. Data analysis

The transcripts of the interviews were organized around the main questions and coded by the researcher. Codes were given to allow for the detection of similar or dissimilar themes. Codes were decided upon after much discussion with colleagues. Transcripts were then compared to find the common themes. Members of the research team then met and discussed themes from their interviews, from which assertions were generated. After the assertions were developed, the researchers returned to the coded data and looked for sections of the interviews that either supported or contradicted the individual assertions. From there the researchers gathered to pool their data, cooperatively working to operationalize terms used in the assertions and determine the strength of support for and contradictions presented by selections from individual interviews. A final analysis was performed to extract the pertinent information.

Ⅲ. Research Results

1. The perception of teachers about the experiment of measuring the Earth's size

The Eratosthenes's experiment method of measuring the Earth's size is suggested for the second-year secondary school textbook. Teachers showed these features while teaching this content.

1) Little awareness of the concept of the Sun's altitude

Teachers focused on explaining the method, the process and the expression of measuring the Earth's size but didn't recognize the scientific concept like solar altitude. Because of that, they concentrated on finding the value of the Earth's size by finding a center angle using alternate angles and making a proportional expression. They also focused on making students understand the related mathematical knowledge in that process.

This is the content of Teacher A's interview as to how she teaches the experiment about the size of the Earth.

> First, I explained it using a friendly material like a piece of pizza or pie because it is difficult for a mathematical formula or expression. I asked how many whole pieces are there if one piece is 45°. And then, I asked the value of all the pieces after I tell them length of one piece's arc. Like this, I taught students concepts and lead the relationship between the length of the arc and the size of the central angle.……Then, students actually measured the values and calculated them.
> In an illustration, I drew a circle in a board and I set the size of the central angle as θ and set the length of the arc as ℓ. As I mentioned above, I explained that we have to measure ℓ actually. In the case of θ, first, I explained that sunlight comes vertically to a stick in Syene and a stick in Alexandria has a shadow using the illustration. And I explained that we can measure the central angle if we measure the angle between the stick and the shadow because there are corresponding angles and the corresponding angles are the same. Oops! Not corresponding angles, alternate angles! (Teacher A)

Teacher A ran the Earth's size measurement class after making students understand the mathematical knowledge by explaining the relationship between the size of a central angle of a circle and the length of an arc using a piece of pizza. The teacher conducted class only for understanding the formula and didn't recognize the solar altitude. Also, the teacher made a mistake by using the corresponding angles instead of alternate angles.

The other teacher also explained that the size of the Earth can be measured by using a proportional expression or alternate angles. And they used an easy example like a piece of pizza for understanding the relationship between the size of the central angle and the length of the arc. But the students thought it was difficult. Teachers used the method of Eratosthenes' measurement using alternate angles but they did not teach the difference between the angles of Alexandria and Syene.

> I explained that we can measure the Earth's size through the proportional expression using the length of the arc between Alexandria and Syene and the difference of latitudes which are found by measuring the angle between the stick and the shadow. (Teacher D)

Teacher D mentioned the angle between the stick and the shadow, but didn't specifically explain what it meant.

> I explained the illustration in the textbook like the length of the arc and the difference of angles between Alexandria and Syene from the center of the Earth by drawing alternate angles. (Teacher E)

Teacher E did mention the difference of the angles between Alexandria and Syene but didn't explain it.

Like this, most teachers do not recognize the concept of the solar altitude which is the angle between the shadow of the stick and the thread. They find the value of the central angle between two regions with alternate angles after they measure the angle between the shadow of the stick and the thread. Then they measured the size of the Earth using the relationship between the length of the arc and the size of the central angle. This method could be a problem because the students know the angle between the shadow of the stick and the thread (7.2°) as mere mathematical value.

2) Mainly use of a story or an illustration rather than an explanation of the principle

Most teachers introduced Eratosthenes's story or some related illustrations suggested in the textbook and not an explanation of the scientific principle, evidence or concept about the Earth's size measurement in their class.

> With this picture, I taught the students that there is no shadow in Syene and there is a shadow of a stick in Alexandria. I explained that Eratosthenes measured the Earth's circumference with the principle that the size of a central angle is proportional to a length of an arc using the angle to students. (Teacher C)
>
> First, I gained the students' interest on this content by telling Earatosthenes's story with fun like 'Eratosthenes walked or rode on a camel to go there.' even if it is not proven ····· I usually explain it using the illustration in the textbook. (Teacher E)

Teachers teach students using the illustration and telling Eratosthenes's story to arouse their interest. But the class is lead by focusing only on the student's interest and not on the mathematical principle as well as the meaning of the angles measured in the experiments and why the angle between the two regions is being measured.

3) The perception about several problems in the process of experiment

Teachers said that they can't do an accurate experiment because of an error caused by several problems in the process of experiment. These problems prevent teachers from doing a direct experiment and lead them to conduct their lessons by merely identifying whether or not the formula is correct. The following contains the interview conducted with Teacher E, where she mentioned that there was an error in the process of the experiment.

> We performed an experiment with a

basketball, two chalks and the sunlight from the window of the class instead of doing it outside. But there was an error in the result. When we measured the size of the angle, we could set the chalk vertically according to the sunlight but it was hard to set the other chalk vertically because it was oblique to sunlight. It made it hard to measure the angle accurately and whenever the experiment is conducted, the error range changed a lot from + to −. (Teacher E)

Teacher E conducted the experiment with a basket ball and sunlight as suggested in the textbook, but replaced the sticks with chalks. The teacher said that it is difficult to measure the angle because the chalk is not set vertically. Other teachers didn't teach a note of caution or a scientific error in the experiment and they just gave lessons to identify Eratosthenes's experiment method.

2. The perception of students about the experiment of measuring the Earth's size

The following features were found after the analyzing the interview about the experiment for students who learned the Earth's size measurement in the textbook.

1) Measuring the size of the Earth only using alternate angles

Students said that they use alternate angles when they measure the Earth's size. As shown in Figure 1, there is a method in the textbook that can be used to find the size of the central angle between the two regions using alternate angles.

In other words, it is to find the value of the central angle by using the angle($\angle\theta'$, 7.2°) between the stick and the thread. But the method that addressed alternate angles in the textbook made it difficult to understand the accurate concept of 7.2° which is the difference of solar altitudes between two regions. And students also think that the measurement of the Earth's size is only a mathematical principle.

The following are explanations about the Earth's size measurement and a drawing(Figure 2).

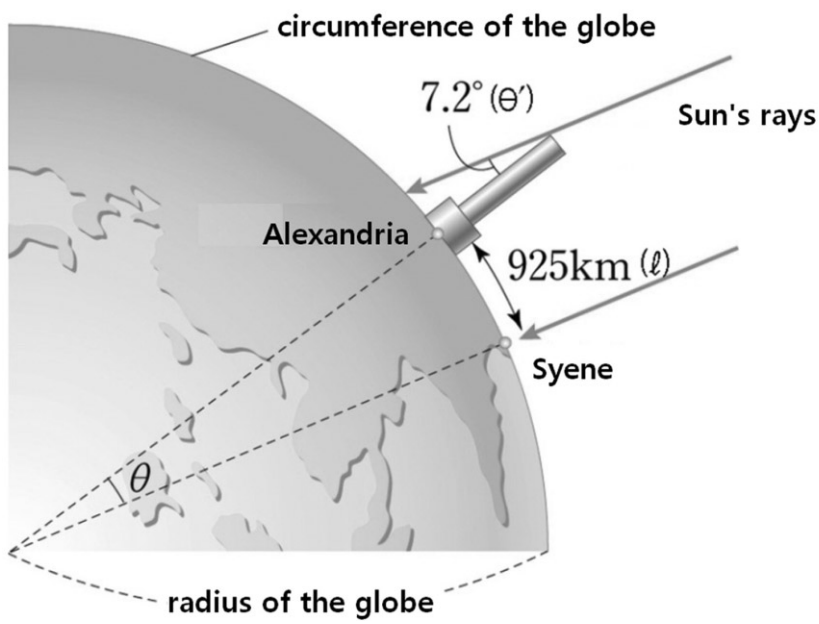

Fig. 1 *Illustration measuring the Earth's size in textbook*

(After drawing Figure 2) The size of the angle and the length of the arc in a fan shape are directly proportional according to the angle. We can find the length of the Earth's circumference using the proportional expression of 7.2° and 925km. Eratosthenes saw that there is no shadow of a well in Syene at noon and there is a shadow in Alexandria. So he measured it by setting two sticks on each region at noon. As a result of this, there is no shadow in Syene and there is a shadow in Alexandria. Eratosthenes gets 7.2° by measuring the end of the shadow with a thread on the assumption that sunlight is parallel. Alternate angles are the same between the two parallel straight lines. So by drawing a fan shape connecting Syene and Alexandria, the size of the central angle and the size of the angle between the shadow and the tip of the stick are the same. Therefore, the central angle is 7.2°. And the proportional expression is 7.2° : the length between the two sticks = 360° : the circumference of the globe on the assumption that the Earth is completely round. (Student B)

Student B can't explain the definite concept of 7.2° and used alternate angles to find the size of the central angle in a fan shape. Student D also used the alternate angles between the shadow and the stick to explain the method of measuring the Earth's size. The followings are student D's interview content and the drawing(Figure 3) based on the explanation.

First, I sat a stick vertically in Syene to have no shadow and sat the other stick in Alexandria to have a shadow. I connected the tip of the shadow and the stick. And θ' and θ are the same because they are alternate angles based on the fact that sunlight is parallel. Then I came up with the distance and the central angle between two regions using parallel lines theorem because it is impossible to measure it directly. Finally, I found the value using the proportional expression which is θ: 360° = ℓ : $2\pi R$. (Student D)

Unlike other students, Student E explained how to measure the size of the Earth and explained how to find the size of the central angle using the principle of alternate angles.

(After drawing Figure 4) The first condition is that the Earth is completely round. If the Earth is shaped with edges like a rectangle or a cube, it would be hard. And if the sunlight is not parallel, it would be hard to measure the Earth's size because we cannot apply the principle of alternate angles. The method of

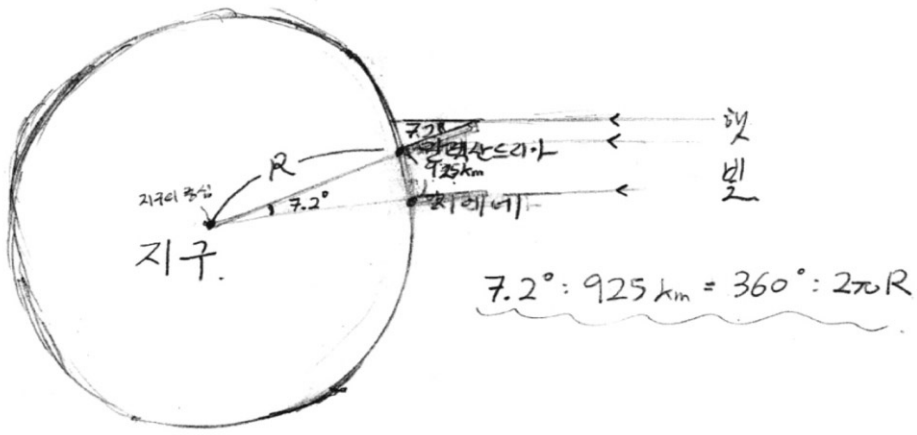

Fig. 2 *Student B's drawing about the measurement of the Earth's size*

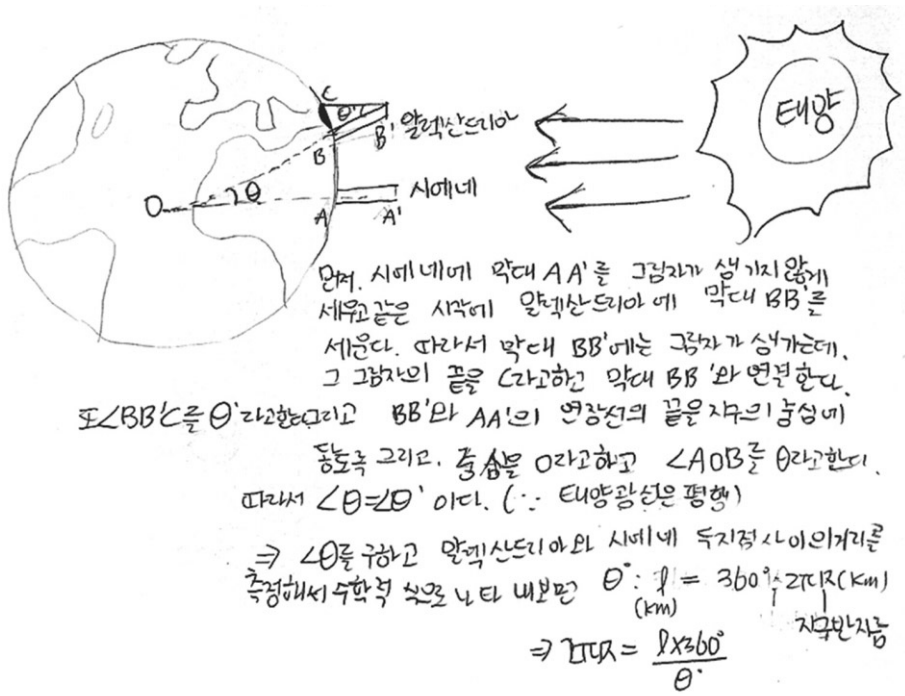

Fig. 3 *The drawing of student D's measuring method of the Earth's size*

measuring the Earth's size begins by setting a stick in a point because sunlight is parallel. And a shadow appeared because of the sunlight and an angle can be created by linking a thread from the shadow and the tip of the stick. We find the angle between the thread and the stick. If we use that angle, then we can measure the Earth's size. We can measure the Earth's size if we find the distance between two regions and the size of the central angle using the principle of alternate angles. (Student E)

All students who participated in this study used the principle of alternate angles in the textbook when they explained the method of

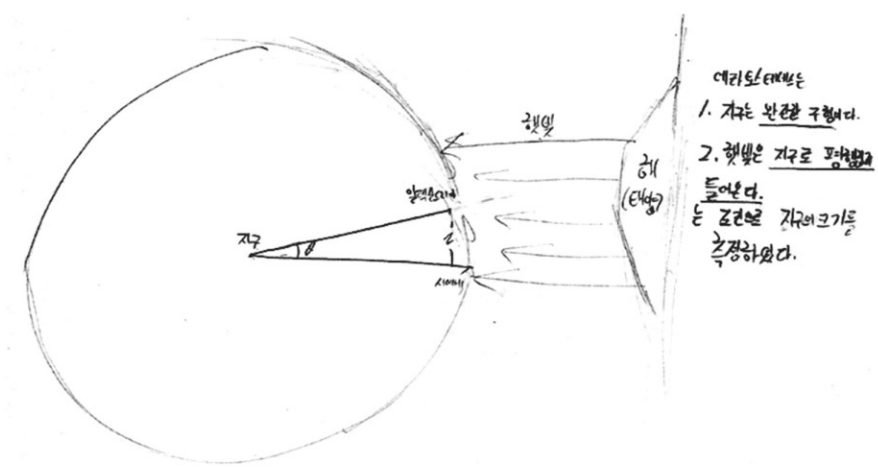

Fig. 4 *The drawing of student E's measuring method of the Earth's size*

measuring the Earth's size. These explanations are the same with those of the teachers, but no one understood or mentioned the accurate meaning of 7.2 found by using alternate angles.

2) Lack of understanding of the meaning of the shadow in the experiment

Students said that they used two sticks to measure the size of the Earth. Students said that one stick has to be set without a shadow, and the other has to be set with a shadow. But the students only mentioned that as a process of the experiment without understanding the scientific meaning of the shadow. The length of the shadow in this experiment is an important clue when measuring the Sun's altitude and we have tried measuring the size of the Earth in Korea with the use of such altitude(Chae, 2012). But students, except for student B, said that they cannot measure the size of the Earth in Korea because they didn't connect the length of the shadow with the solar altitude. The students believe that they have to conduct the experiment in a place without a shadow, like Syene, in order to measure the size of the Earth.

> Not having a shadow means that the sunlight comes to the stick as a straight line and having a shadow means that sunlight and the stick are not parallel. So we cannot measure the size of the Earth in Korea because there is shadow everywhere. (Student A)

> We can't measure the size of the Earth in Korea because it is near the equator. Therefore, it gets plenty of sunlight. There is no shadow in the equator because it is parallel with sunlight. But Korea is located in the northern hemisphere, so it is impossible not to have a shadow because of the shape of the Earth. We have to do that in the equator. (Student E)

Student A and Student E explained that the reason for the difference in the shadow is parallel sunlight. Students think that they can measure the Earth's size only in the equator that is parallel with sunlight.

Student E explained that the difference in the length of the shadow is related to the Earth's shape and thought that the different length of the shadow at the same time is an evidence that the Earth is round.

> If the Earth is flat, there should be no shadow anywhere because sunlight becomes parallel. If the Earth is round, there is a shadow because it is set obliquely. There is a shadow in some place and there is no shadow in other places at the same time. It means the Earth is not flat. It could be the evidence that 'the Earth is round'. (Student E)

Student B said that we can measure the size of the Earth in Korea using the difference in angles. But in an additional interview, the student recognized 7.2°, which is measured by using the length of the shadow as the evidence of the Earth's shape and not the angle of the Sun's altitude. Therefore, Student B mentioned the difference between the angles but can't formulate the scientific concept.

> In Korea the size of the Earth is measured by using the difference in angles. If the angles are different, we have to subtract the smaller value from the bigger value. (Student B)

> (7.2°) is not the angle and whether the shadow appears or not. If the Earth is flat, there would be no shadow anywhere. Does the fact that there is a shadow in some parts of the Earth prove that it is round? (Student B)

Students understood that the difference in the shadow of the two sticks is related to the parallel sunlight and the round shape of the Earth. The reason why they can't connect it with the Sun's altitude is because the experiment in the textbook didn't mention the solar altitude.

Therefore, it needs to suggest that the difference in the length of the shadow is related to the Sun's altitude in the textbook to give them the opportunity to measure the Earth's size directly in Korea.

3) The limitation when measuring the Earth's size

Students answered that the experiment of measuring the size of the Earth has several difficulties in the experimental process. The following is Student A's interview content.

> It is hard because the Earth is not completely round. Also, even if it has a precise radius, it is not constant because polar radius and equatorial radius are not the same. The size of θ is not accurate and we can't directly measure the size. (Student A)

Student A said that the Earth is not a perfect sphere and that the central angle of the Earth is not accurate, which is measured by this method. Student B, C and D said that there is an error because the Earth is not a perfect sphere, the longitudes between two regions are not corresponding and we can't measure the accurate distance.

> When we measure the distance between Syene and Alexandria, there is an error because they are not in the same longitude. Also the Earth is not a perfect sphere. It is division algebra which the equator is a little swollen. (Student B)

> The Earth is oval so the length of the equator is a little longer. Also the two cities, Syene and Alexandria, are not located in the same longitude. I can't measure the distance between the two cities accurately. (Student C)

> I can't measure the distance between Alexandria and Syene accurately. They are not located in the same longitude, so I can't get the accurate value. Also, I can't find the exact value of the proportional expression because the Earth is oval while the equator is a little swollen than the polar area. (Student D)

Student E explained the shape of the Earth and the difficulty of measuring the distance between two regions. And the student suggested that the limitation of the experiment is that there is no evidence that sunlight is always parallel.

> It is difficult to find the precise distance between Syene and Alexandria because they are not in the same longitude. So there is an error in the size of the Earth. Also, it is difficult because the Earth is not a perfect sphere and there is no evidence that sunlight is always parallel. (Student E)

4) Barely doing the experiment of measuring the Earth's size

Students responded that they learned the lesson about the measurement of the size of the Earth through an explanation and not through an experiment.

> No. We didn't the experiment with a globe and we just learned a theory. (Student B, C, D, E)

According to preceding research, teachers teach students based on a lecture or textbook and not through an experiment in most countries(Giddings & Waldrip, 1993). But an experiment can be used to improve students' conceptual change successfully. Learning science through some theories can limit the student's understanding of the accurate scientific concept. Therefore, it is necessary to develop an easily available experiment method, which takes less time.

Ⅳ. Conclusion

Upon analyzing the teaching method and perception of teachers and students about the

experiment of measuring the Earth's size, the results are as follows.

First, teachers focus on an experiment method and a mathematical formula in the experiment of measuring the Earth's size and they did not recognize the difference of solar altitude, which is the most important scientific principle. Also, their lessons were based on Eratosthenes' s story or some related illustrations suggested in the textbook and not an explanation of the principle. And most teachers do lectures using theories than experiment because the experiment of measuring the Earth's size has many difficulties in the process of measurement. These research results are thought to be caused by problems in experiment and illustration suggested in the existing textbook as Chae(2012) revealed.

Second, students thought that the Earth's size can be measured by using alternate angles only and not by measuring the difference of the Sun's altitudes between two regions. Therefore, nobody accurately understands what 7.2°, which is measured in the experiment means. Students falsely believe that the length of the shadow is the phenomenon in the experiment because sunlight is parallel and the Earth is round. And students thought that they cannot measure the Earth's size in Korea because they didn't consider the difference of the Sun's altitudes according to the length of the shadow. Students and teachers' awareness of measuring the Earth's size is similar. This means that students were affected by teachers' explanations and illustrations in textbook using the alternate angles when to measure the size of the Earth.

In order to let students meaningfully participate in an experiment and develop their knowledge in Science, teachers should know the related knowledge and make students recognize the purpose and the principle of the experiment(Hart *et al.*, 2000). Therefore, teachers need to be aware of the difference in solar altitudes and textbooks need to be reconstructed by reflecting on this study.

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