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Basic Astronomy Concepts In The Footsteps Of Eratosthenes

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Abstract

Based on Eratosthenes' method of "Measuring the Circumference of Earth," dating from 276 BC, this study is the result of a five-day, three-stage, science school, "I am Learning about My Planet" with the intent of having participants gain understanding of the basic concepts of astronomy in a non-traditional setting and using a non-traditional method. The first stage involved astronomy science schools with 30 primary school teachers and the second stage involved 30 primary school pupils (aged 14). The last stage completed a "Measuring the Circumference of Earth" experimental activity with the participation of both the teachers and the pupils. A pre-test and post-test of 13-items, based on "The Astronomy Diagnostic Test" and the Turkish educational curriculum evaluated changes in participants. A comparison of the data from the teachers and the students produced interesting results, notably that more pupils than teachers answered certain questions correctly. Furthermore, experiment produced a unique instrument for measuring the circumference of Earth, with a calculated margin of error of 0,17%.

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Keywords:

1. Introduction

Throughout human existence, curiosity of the Earth, a desire for understanding it and the mechanisms of its functioning, and using that knowledge to improve life have been a concern of humans. This curiosity led to the inception and development of basic natural sciences. In this context, some of the most significant concepts that needed investigation were the shape and dimensions of the Earth and human's position on it. In the last 30 years, a significant amount of research has investigated astronomy with a focus, in general, on the extent of basic understanding of concepts of astronomy (Vosniadou & Brewer 1985; Zeilik et al. 1998; Baxter 1989; Trumper 2001; Lelliottand & Rollnick 2010). Many studies revealed that, although students – and even adults – have some knowledge of basic astronomy and certain mental models, these differ from the scientific and present difficulties in concretization (Klein 1982; Baxter 1989; Sharp 1996; Trundle et al. 2002; Mant & Summers 1993). Questioning the shape of Earth elicited responses such as, "globe", "ellipse", "geodesic"; whereas, the question, "How did you reach this conclusion?" elicited very few correct answers, with most of them implying that the Earth is flat rather than curved (Vosniadou & Brewer 1985). In addition, despite common acceptance that the Earth rotates on its axis and orbits the sun, very few correct answers are given to the question, "How do you prove it?" (Sneider & Pulos 1983;

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Vosniadou & Brewer 1985, 1989, 1990). Although many countries teach the basics of astronomy in their schools' curricula, few facilities exist for experiments that the students could complete to determine the shape, dimensions, and position of Earth. This makes the comprehension of basic knowledge difficult, and students, consequently, develop an aversion to the study of nature and the basics of science (Vosniadou & Brewer 1994).

Throughout the history of humankind, wonder of the Universe, attempts to uncover its secrets, and explain humans' position in it have existed. This curiosity necessarily entails questioning and learning nature's basic mechanisms and functioning. This process of questioning and learning involves various scientific methods particular to different cultures. Humans' curiosity about the shape and movements of the planet and its relations with the sun, the moon, and other planets is characteristic of the rise of scientific inquiry, of civilizations and cultures. Scientific processes become meaningful not through rote learning but through comprehending the underlying basic mechanisms and causes. One of the fields, traditionally using memorization rather than internalized is, unfortunately, astronomy (Vosniadou & Brewer 1985). For instance, in the Turkish educational system, the shape, dimensions, and basic functioning of Earth are mostly taught and learned at "knowledge" level (Kalkan & Kıroğlu 2007). In order to go beyond this "knowledge" level and enable students to "comprehend" rather than "memorize" the concepts, creation of an experimental setting allowed students, living in two Turkish cities on the same longitude but about 550 km apart (Samsun and Hatay) to accomplish observations and experiments by themselves.

The current study, employs the method of "Measuring the Circumference of Earth" developed in 276 BC by Eratosthenes who measured the lengths of the shadows of sun rays in the Egyptian cities of Alexandria and Syene. Eratosthenes' discovery was in the second century BC in Alexandria, Egypt, which was considered the largest metropolis of the time. Sagan (1980) relates this process as follows:

> *"Eratosthenes was the director of the great library of Alexandria, where one day he read in a papyrus book that in the southern frontier outpost of Syene, near the first cataract of the Nile, at noon on June 21 vertical sticks cast no shadows. On the summer solstice, the longest day of the year, as the hours crept toward midday, the shadows of temple columns grew shorter. At noon, they were gone. A reflection of the Sun could then be seen in the water at the bottom of a deep well. The Sun was directly overhead.*
>
> *It was an observation that someone else might easily have ignored. Sticks, shadows, reflections in wells, the position of the Sun - of what possible importance could such simple everyday matters be? But Eratosthenes was a scientist, and his musings on these commonplaces changed the world; in a way, they made the world. Eratosthenes had the presence of mind to do an experiment, actually to observe whether in Alexandria vertical sticks cast shadows near noon on June 21. And, he discovered, sticks do.*
>
> *Eratosthenes asked himself how, at the same moment, a stick in Syene could cast no shadow and a stick in Alexandria, far to the north, could cast a pronounced shadow. Consider a map of ancient Egypt with two vertical sticks of equal length, one stuck in Alexandria, the other in Syene. Suppose that, at a certain moment, each stick casts no shadow at all. This is perfectly easy to understand - provided the Earth is flat. The Sun would then be directly overhead. If the two sticks cast shadows of equal length that also would make sense on a flat Earth: the Sun's rays would then be inclined at the same angle to the two sticks. But how could it be that at the same instant there was no shadow at Syene and a substantial shadow at Alexandria?*
>
> *The only possible answer, he saw, was that the surface of the Earth is curved. Not only that: the greater the curvature, the greater the difference in the shadow lengths. The Sun is so far away that its rays are parallel when they reach the Earth. Sticks placed at different angles to the Sun's rays cast shadows of different lengths. For the observed difference in the shadow lengths, the distance between Alexandria and Syene had to be about seven degrees along the surface of the Earth; that is, if you imagine the sticks extending down to the center of the Earth, they would there intersect at an angle of seven degrees. Seven degrees is something like one-fiftieth of three hundred and sixty degrees, the full circumference of the Earth. Eratosthenes knew that the distance between Alexandria and Syene was approximately 800 kilometers, because he hired a man to pace it out. Eight hundred kilometers times 50 is 40000 kilometers: so that must be the circumference of the Earth.*
>
> *This is the right answer. Eratosthenes' only tools were sticks, eyes, feet and brains, plus a taste for experiment. With them he deduced the circumference of the Earth with an error of only a few percent, a remarkable achievement for 2200 years ago. He was the first person accurately to measure the size of a planet."*

2. Method

This is an experimental study to determine the change in primary school pupils' and teachers' knowledge of basic concepts of astronomy following a unique science instruction they received. The research model is a single group pre-test/post-test experiment.

2.1. Universe and Sample

The research universe consists of teachers from various cities in Turkey who volunteered to attend the Science School Turkey and eighth-year primary school pupils in Samsun. In processing the applications to the Science School project, the teachers' regions, seniorities, and subjects were considerations. Thirty primary school teachers and 30 eighth-year primary school pupils took part in the study.

2.2. Data Collection Instrument

This study used two types of instruments for collecting data. One was a basic astronomy scale and the other was a worksheet. To detect any changes, following the science schools, the participants completed a 13 item test designed from "The Astronomy Diagnostic Test" (Zeilik 2002; Hufnagel 2002) and the Turkish educational curriculum. Pilot studies, completed prior to administration of the test, allowed amendments to the test items where necessary. The Kuder Richardson (KR) 20 reliability index for the test was 0,58.

The instrument for collecting data included worksheets that the students used for entering data and calculations in the activity for measuring the circumference of Earth.

2.3. Data Analysis

Analysis of the quantitative data collected from the teachers and pupils through pre-tests and post-tests during the project used SPSS 16 computer program. Following these analyses, collective interpretation of the pre-test and post-test data determined the changes in the participants' knowledge of basic astronomic concepts. Analysis of the worksheets, distributed to the pupils in the activity for measuring the circumference of Earth, compared the pupils' calculations with real values and calculated the percentage of errors.

2.4. Research Stages

The study entitled "I am Learning about My Planet" had three stages. The first stage consisted of science school for teachers, the second stage for pupils' science school, and the third stage involved measuring the circumference of Earth with the pupils.

Teachers' Science School: A two-day science school included 30 primary school teachers from various regions, with different levels of seniority, and teaching different subjects. In the science school, field experts presented basic astronomic concepts to the teachers.

Pupils' Science School: A two-day science school included 30 pupils from four primary schools with different socio-cultural demographics in Samsun.

The subject headings of the training given in the science schools with the teachers and the pupils are:

- Movements of the Sky and the Solar System
- Cosmic Voyage (documentary screening)
- The Universe and Us
- The Seasons
- Solar and Lunar Eclipses
- Our Location in the Universe
- The Cold Face of Change (documentary screening)

- Astronomy Resources on the Internet
- Concepts of Proximity and Distance in the Planetarium
- Planetarium Screening (The Oasis in the Universe and the Astronaut)
- Sky observations

Measuring the Circumference of Earth: The activity for measuring the circumference of Earth occurred, simultaneously, in the Turkish cities of Samsun and Hatay. Almost on the same longitude, these two cities are, arguably, suitable for measurements. Four primary schools from Samsun, identified as A, B, C, and D, paired city, identified as paired with four from Hatay, identified as E, F, G, and H. During the experiment, the pupils shared their data with each other through video conferencing.

School A Samsun ⟷ School E Hatay
School B Samsun ⟷ School F Hatay
School C Samsun ⟷ School G Hatay
School D Samsun ⟷ School H Hatay

Developing the Instrument for Measuring the Circumference of Earth: One of the most important parts of the project "I am Learning about My Planet" was the necessity for extending the sticks and measuring their shadows' lengths to extend through the centre of the Earth. While these extensions can more accurately extend through Earth's centre on large, flat terrains, relative errors are inevitable in mountainous regions. For this reason, development of a special measuring instrument allowed pupils to use Eratosthenes' 2300 year-old method with a lesser margin of error. The basic technique of this instrument is measurement of the shadow of a stick hanging from a thin cord; the Earth's gravity points the stick toward Earth's centre. The stick hangs at a 90 degree angle over the centre of a round table whose diameter is one meter. The stick is perpendicular to Earth's surface. The ruler on the table has 1-mm intervals marked. In addition, as seen in the figure 1, to avoid movements due to wind, the table has adjustable legs, each with an angle of 120 degrees, and stabilized at the instant the stick's direction is toward the Earth's centre, thus preventing any movements. This system allows measurements on flat and mountainous terrain alike. The dimensions of the instrument are 120 x 120 x 80 cm.

Figure 1. Measurement instrument

3. Findings And Discussion

3.1. Stage One

The graph in Figure 2 shows the percentage change from the 30 teacher's correct answers in the 13-item pre- and post-tests. While the average of teachers' correct answers in the pre-test was 47,93%, it was 62,58% in the post-test.

Consequently, the contribution of the basic astronomy science school to this change is 14,65%. Following the science school, while the teachers' percentages of correct answers rose to some extent for some questions (Items 2, 3, 5, 8, 10, 11, and 12), they remained unchanged in others (Items 1, 4, 6, 9, and 13), as Table 1 and Figure 2 show. Items 1, 4, 6, 9, and 13 are questions requiring three-dimensional thinking that involve such basics as an individual's position on Earth, Earth's rotation on its axis, other nearby celestial bodies' movements relative to those of Earth (the Earth's orbit around the Sun, the Moon's orbit around the Earth, and their position in relation to the stars). The reason for observing no change for questions requiring three-dimensional thinking following the science school is that teachers' may resist comprehending these concepts. While the expectation is that teachers acquire knowledge of these basics concepts in pre-service training and from daily experiences, their resistance to internalizing the concepts encompassed in the questions is an interesting finding.

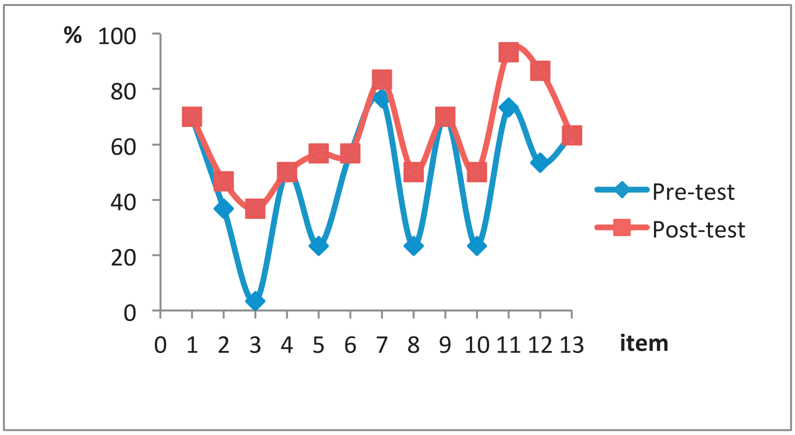

Figure 2. Graph showing percentages of the teachers' correct answers in pre- and post-tests

Table 1. Correct answer ratio and gain index values $\langle g \rangle$ according to pre-and post-test results for teacher and pupils.

	STUDENT			TEACHER		
Item	Pre-test % N=30	Post-test % N=30	Gain $\langle g \rangle$	Pre-test % N=30	Post-test % N=30	Gain $\langle g \rangle$
1. Earth's rotation	60,0	63,3	0,08	70	70	0
2. Solar eclipse	26,7	50,0	0,32	36,7	46,7	0,16
3. Seasons	3,3	6,7	0,03	3,3	36,7	0,34
4. Time zones	70,0	70,0	0	50,0	50,0	0
5. Sun overhead at noon	3,3	26,7	0,24	23,3	56,7	0,43
6. Relative distances	46,7	53,3	0,12	56,7	56,7	0
7. Dimensions	73,3	83,4	0,38	76,7	83,4	0,33
8. Distances	30,0	53,3	0,33	23,3	50,0	0,35
9. Moon's rotation	56,7	76,7	0,46	70,0	70,0	0
10. Earth dimensions	23,3	56,7	0,43	23,3	50,0	0,35
11. Center of the Universe	63,3	80,0	0,45	73,3	93,4	0,75
12. Seasons	46,7	63,3	0,31	53,3	86,7	0,71
13. Shape of Earth	56,7	60,0	0,08	63,3	63,3	0
Mean	**43,07**	**57,18**	**0,25**	**47,93**	**62,58**	**0,26**

As seen in Table 1, comparison of pre- and post-course results can use a normalized gain index, the ratio of the actual average student gain to the maximum possible average gain, as reported by Zeilik, Schau, & Mattern (1999).

Gain index values can range from 0 (no gain achieved) to 1 (all possible gain achieved). The mean gain is a respectable 0,25 for student, 0,26 for teachers as seen in Table 1.

Thirty percent of teachers provide incorrect answers to Question 1 regarding the Sun's rising in the east in the morning, being directly overhead at noon, and setting in the west in the evening. The reason the majority answered "The Earth orbits the Sun" may be that the teachers put daily experiences before scientific facts. In order to provide the correct answer to this question, teachers need to model, mentally, the abstract concepts using daily experiences and scientific facts. Otherwise, teachers may impart incorrect information to students regarding the basics of the plane. The low percentages, which remained unchanged in the pre- and post-tests, for the correct answers for Questions 4 and 13 (50% and 63,3%, respectively) on the movements relative to a person's position on Earth and to the Sun demonstrates that teachers cannot think three-dimensionally and arrive at a modeling.

Question 12 concerns, at "knowledge" level, the occurrence of seasons. While 53,3% of the teachers provided correct answers to this question in the pre-test, the score was 86,7% in the post-test. Question 3, involving the acquisition of the same knowledge as Question 12, but was at the "comprehension" level, rendered 3,3% correct answers from teachers in the pre-test and 36,7% in the post-test. Despite the significant increase in the post-test, the score of 36,7% demonstrates that the teachers do not fully grasp the occurrence of the seasons and lag behind not only at the "knowledge" level. As suggested by Kikas (1998), the major reason for this could be incorrect assumptions that the seasons depend on the distance between the Earth and the Sun rather than on the Earth's tilted axis, and that the Earth should be warmer when closer to the Sun.

3.1. Stage Two

The graph in Figure 3 shows the percentage change for correct answers provided by the 30 eighth-year primary school pupils to the 13-item astronomy test during pre- and post-tests. The pupils' pre-test average of 43,07% rose to 57,18% in the post-test. The contribution of the basic astronomy science school to this change was 14,11%. Following the science school, while the pupils' percentages of correct answers rose to some extent in some questions (Items 2, 5, 7, 8, 9, 10, 11, and 12), they remained practically unchanged in others (items 1, 3, 4, 6, and 13), as can be seen in Figure 3.

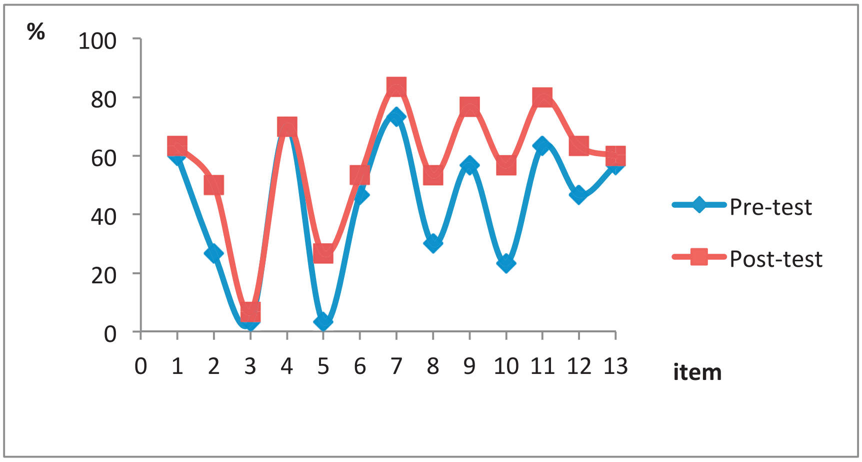

Figure 3. Graph showing percentages of the pupils' correct answers in pre- and post-tests

Question 1 regarding the Sun's rising in the east in the morning, being directly overhead at noon, and setting in the west in the evening garnered 60% correct answers from pupils in the pre-test and 63,3% in the post-test. These results suggest that the science school contributed very little to the change. While 20% of pupils answered "The Sun orbits the Earth" – pre-Copernic school of thought – in the pre-test, this rate fell to 3,3% in the post-test. The 17,7%

change, however, was due not to the right answer but to another incorrect answer, "The Earth orbits the Sun," which suggests that the pupils may be putting their daily experiences before scientific facts. In the post-test, 36,7% of pupils provided an incorrect answer to this question. The reason the majority answered, "The Earth orbits the Sun," similar to the teachers, may be that teachers emphasize daily experiences before scientific facts. In order to render a correct answer to this question, the teacher needs to model, mentally, the abstract concepts using their daily experiences and scientific facts.

Following the science school, the changes in the teachers' and the pupils' performances in the pre- and post-tests were 14,65% and 14,11%, respectively, which, perhaps, appear to be almost identical. Nevertheless, as can be seen in Table 1, the teachers' and the pupils' percentages of correct answers vary for some questions. The explanation for the pupils' higher performance on Question 4, which requires three-dimensional thinking and mental modeling, could be the result of more modeling capability than the teachers.

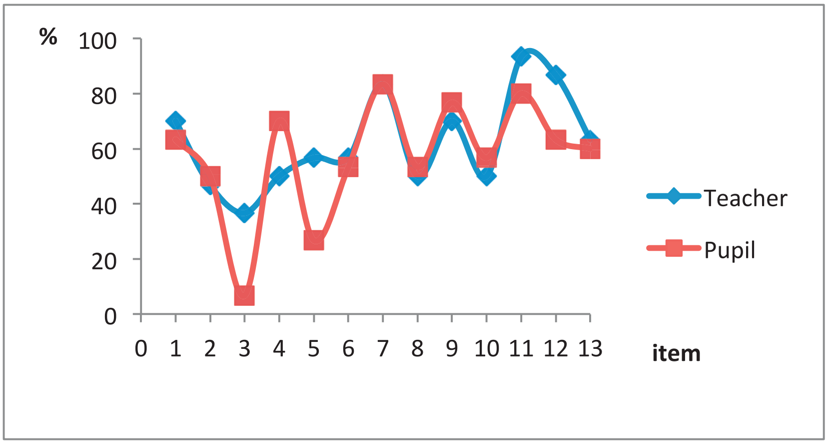

Figure 4. Graph showing the teachers' and the pupils' post-test performance

3.1. Stage Three

Table 2. Results of the activity for measuring the circumference of Earth

School	Radius	Circumference	% Error
Schools A & E	6399 km	40185 km	% 0,43
Schools B & F	6374 km	40032 km	% 0,04
Schools C & G	6373 km	40022 km	% 0,03
Schools D & H	6383 km	40090 km	% 0,18

While McCarthy & Petit (2004) contended that the Earth's radius is 6371 km, Bekeris et al. (2011) asserted 6375 ± 25 km. Taking these figures into account, the four pairs of schools in the project arrived at results similar to that in the literature. Compared to the radius calculated by McCarthy & Petit (2004), the schools reached the same conclusion with error margins of 0,43%, 0,04%, 0,03%, and 0,18%, respectively as shown in Table 2. The average error margin of these four pairs of schools was 0,17%. These results, shared by the pupils in two cities on the same longitude but some 750 km apart, demonstrate that the pupils were successful in their measurements and that the measurement instrument served its purpose.

4. Conclusion And Suggestions

This study first considered teachers' and the pupils' knowledge of basic astronomical concepts and then attempted to detect any changes in their knowledge following a programme within the boundaries of the project, and by comparing the results from the teachers and from the pupils simultaneously. The pre-tests revealed that the teachers and the pupils had more or less the same levels of knowledge of basic astronomy. The post-tests following the two-day science schools revealed, on the other hand, almost identical levels of change for the teachers and the pupils (14,65% and 14,11%, respectively).

Notably, the teachers responsible for teaching basic astronomical concepts in the primary curriculum had a similar level of knowledge as the pupils and showed an almost equal rate of improvement following the science school. The expectation is that teachers be more knowledgeable in the basics of astronomy in order to be able to correct their pupils' mistakes, but this study suggests similar levels of knowledge and mental modeling among teachers and pupils.

Observations indicate that the teachers had difficulty with the questions which required three-dimensional thinking to understand the movements of the Earth, the Moon, and the Sun relative to one another, and that they resisted changing their mistakes even after the science school. The pupils, on the other hand, performed better than the teachers on Question 4 which required three-dimensional thinking and mental modeling.

Both the teachers and the pupils had similar mental models of the Sun rising in the east in the morning, being directly overhead at noon, and setting in the west in the evening. Personal observations, which individuals may prefer over modeling arising from scientific processes, may be the resulting interpretation of this phenomenon.. Likewise, the teachers' and the pupils' mental models of occurrence of seasons focus towards the "distance between the Earth and the Sun." Both instances of modeling show that the teachers as well as the pupils emphasize daily experiences rather than scientific facts and are firmly committed to preconceived models.

The pupils measured the Earth's circumference with the help of specific equipment. Their calculations were 40185 km, 40032 km, 40022 km and 40090 km as shown in Table 2. These results are significant in that they are similar to the actual value and data appearing in the literature (Bekeris et al. 2011; McCarthy and Petit 2004). Further along the activity, the pupils shared their data with each other and, using the Earth's circumference, they calculated the Earth's radius, its volume, and its average density. Furthermore, from their positions on Earth, the pupils were also able to predict and interpret the movements of the Earth and the Sun, the force of gravity, and the shape of the Earth based on different lengths of shadow cast by the Sun in different positions.

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