2. Try it. What happened?

Concept introduction. When a large marble strikes a small one moving in the opposite direction, the speed of the large marble does not change much, but the small marble bounces away very quickly. (In fact, light bouncy objects move away from heavy bouncy objects with a speed about twice the speed at which the heavy bouncy object is moving, regardless of the speed the light object has before the collision.)

Multiple ball bounce. You can do this same thing in a different way. First, test how bouncy the high-bouncing ball and table tennis ball are by dropping them on the tabletop and seeing how high each bounces. Next, sit the table tennis ball on top of the high-bouncing ball, hold them about 10 cm above the tabletop, and drop them so they fall together. What happens after they strike the table?

After the heavy, high-bouncing ball strikes the tabletop, it begins to move upwards. However, the light, table tennis ball is still moving downwards, and after they collide, the lighter ball again moves away quickly, just like before with the light and heavy marbles. The same thing happens when a rolling bowling ball (heavy) collides with a beach ball (light) of about the same size moving in the opposite direction.

Peter Eastwell

Learning from History: A Lesson on the Model of the Earth

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Abstract

It is suggested that historical material concerning the model of the earth be utilised in the science classroom to construct narrative explanations. The article includes the various ancient models of the earth, the discovery of the spherical earth model, and the arguments and experiments coupled with it. Its instructional gain may lie in the consequently created situations in which students are led to reflect on their own concepts/models of the subject and to appreciate the diversity in thinking about it.

Introduction

Research during the last decades has shown that young students construct for themselves alternative models of the earth as opposed to accepted scientific knowledge (Liu, 2005a, 2005b; Nussbaum, 1979, 1985; Nussbaum & Novak, 1976; Sneider & Poulos, 1983; Vosniadou & Brewer, 1992, 1994). Most telling is the evidence that "synthetic models" (Vosniadou & Brewer, 1992, 1994), such as a hollow-spherical shape for the earth with people living inside on a flat ground, arise while children try to reconcile the scientific model of the spherical earth with their daily observation of a flat ground. Liu's (2005b) recent study of 8- to 12-year-old Taiwanese and German students' conceptions of the universe reveals that, looking at solely the shape of the earth, the majority of the students give scientifically correct responses. However, when the questions are extended to the spatial relations of the earth and the obvious celestial objects, it becomes clear that the children actually have difficulty relating what is viewed on the surface of the earth with what is explained by other people, such as the horizon as an indicator of the spherical shape of the earth and the rise and setting of the sun as the result of the earth orbiting the much bigger sun. This kind of difficulty gives rise to statements like “no cloud is present beneath the earth” and “earth stays still, and the sun and the moon circle around it,” as shown in Figure 1.

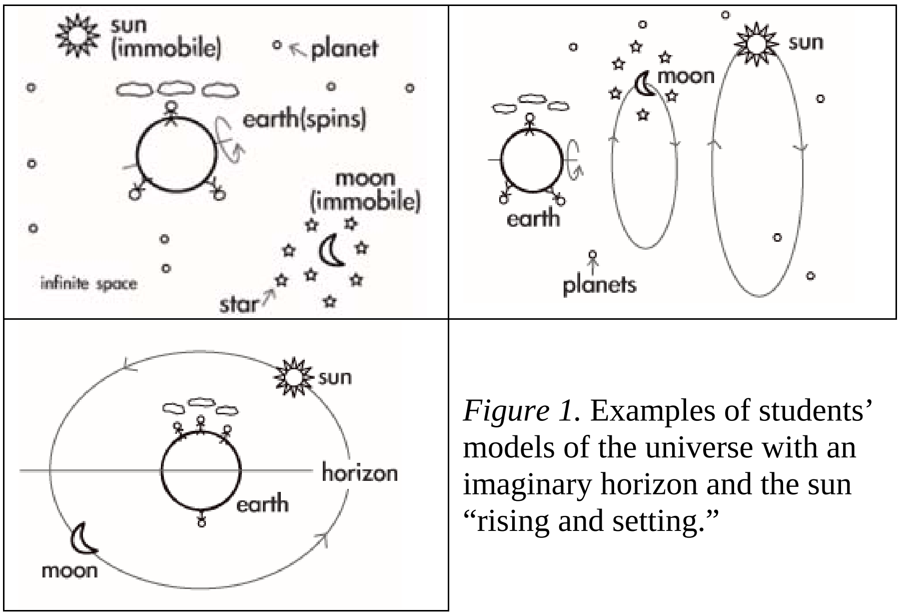

Figure 1. Examples of students’ models of the universe with an imaginary horizon and the sun “rising and setting.”

At this point, it seems to be clear that students’ difficulty in understanding the earth model is derived from the perspective students take from where they are located. To understand the sphericity of the earth and its position in the universe, the student must first realize there is a difference between what is seen on the surface of the earth, while the observer is a tiny point, as opposed to the whole earth, and outside the earth, while the earth can be fully captured in the view. That is, the difference between the perspectives taken on and beyond the earth should be recognised and comprehended. Yet simply describing this difference may not be sufficient to ensure meaningful learning of the subject. We need to lead students to a situation in which they can reflect on their own ideas in a way that the underpinning of these ideas is emphasized and thereby proceed to understand and appreciate diverse thoughts derived from their connected contexts.

It should be an instructionally meaningful, although not the only, approach to creating such a situation through the use of historical material. It is suggested that narrative explanations of the structure of the earth be constructed, including the various ancient models of the earth, the discovery of the spherical earth model, and the arguments and experiments coupled with it. The instructional gain may lie in the consequently created situations in which students are led to look at their own concepts/models of the subject, as well as others. Furthermore, there is a potential to convey some aspects of the nature of science, such as the interrelations between concepts/theories (models) and methods.

Historical Models of the Earth

Everyday experience, in the past as in the present, is compatible with the idea of living on a flat earth. Ancient people genuinely believed that if you went far enough you would fall off the edge. From around 3,000 B.C. onward, man has articulated and documented various ideas about the shape of the earth in different temporal and spatial settings. For example, the ancient Chinese described the earth as a chess-board, whereas their Egyptian counterpart thought the earth was a rectangular box. The early earth models very often show a close linkage to man's pursuit of an "ideal" structure of the world.

Looking at the Western world, the story of man's ideas about the earth's shape and its position can begin with the Babylonians (before 3,000 B.C.), virtually the earliest wisdom we can reach, who imagined the earth being like an oyster and occupying the central place of the universe. In this model, the northern half of the earth was called the upper, associated with life and light, whereas the southern half was called the under, associated with darkness and death. Each of the halves are composed of seven stages, and beyond the uppermost stage we find the stars.

During the 8th century B.C., Homer described, in his remarkable mythological text, that the earth is flat like a shield, upon which is the land, a single island, surrounded by the ocean. The sky, or heaven, is seemingly pictured as solid, as he used metaphors such as iron or bronze in several passages.

It is Anaximander (about 555 B.C.) who established the first recorded mechanical model of the universe, in which the earth is a cylinder with the sun, moon, and stars located on concentric rotating cylinders. Planets were not explained. The sky surrounded the earth, and beyond the sky was a region of fire. There the sun, moon, and stars were holes in the sky, through which the fire could be seen. This view should be taken as revolutionary, as previously all heavenly events and entities had always been interpreted in terms of gods.

Early natural philosophers soon arrived at the idea of the spherical earth. It is around the 6th century B.C. when a spherical earth became self-evident in the western world. The spherical earth was often thought to be floating on water. However, Greek philosophers also concluded that the earth could only be of a spherical shape because that, in their opinion, was the "most perfect" shape.

Thales (640-562 B.C.) made one of the first attempts to explain the nature of the universe in philosophical terms. He proposed that the earth is shaped like a ball, floating on a water base at the bottom of a big bubble in which the world exists. Outside the big bubble is the universe, a gigantic ball of water, in which the heavenly bodies float. Most significant about his thoughts is the belief in the spherical shape of the earth, and the use of navigators' narratives, which reported the variation of the positions of stars and constellations going from one region to another of the world, to support his assertion.

Pythagoras of Samos (580-500 B.C.) also recognized the sphericity of the earth, most probably as a result of his belief that the sphere was the perfect shape rather than any scientific reasoning. Nevertheless, he went about searching for observational evidence to support this assumption. What convinced him was the lunar eclipses and the way ships disappear from view on the horizon. During a lunar eclipse, the earth casts a round shadow on the moon that can only be caused by the earth being a sphere. The phenomenon that when a ship returned to port, first its mast tops, then the sails, and finally its hull gradually came into view can only be explained when the earth is spherical (Figure 2).

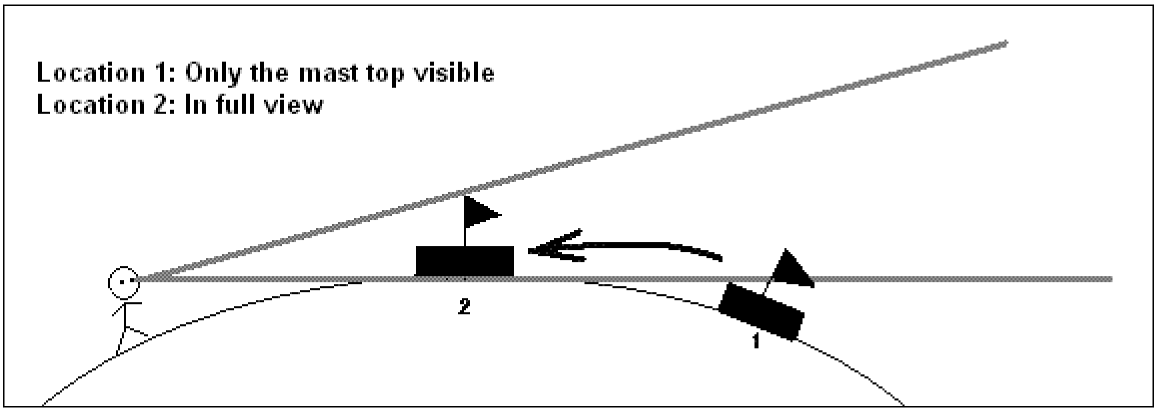

Figure 2. The way a ship appears on the horizon.

Aristotle's and Erathostenes' Discovery of the Sphericity of the Earth

It is Aristotle (384-322 B.C.) who set out to "study" this idea of the sphericity of the earth and to give reasons for it. His reasoning illustrates the attempts and the paths to view the earth from the perspective taken beyond the surface of the earth, and consists of three pieces of observed evidence. The first, and strongest, reason was lunar eclipses, as already contended by Pythagoras. During a lunar eclipse, the earth's shadow on the moon is always round. The only object whose shadow is always circular, no matter what its orientation, is a sphere. Aristotle wrote, in his *On the Heavens II*:

> Further proof is obtained from the evidence of the senses. If the earth were not spherical, eclipses of the Moon would not exhibit segments of the shape which they do. As it is, in its monthly phases the Moon takes on all varieties of shapes - straight-edged, gibbous and concave - but in eclipses the boundary is always convex. Thus, if the eclipses are due to the interposition of the Earth, the shape must be caused by its circumference, and the Earth must be spherical. (Evans, 1998, p. 47)

Aristotle's second reason for the spherical shape of the earth was taken from another predecessor, Parmenides, and based on the different heights of the stars observed in various parts of the world. The following excerpt clearly illustrates his argument:

> Observation of the stars also shows not only that the Earth is spherical but that it is of no great size, since a small change of position on our part southward or northward visibly alters the circle of the horizon, so that the stars overhead change their position considerably, and we do not see the same stars as we move to the North or South. Certain stars are seen in Egypt and the neighbourhood of Cyprus, which are invisible in more northerly lands, and stars which are continuously visible in the northern countries are observed to set in the others. This proves both that the Earth is spherical and that its periphery is not large, for otherwise such a small change of position could not have had such an immediate effort. (Evans, 1998, pp. 47-48)

Lastly, Aristotle also produced the argument that all earthly substances move towards the center, and thus would eventually have to form a sphere:

> Its [the earth] shape must necessarily be spherical. For every portion of earth has weight until it reaches the centre, and the jostling of parts greater and smaller would bring about not a waved surface, but rather compression and convergence of part and part until the centre is reached. The process should be conceived by supposing the earth to come into being in the way that some of the natural philosophers describe. Only they attribute the downward movement to constraint, and it is better to keep to the truth and say that the reason of this motion is that a thing which possesses weight is naturally endowed with a centripetal movement. When the mixture, then, was merely potential, the things that were separated off moved similarly from every side towards the centre. Whether the parts which came together at the centre were distributed at the extremities evenly, or in some other way, makes no difference. If, on the one hand, there were a similar movement from each quarter of the extremity to the single centre, it is obvious that the resulting mass would be similar on every side. For if an equal amount is added on every side the extremity of the mass will be everywhere equidistant from its centre, i.e. the figure will be spherical. (Stocks, n.d., section 14, ¶ 4)

Presumably, the most impressive demonstration of the earth's spherical shape was presented a little later by Erathostenes of Alexandria (276-194 B.C.). The shadow of a pillar was measured, at noon on the same day (the summer solstice), in each of two places of different latitudes, Alexandria and Syene (the modern city of Aswan, located south of Alexandria, on the banks of the Nile). His assumptions include:

- The earth is spherical (which seemed to be already commonly accepted in his time).
- The sun is very far away, compared to the size of the earth. Therefore, rays of sunlight striking different places on the earth can be considered to be parallel.
- Alexandria is due north of Syene (which is not exactly true, but it introduces a minor error only into the result).

Erathostenes recorded the one in Alexandria to be a certain length and precisely at an angle of 7.2°, whereas the other in Syene, on the tropic of Cancer, was not measurable because the sunlight went straight down from above the pillar. The results can be explained only on the basis that the earth is spherical. Furthermore, knowing the distance between the two places of almost the same longitude to be 5000 stades (a common unit of length in the ancient world, where an Egyptian stade is approximately 0.157 km), Erathostenes calculated the length of the earth's polar circumference (by dividing 360° by that shadow angle and multiplying by the above distance [see Figure 3]) to obtain 39,250 km, a value similar to that used today.

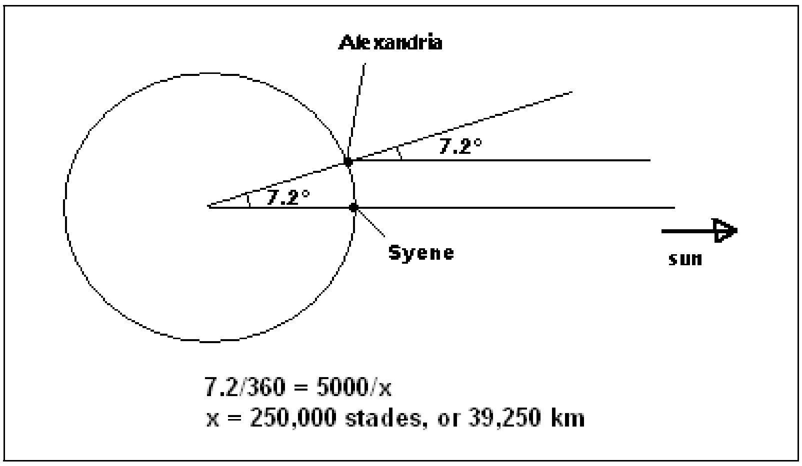

Figure 3. Erathostenes' calculation.

As late as the 16th century, the same arguments were used for the sphericity of the earth, as Nicholas Copernicus (1,473-1,543 A.D.) wrote in his work *De Revolutionibus*:

> The earth is also spherical, since it presses upon its center from every direction…. For a traveller going from any place toward the north. That pole of the daily rotation gradually climbs higher, while the opposite pole drops down an equal amount. More stars in the north are seen not to set, while in the south certain stars are no longer seen to rise … evening eclipses of the sun and moon are not seen by easterners, nor morning eclipses by westerners, while those occurring in between are seen later by easterners but earlier by westerners.
>
> The waters press down into the same figure also, as sailors are aware, since land which is not seen from a ship is visible from the top of its mast. On the other hand, if a light is attached to the top of the mast, as the ship draws away from the land, those who remain ashore see the light drop down gradually until it finally disappears, as though setting. (Rosen, n.d., chap. 2, ¶ 1, 2)
>
> The earth together with its surrounding waters must in fact have such a shape as its shadow reveals, for it eclipses the moon with the arc of a perfect circle. Therefore the earth is not flat, as Empedocles and Anaximenes thought; nor drum-shaped, as Leucippus; nor bowl-shaped, as Heraclitus; nor hollow in another way, as Democritus; nor again cyclindrical, as Anaximander; nor does its lower side extend infinitely downward, the thickness diminishing toward the bottom, as Xenophanes taught; but it is perfectly round, as the philosophers hold. (Rosen, n.d., chap. 3, ¶ 5)

Therefore, the spherical shape of the earth was determined, repetitively and consistently, based on (1) the positions of the stars observed in different places, (2) the way in which a ship disappears from sight after departing from land, and (3) the occasional lunar eclipses.

Classroom Practice

This historical material can be used to assist students in understanding different early models of the earth, the backgrounds that created these ancient models, and the evidence provided to support them, and in turn help create a setting in which students may start to discover their own models and discuss them. A list of suggested activities and procedures for a science lesson plan follows:

1. Encourage students to brainstorm a model of the earth based on their everyday observations.
2. Have students discuss their models and further discuss what the term *model* means.
3. Present several historical models of the earth, along with their settings and explanations provided by scientists.
4. Have students reflect on the relations between a model, explanations it provides to account for the phenomena, and the background of its time.
5. Have students replicate historical observation and experiment, such as observing the ship appearing/disappearing on the horizon and conducting Erathostenes' measurement in a similar way.

Before introducing the historical material, the teacher may first ask students to describe the motion of the sun, moon, and stars in the sky and further encourage them to construct a model of the earth based on only this kind of observational information from the naked eye, as the people in the ancient world did. They should also have the opportunity to present their models to the class, and to ask questions and discuss how well each model explains what we see in the sky. In addition, it can be interesting to discuss the term model, perhaps described as a person's explanation for something that has been observed, including the explanations that students provide.

While introducing an historical model, students should be encouraged to imagine that if they went to school at its time, they might have been taught that this model was the only way to explain the observations of the sun, moon, and stars. For each model, and the explanations that go along with it, students should also be encouraged to think about how these explanations might have evolved and how they reflect the common beliefs and surroundings of the people who created them.

Students can re-do the observations and experiments that are often technically simple but nevertheless brought about plausible alternative arguments. The early astronomical models were basically established through sky-gazing. Astronomers in different places of the world observed and documented the sky carefully and thereby developed their visions of the universe. As mentioned in the previous section, the model of the spherical earth was historically supported by three pieces of observational evidence with naked eyes: the changing positions of the stars due to the observer's locations, how ships disappear on the horizon, and lunar eclipses. It should be reasonable that students may revise their concepts and models if similarly watching the sky and the horizon carefully. Through the observation of the sun, moon and stars, from different angles (e.g., from the sea [horizon]), students may further develop a sense of spatial relations of heavenly bodies and the earth.

Students' direct encounters with natural elements will most likely arouse questions and doubts. Students should be encouraged to express their ideas and to offer solutions, and furthermore learn to understand and accept different points of view. At this point, they are on their way towards understanding the multiple hypotheses and clarifications that form part of the process of scientific enquiry. We can then expect our students to appreciate possible models, different from the concrete ones essentially linked to emotion, that are linked to imagination and reasons. The earth, for example, is apparently flat or irregular in shape, as we observe it on its surface, but is really spherical as we now understand it. As another example, young students often explain the day/night cycle as a result of the sun revolving around the earth, which is apparent in their everyday life, but what is real is that the earth's rotation gives rise to the alternation between day and night. The task for the teacher is to underline this contrasting feature while teaching the earth model in the classroom.

The experiment done by Erathostenes to measure the lengths of the shadows, at the same time in different places, can also be presented to, or even replicated by, secondary students in order to improve their understanding of the earth model. It illustrates an early, yet then advanced, approach to tackling the problem of the earth's shape and size. There is also the opportunity, in this kind of activity, for students to grasp some aspects of the nature of science, particularly the connections between concepts/theories and methods.

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Critical Incident

An Invitation

Readers are invited to send, to the Editor at editor@ScienceEducationReview.com , a summary of a critical incident in which you have been involved. A critical incident is an event, or situation, that marks a significant turning point, or change, for a teacher. The majority of critical incidents are not dramatic or obvious, but are rendered critical through the analysis of the teacher (see Volume 3, p. 13 for further detail). You might describe the educational context and the incident (please use pseudonyms), analyse the incident (e.g., provide reasons to explain your observations), and reflect on the impact the incident made on your views about the learning and teaching process. Upon request, authors may remain anonymous.

We have undoubtedly all done things about which we were very pleased, and perhaps done other things about which we did not feel so pleased, and we all need to remain reflexive of our practice. While teachers will view an incident through the lenses of their own professional experiences, and may therefore explain it differently, this does not detract from the potential benefits to be gained from our willingness to share our experiences and thus better inform the practice of other teachers.

Investigating With Models

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Background. Students, in their second year of a teacher-training programme, enrolled in a year-long Studies in Subject course to enhance their science content knowledge. A module in the course focused on astronomy understanding and one pedagogical strategy used in teaching this is the use of 3-D models. Students were encouraged and "pushed" to engage in classroom demonstrations and discussions using 3-D models.

Since the teaching used 3-D models, it seemed natural to assess individual student understanding using 3-D models. After 3 years of using this form of assessment, one student I was assessing at the time stopped in the middle of modeling an answer. I waited for a couple of minutes and then