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Jorma Ojala[a]
[a] Department of Teacher Education, University of Jyväskylä, Finland

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The third planet

Jorma Ojala, Department of Teacher Education, University of Jyväskylä, Finland

This paper examines the conceptions of planetary phenomena related to temperature change as held by primary school teacher trainees at the Department of Teacher Education of Jyväskylä University. The data were collected by means of an essay test, supplemented by interviews. The results show that very few students have internalized these phenomena in accordance with present-day scientific concepts. The significance of the Earth's sphericity seems particularly obscure. The influence of the angle of inclination of the Earth's axis is misunderstood. Similarly, temperature differences are erroneously attributed to the distance from the sun of the Earth or of a particular place. The students do not reach their conclusions by inference, but rather attempt to remember what they have been taught. There are defects in their logical thought, several answers contained no explanation whatsoever, and cause-and-effect relationships are reversed.

Introduction

This study examines the concepts held by trainee primary school teachers as to why there are temperature variations on the surface of the Earth. The theoretical background to the study lies in the constructivist notion of learning. In examining the learning of science, it has been observed that pupils often do not correctly learn scientific information in school. One of the reasons identified relates to the pupils' own erroneous notions, which deviate in many ways from accepted explanations. An approved understanding would then require the abandonment of their own naive notions and the replacing of existing information structures by widely accepted notions (Posner *et al.* 1982, Hewson and Thorley 1990). Furthermore, with regard to complex matters, it has been observed that school instruction often increases the number of incorrect notions (Osborne and Freyberg 1985).

It has been suggested that the education of science teachers should include more study of the philosophy of science (Nussbaum 1989). Teachers often fail to understand the complex reciprocal relationship existing between theory and experience, and consider scientific theories and models to conform totally with reality. Similarly, the general idea that it is possible to make observations without any pre-theories is found in teachers (Hodson 1986, Duschl 1988).

There have been earlier investigations related to planetary phenomena. The results of these studies reveal that the pupils' concepts are inaccurate even in basic matters (Nussbaum 1979, Klein 1982, Baxter 1989). The latter studies examined the issues from the perspective of physics and astronomy.

The geographical viewpoint

The phenomenon chosen for the study was temperature variation on the surface of the Earth. At the lower stage of the Finnish comprehensive school, this topic is dealt

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with on several different occasions. Planetary phenomena first occur in environmental studies in both first and second classes, with 7- to 8-year-old pupils. Geography is taught as a separate subject from the third year and in the comprehensive school this is regional geography. Beginning with the child's own locality and immediate environment, teaching proceeds to increasingly distant areas, following the principle of spiralling, with all the different regions of the globe gradually being studied. At the lower level of the comprehensive school, where geography teaching would be the responsibility of the students participating in this study, many regions of the Earth are examined. The geography taught in the upper secondary school differs from that in the comprehensive school in that the syllabus is based on general geography. Planetary phenomena are dealt with in the first geography course at senior secondary level when pupils are generally 16 years old. The topic is revised in the third year of senior secondary school as part of preparation for the school-leaving examination.

It is apparent from the foregoing that this phenomenon, central to geography, has been given due attention in the school curriculum since it is dealt with on several occasions at different levels. In the senior secondary school particularly, there is an in-depth and thorough examination of the topic. The planetary nature of the Earth is an excellent way of structuring the subject-matter. Climate is defined as a consequence of this planetary nature. Other factors also influence climate, but their significance is lesser. The climate in turn is crucial from the point of view of the survival of plants, wildlife and human beings. Conditions in any place on the globe can thus be inferred very precisely on the basis of its location.

The authors of a senior secondary school geography textbook state that it is important to understand the phenomena that relate to the planetary nature of the Earth and its part in the distribution of the sun's radiation (Kytömäki *et al.* 1982).

Research methodology

This paper examines the extent to which the wishes of the authors of the above-mentioned book have been fulfilled in respect of students of the Department of Teacher Education of the University of Jyväskylä.

The study sought answers to the following questions:

1. Do students who have completed comprehensive school and senior secondary school correctly understand the reasons for regional differences in temperature?
2. What kind of explanations do students offer for planetary phenomena?
3. What is the cause of any erroneous conceptions?

The subjects were second-year primary school teacher trainees at the University of Jyväskylä. The profession of primary school teacher is very popular and there is no shortage of would-be students. A strict selection procedure means that very many applicants fail to gain a place. The successful applicants have done extremely well at school and in their school-leaving examinations. It could be assumed that the subjects had successfully learned such a central topic. On the other hand, students undertaking primary teacher training are not, as a rule, particularly motivated by science subjects, but rather by arts and crafts. The results should therefore not be generalized to all students with school-leaving qualifications.

Many different methods have been developed for the study of prior knowledge (Driver and Erickson 1983). The results of this study are based on a written enquiry, in other words a so-called essay test (Stewart 1980). An entire year class, a total of 87 students, took part in the test. The topic had been previously revised in small-group geography classes. The time allowed for the test was one hour. The students were asked to give written answers to the following open questions:

> Many different factors affect the temperature prevailing in a certain place.
>
> Which is the most important factor of all from the point of view of temperature differences on the globe? Give as short an answer as possible, using a maximum of one sentence. Give a brief explanation of the other factors that affect temperature.

The written material was supplemented by interviews which were carried out in stages. The first stage consisted of open questions. The second stage made use of diagrams employed in the presentation of planetary phenomena. At the third stage the same questions were asked using physical models.

Results

The following section is a systematic presentation of the explanations put forward by the students for temperature variation on the globe. The presentation begins with incorrect replies and progresses through various erroneous models towards concepts that approach correctness, concluding with completely correct answers.

A. Child-like, teleological explanations

The Earth revolves around the sun at a suitable distance and the Earth is at just the right angle to the sun. [This reply is reminiscent of a small child's answer to the question 'Why is there night?' 'So that we can sleep.' Four answers fell into this category.]

B. An answer containing no explanation and using circular logic

Light from the sun affects temperature differences on Earth most of all.

In my opinion the most important factor affecting temperature differences on Earth is the rotation of the Earth. [11 students gave replies of this type.]

C. Cause and effect are confused

The most important factor affecting temperature differences is the winds, which carry air masses, ocean currents, etc. [7 replies were of this type.]

D. Variation in distance causes temperature differences

Answers of this type fall into three different groups. The most important factor affecting temperature differences is:

D1. Distance from the equator – distance from the sun
and
The equator is nearer the sun, therefore it is the warmest climatic belt. [3 students replied in this way.]

D2. The distance of location X, i.e. the angle of the Earth's inclination. [7 students' replies fell into this category.]
D3. The nearer the sun one is, the warmer it is. Because of the Earth's rotation the temperature varies with the seasons. [4 students offered this explanation.]

A total of 14 students were of the opinion that the most important factor affecting temperature differences is the distance of the locality from the sun. In principle this idea is logical and correct, but in reality the situation is not the same as these answers imply.

As figure 1 shows, the distance of a particular locality from the sun varies as a result of the Earth's sphericity; thus, equatorial areas are nearer the sun than arctic regions.

As figure 2 shows, because of the Earth's inclination, areas nearer the sun are warmer. Correspondingly, areas facing away from the sun experience winter because they are more distant.

As figure 3 shows, because of the Earth's eccentric orbit, the sun gives off most heat when the Earth is close to the sun. Winter, on the other hand, occurs when the Earth's orbit takes it further from the sun.

The students' answers are extremely interesting because the underlying mental image has been learned at school. These replies will be analysed in more detail below in the discussion of results.

E. The angle of the sun's rays is the most important factor affecting temperature differences

Clearly, for most of the respondents, the commonest reason for temperature differences is that the angle of the sun's radiation varies in different parts of the globe.

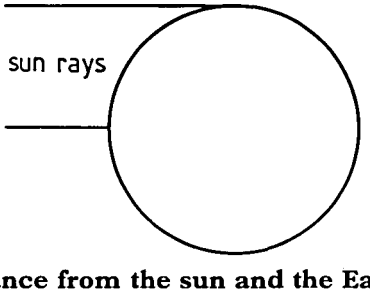

Figure 1. Distance from the sun and the Earth's sphericity.

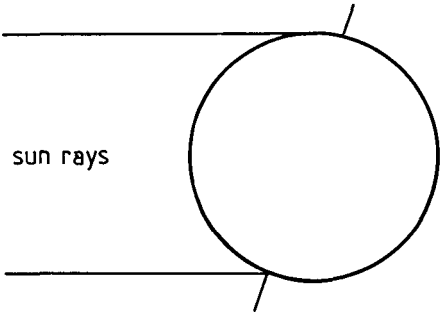

Figure 2. The Earth's inclination in relation to the sun.

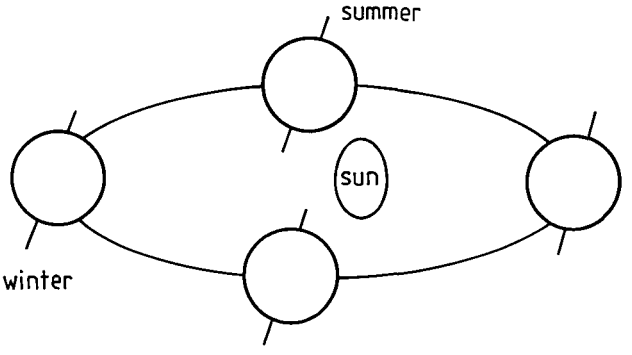

Figure 3. The Earth's eccentric orbit.

A total of 28 replies gave this as the most important reason. The following are examples of these types of reply.

E1. The most important factor affecting temperature differences is the inclination of the earth's axis: The following answers reveal that the respondents see the angle of inclination of the sun's rays varying in different parts of the world because the axis is inclined to the plane of orbit.

> The Earth's axis is not straight.
> The angle of inclination of the Earth to the sun affects temperature differences on Earth. For example, in polar regions the sun is never able to produce enough heat at any time of the year. The equator, on the other hand, is always in the direct line of the sun.
> The most important cause of temperature differences is the inclination of the Earth's axis, with the result that different areas receive different amounts of solar radiation.

It is particularly significant that no fewer than 17 respondents conceive the angle of incidence of the sun's rays as varying in different parts of the globe, mainly as a consequence of the angle of inclination.

E2. Planetary relations are left completely open:

> The position of the globe.
> The sun and the Earth's position to it.
> The location of the sun in relation to the Earth.

A total of 7 replies of this type were given.

E3. Temperature differences result from variations in the angle of inclination of the radiation:

> Temperature differences result from the fact that the radiation from the sun is focused in a different way at different times in different places.

This reply is in principle correct and contains a high degree of abstraction, but it fails to give the actual cause and it is impossible, on the basis of the reply, to infer how the respondent explains the phenomena. The following replies are of the same type:

> The most important factor affecting the prevailing temperature in a certain locality is the angle at which the sun's rays shine in that place.

The following answer is in itself concise and excellent – and taken straight from the textbook.

> The amount of solar radiated energy in relation to each unit of area.

The answers exemplified above do not contain direct errors. Their weakness, however, is that a mental jump has been made to the resulting phenomenon and that the thought process has not started from the underlying factors. There were only four replies in this category.

F. Location

A total of 17 replies mentioned the word 'location' or 'latitude' in explaining the most important factor affecting temperature differences. The word 'location' has the ring of a geographical term, but, as may be deduced from the above replies, things are not that simple: even though the answer appears to be correct, there is no certainty that the respondent has a correct conception of the matter.

F1. Location is combined with the angle of inclination of the sun's rays:

> The most important factor affecting temperature differences is latitude, because this determines the angle of the sun's radiation with regard to the area in question. [5 replies fell into this group.]

F2. Location in relation to the equator:

> The most important factor affecting temperature differences – the location of the area with regard to the equator.
> The distance of the locality from the equator.

There were 12 answers of this type; in themselves correct, but the primary causes of the phenomenon have been 'jumped over' in the reasoning underlying the replies. This method means the information is not based on an original observation, with the resulting danger that the subject is not correctly conceptualized and the fundamental nature of the phenomenon is not understood. The thought process then ceases to be consistent and logical. It is the use of the equator as a fixed point that particularly reveals the concreteness of the thought process.

G. The Earth's sphericity

> Since the Earth is a sphere, radiation from the sun does not fall equally on different parts of the Earth. Equatorial areas receive the most radiation and polar regions the least. Other factors affecting the Earth's illumination and temperature, apart from its spherical shape, are its annual solar orbit and the angle of inclination of its axis to the ecliptic. In geography it is important to understand these things. (Kytomaki *et al.* 1982)

As becomes obvious from the preceding answers, the wish of the authors for pupils to understand the fundamental importance of these phenomena has been fulfilled in very few cases – of the 87 respondents, only 5 gave a correct answer. Examples of these answers:

> The Earth is a sphere (in different places at the same time).
> The Earth's axis is tilted to the plane of its orbit. This causes variations in temperature in the same place in the different seasons.

A further completely correct answer:

> The most important factor is probably that the Earth is round and revolves at an angle and orbits the sun. The angle of the sun's rays to the Earth varies.

The following reply also belongs to this category, but it differs from the previous ones:

> The most important factor affecting temperature differences on Earth is the immediate effect of the amount of sunlight (energy) in a day. This in turn is determined by the inclination of the Earth's axis and the elliptical shape of the Earth's orbit. Furthermore, because of the inclination of the Earth's axis, and the fact that the Earth is round, the rays of light remain in the atmosphere longer in a polar region than near the equator (N.B. light travels in a straight line). In the atmosphere sunlight transfers its energy to so-called intermediary substances – such substances do not exist in space – and because at the equator a ray of light travels a considerably shorter distance through the atmosphere than in polar areas, more energy is conserved until it reaches the Earth at the equator than at the poles.

The respondent's interpretation of the importance of the Earth's sphericity combines the significance of the sphere with the distance covered by rays of light at the equator compared with polar regions. The notion in itself is quite correct, but not the most important phenomenon resulting from sphericity.

The following reply, also correct, is different from the foregoing in its concreteness:

> The most important factor affecting temperature differences is the spherical shape of the Earth. (Differences in temperature at the South Pole and in the Tropics) seasonal variation in the same area is caused by the Earth's tilted position in regard to the sun.

Discussion

The answers were surprisingly erroneous when it is remembered how essential a phenomenon is being dealt with from the viewpoint of both everyday life and geography. The subject-matter has been tackled in school by several different teachers on several different occasions. The teaching, however, has evidently been ineffective and the majority of students participating in the study are unaware of their erroneous ideas, preserving, in unchanged form, their child-like notions (Posner *et al.* 1982). Future teachers, then, have confused and incorrect information. Matters relating to planetary features have not been understood as a consistent system. The significance of various phenomena and their interrelationships remain obscure and unstructured. The phenomena are considered as separate entities. The significances of the various factors are confused with each other and incorrect explanations are given for planetary phenomena. It appears probable that the participants in the study would teach this subject-matter incorrectly.

The most interesting result of the study is the observation that the illustrations in textbooks, the purpose of which is to concretize planetary phenomena, actually cause three different erroneous mental images, and consequently three erroneous concepts relating to the importance of distance as a cause of temperature difference. The particular models in question, however, are theoretical constructs which correspond to reality in only certain respects. In other respects they strongly deviate from reality, producing an extremely defective image of proportion and scale.

Pupils interpret diagrams on the basis of their knowledge at that point in time. It is very probable that they do not make a mental comparison with reality and notice the incorrect proportions given in the diagrams. They interpret the images as they see them and reach logical conclusions on the basis of them. The uneven distribution of solar radiation over the Earth's spherical surface is concretized in textbooks by means of a diagram which helps pupils to visualize and understand the topic. In the picture showing the distribution of solar radiation and the Earth's tilted axis, the 'sun's rays' are long in the polar regions and short at the equator (figure 1). Looking at this picture produces an extremely strong mental image that the equatorial areas are considerably nearer the sun than are the polar regions. This same mental image can be recognized in the thinking of several of those participating in the study. Unfortunately, this mental image is incorrect. The difference is naturally so small in relation to the sun's distance from the Earth that in reality its significance from the point of view of temperature is negligible. There are diagrams in existence that do not produce incorrect mental images so powerfully (figure 4).

A similar incorrect mental image also derives from the significance of the angle of inclination of the axis. Several students believe that as a result of the axis's angle of inclination the distance to the sun is shorter in the summer and that, correspondingly, winter occurs when a particular place is more distant – on the side of the Earth facing away from the sun. This mental image is connected to the diagram given in textbooks showing the Earth's orbit round the sun (figure 2). The pupils' thoughts are confused by the common practice of showing all four seasons in the same diagram with the result that the sun appears to be orbited by four Earths. The Earth's position in its orbit at different seasons should be illustrated in a series of four diagrams with each season being presented separately.

Furthermore, students wrongly interpret the importance of distance by assuming that it is summer in Finland, for example, when the Earth's orbit takes it nearest the sun (figure 3). In reality summer in Finland occurs at the point where the Earth's

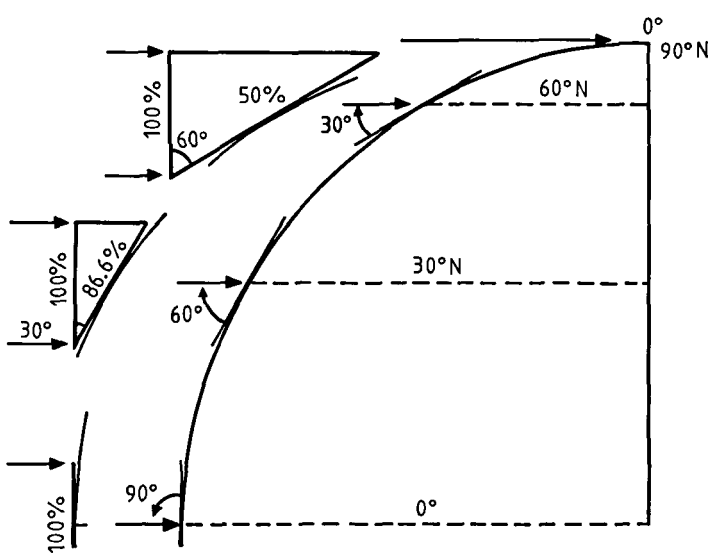

Figure 4. An alternative way of presenting the uneven distribution of the sun's radiation over the Earth's surface.

orbit takes it furthest from the sun. The idea in itself is quite reasonable and logical, but erroneous. Textbook illustrations should not emphasize the eccentricity of the Earth's orbit since they may lead to false inferences; the sun should be shown in the centre of the illustration.

It can be deduced from these observations that planetary phenomena have been incorrectly taught to many pupils in school since teachers themselves may have an incorrect conception of the matter. It also appears probable that teachers do not perceive the degree to which children misinterpret the illustrations used to describe the phenomena. The respondents failed to notice their erroneous thinking models and the contradictions related to them. The point of departure has not been the erroneous ideas already existing in the pupils' minds but rather a method based on the tradition of transferring a ready piece of information. Students were unable to make effective use of the knowledge already taught in school. Instead, they were only able to recall the information in a very incoherent, confused and inaccurate manner. Their own intuitive, alternative explanatory models, however, have been preserved in their minds in a very serviceable form.

A surprising number of replies contained no explanation whatsoever. These replies reveal a thought process where things are learnt as separate, self-evident truths instead of as the results of a search for the evidence underlying knowledge and the use of logical inference. Learning of this sort, where things are memorized by heart, has little value.

The diagrams in several textbooks are ambiguous and should be replaced by better ones which do not cause erroneous visual images. Comparing the diagrams with reality does not remove this problem. It is particularly problematic that these illustrations are already in textbooks for environmental studies. It is nevertheless probable that these illustrations lead to incorrect learning amongst 7- to 8-year-olds, suggesting that it might be better to remove them completely from textbooks for this age group.

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