Using Ancient Chinese and Greek Astronomical Data: A Training Sequence in Elementary Astronomy for Pre-Service Primary School Teachers

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Abstract

A lot of researches have been carried out all over the world, that promote history of science as a powerful science teaching tool. Because the ways of choosing and using historical elements depends on teachers' or researchers' educational purpose, any attempt to support a single model-to-use seems difficult and probably irrelevant. However, specific intentions may reflect specific and prescriptive terms of using historical materials. This work aims to enlighten this aspect. It is an attempt to organize a particular use of the history of science which takes place in the teaching of astronomy in primary school. Here, ancients' Greek and Chinese historical elements are chosen and organized according to specific educational and conceptual constraints that include the construction of the quasi-parallelism of the solar rays reaching Earth surface, and the spontaneous modeling of the propagation of the Sunlight leaning on divergent rays. This leads to an original teaching sequence were historical elements are mixed up with non historical ones. This organization (called "historical-based educational reconstruction") forms the support of a pre-service training session developed for future primary school teachers. This session aims to provide future teachers with an elementary cosmological knowledge (shape and size of the Earth, Sun-Earth distance…), to provide some reference marks of history of ancient cosmologies (spherical and flat Earth) resulting from two distinct contexts, and to approach some aspects associated with Nature of Science (NOS). Specifically, we emphasize the reliability of two different models that appear to be consistent with the same class of experimental data. One of these consistent models is close to students' spontaneous way of modeling the situation. This proximity favors a free discussion on the status of hypotheses and on the status of error, on the role (often minimized) of inductivism, on the role (often promoted) of measurements in science and in science education. One original aspect of this work is to run a model today invalid until it produces some numerical results in order to show how complex it is to invalidate a consistent model.

1. Introduction

History of sciences is often promoted as a powerful science teaching tool particularly to provide students with a more adequate view of the nature of science [1]. In this context, a lot of teaching materials in elementary astronomy have been developed that aim at making students reproduce the procedure supposedly followed by Eratosthenes in the 3rd century BC to calculate the first value of the terrestrial perimeter [2]. In a previous research we investigated the historical relevancy of a certain number of these materials by confronting them to Cleomedes' writing (2nd century AC) which appears to be one of the rare first-hand sources describing Eratosthenes' procedure [3]. This first work led us to elaborate a teaching sequence where Cleomedes' text plays a determining part since it is exploited in order to provide students with a new and appropriate geometrical model of the propagation of the solar rays. In this sequence the quasi-parallelism was reproduced by watching the extremity of two 2-meters long tight strings fixed together at the other extremity to the same nail. Doing so, our attempt was essentially to discuss the reasons and conditions of an educational use of first-hand historical sources. Here, our intention is to promote an educational strategy through the use of historical elements that focuses on students' inappropriate geometrical models of the Sunlight propagation in order to make them evolve progressively.

2. Historical elements

In this article we have chosen to look at two historical narratives describing ancient astronomical distance measurements using the same instrument: the gnomon. The first one refers to a Chinese astronomical measurement, the second one concerns the Eratosthenes measurement of Earth circumference

2.1. Historical elements of the Chinese cosmology

The Chinese text presented hereafter [4] refers to the following observation: the shadow of a vertical eight chi long gnomon located in Yangchen is 15 cun long, at noon, on the day of the summer solstice. The same day at the same time, an identical gnomon located 1000 li south of Yangchen will cast a 14 cun long shadow, and if it is located 1000 li north of Yangchen, this gnomon cast a 16 cun long shadow. The texts presented hereafter deduce from these measurements that the Earth-Sun distance is 80,000 li. Figure 1 helps us to understand this result.

> “According to the Chu Li (Rites of Zhou), the shadow of the Sun at midday during the summer solstice was 1 chi 5 tsun. The place where this particular observation was made was known as the 'Earth centre'. Cheng Chung said that the length of the gnomon shadow template was 1chi 5tsun and that the place where a vertical pole 8chi in length at midday of the summer solstice cast a shadow the same as that of the shadow template, was called the 'Earth centre'. The place corresponds to the present location of Yangchen, in Yingchuan. Cheng Huan said that the shadow cast by the Sun on the Earth surface changed by a length of 1tsun for every change of 1000 li in the horizontal distance (north or south). Since the length of the shadow is 1chi 5tsun, the Sun is 15000 Li away and to the south of the observer. From this it can be deduced that the vertical distance of the Sun is 80000 Li from the Earth's surface”.

Doc.1: The Chin Shu, Ho Peng Yoke, 1966 [4]. Units of length: 1chi=10tsun=35,8cm; 1tsun=3,58cm, 8chi=2,86m and 1Li=560m. Figure 2 illustrates Wan Fan piece of work (doc.1).

In the Chinese cosmology of that time, the Earth is flat: whenever one moves 1000 li south, the shadow of the gnomon goes down by 1 cun; As in Yangchen the gnomon's shadow is 15 cun long, it is then necessary to move 15,000 li south of Yangchen to be directly under the Sun. Considering that in Yangchen the shadow of an 80 cun long gnomon is 15 cun long, the height of the Sun must be 80,000 li. A student may obtain this result today using Thales' theorem while it is not the method used in the Zhou bi [5].

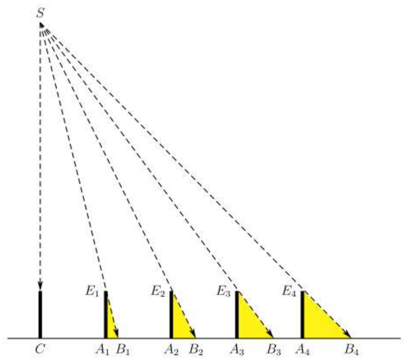

Fig.1.: Every displacement of 1000 li on the Earth surface produces a 1 cun length change in the shadow cast by the gnomon.

2.2. Elements of Eratosthenes measurement

We are told by Cleomedes [6] that Eratosthenes made measurements with a gnomon that cast a shadow onto the graduated inner surface of a hemispherical sundial named scaphe. Eratosthenes knew that on a certain day (summer solstice) at noon in Syene the gnomon of a scaphe cast no shadow, whereas the same day at the same time in Alexandria the shadow cast by the gnomon of an identical scaphe reaches an arc equal to 1/50th of a circle from the base of the gnomon (fig 2). Assuming the parallelism of the sunrays that reach Syene and Alexandria and the fact that both cities are on the same meridian, it is easy to deduce that the distance between Syene and Alexandria is also equal to 1/50th of Earth's circumference (see fig.2) and then to compute the Earth perimeter.

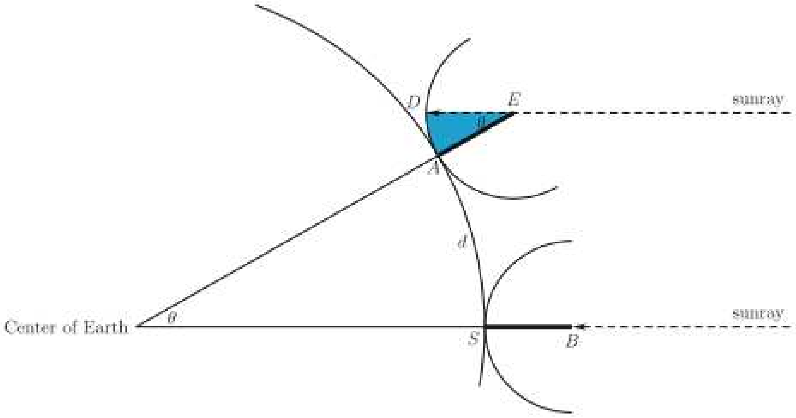

Fig.2: Illustration of Eratosthenes' procedure as described by Cleomedes in "On the circular motion of the celestial bodies (book 1, Chap. 7)" [6].

3. Educational consequences: a learning pathway to reach the parallelism of the Solar rays

From the historical elements presented above we organized a learning pathway that focuses on an appropriate geometrical representation of the propagation of the light emitted by the Sun. This pathway takes into account one of the most current spontaneous ways of drawing the Sunlight propagation used by students in order to solve the question of the shadows described above (see fig.3). More specifically, our intention is to rest on this type of drawing which usually uses divergent rays emitted from a "close" Sun in order to make it evolve gradually up to a more adequate representation.

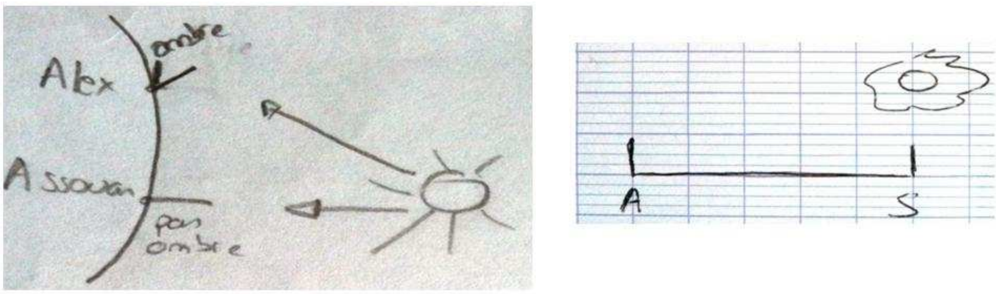

Fig.3: Two examples of French students' drawings proposed in order to answer the following question: "Can you explain why during summer solstice at noon, a gnomon casts a shadow in Alexandria and not in Syene?"

This pedagogical strategy is constrained by the fact that modeling Sunlight propagation using divergent rays is not only operating for solving/saving the "shadows" situation but is also not so far from the reference scientific knowledge since the Sun is not a light source located at infinity. Nevertheless, considering the distances involved, we decided to approximate the propagation of Sunlight to parallel rays emitted from a Sun located at infinite. Considering the parallelism of the Solar rays as a learning goal, our sequence is elaborated through the use of historical elements chosen and organized in order to respond to specific educational constraints such as students' previous ideas, material possibilities, aspects of Nature of Science [7] inquiry-based pedagogical approach, etc. The idea is not to provide students with history of science but to identify learning levers from a specific historical inquiry involving Greek and Chinese first-hand written sources. These levers are articulated and completed with non-historical elements chosen in order to favour specific inquiry-based activities. Consequently, our learning pathway takes the form of a "Historical-Based Educational Reconstruction" as the result of a negotiation between an historical inquiry and an inquiry concerning educational constraints.

The following steps organize this pathway:

- Step 1: Students answer the following question: “Can you explain why during the summer solstice at noon, a gnomon casts a shadow in Alexandria and not in Syene ?”
- Step 2: Students are given a Wan Fan text (see doc.1) and the corresponding cosmological context. They are asked to understand how Sun-Earth distance can be found from both procedures and measures reported in the text.
- Step 3: With simple material (punctual light source, sheets of paper, rulers...) students are asked to check the validity of Wan Fan procedure (see fig.4).
- Step 4: The actual value of Earth-Sun distance is compared with the one given in Wan Fan text. Wan Fan hypotheses concering the shape of the Earth is discussed.
- Step 5: Students are introduced to the *scaphe*. They are provided with the following information: “if we measure the length of a shadow on the surface of the Earth by means of a *scaphe* we find that the angle at the top of the gnomon evolves according to a progress of type α, 2α, 3α,... for every movement of the *scaphe* of an angle α measured at the center of the Earth (see fig.5).
- Step 6: Students are asked to find a way of calculating the perimeter of the Earth using the observations introduced in step 1.

Fig. 4: A set of folded papers located in order to reproduce Wan Fan experiment.

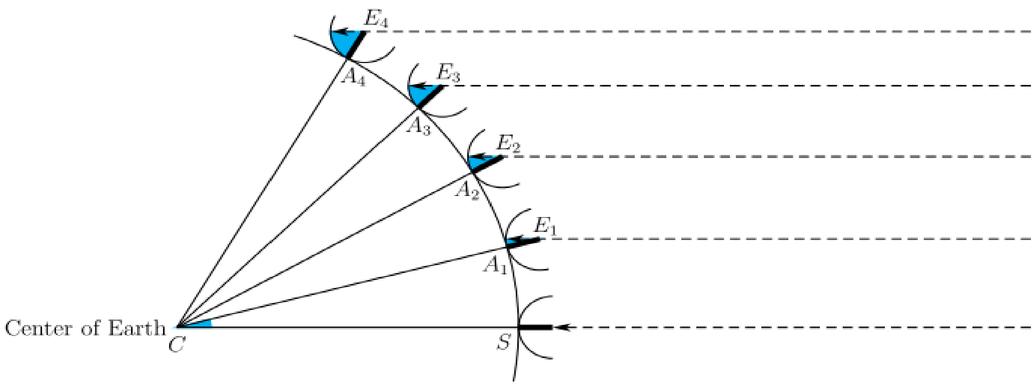

Fig.5: The angle at the top of the gnomon evolves according to a progress of type α, 2α, 3α... for every movement of the *scaphe* of an angle α measured at the center of the Earth. This information is not historically based but is added in for educational needs and according to educational constraints.

4. Perspective

Astronomy is an important part of the primary science curriculum in France (students aged 6-10). This includes, for example the use of shadow statements in order to characterize the apparent movement of the Sun across the horizon connected with the construction of sundials (French National Curriculum for Primary School). Nevertheless in France (as in most part of the world) primary school teachers know little about science since they mostly studied human and social sciences. This is particularly true in the specific area of astronomy where pre-primary school teachers have many misconceptions concerning the Earth shape, the season phenomenon, the day and night cycle, etc. [8]. Consequently pre-service teachers' training in astronomy plays a determining part. In this context, we decided to implement our sequence in the framework of a three-hour ordinary pre-service training session concerning elementary astronomy for future primary school teachers. In the end, the idea is to provide students with operative science teaching tools that could be used within their science classroom the next year. The sequence has been implemented with five pairs of students. From a pedagogical point of view, it favors an active participation of the students and has been evaluated positively. This may be seen as a way of addressing the confidence of pre-service teachers to teach primary science and technology. Another way of addressing the 'confidence issue' was the use of a constructivist strategy using peer discussion in an environment which encouraged students' questioning.

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