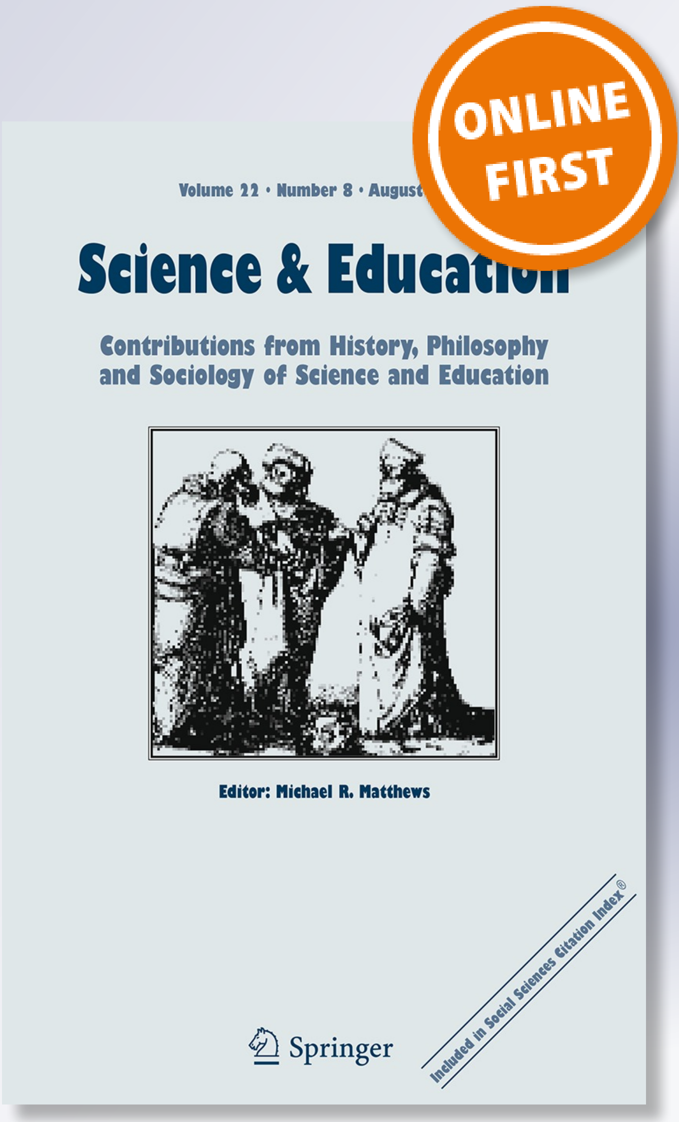
Using Ancient Chinese and Greek Astronomical Data: A Training Sequence in Elementary Astronomy for Pre-Service Primary School Teachers

Cécile de Hosson & Nicolas Décamp

Science & Education
Contributions from History, Philosophy and Sociology of Science and Mathematics

ISSN 0926-7220

Sci & Educ
DOI 10.1007/s11191-013-9625-2



Springer

Sci & Educ
DOI 10.1007/s11191-013-9625-2

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

Cécile de Hosson · Nicolas Décamp

Abstract A great amount of research has been carried out world-wide to promote history of science as a powerful science teaching tool. Because the ways of choosing and using historical elements depend on teachers' or researchers' educational purpose, any attempt to support a single model-to-use seems difficult and probably irrelevant. However, specific purposes may reflect specific and prescriptive terms for using historical materials. Our work aims to show up this aspect. It is an attempt to make elements of the history of astronomy involved in the elaboration of a training session for future primary school teachers. 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 solar rays reaching Earths' surface, and the spontaneous modeling of the propagation of Sunlight leaning on divergent rays. This leads to an original teaching sequence were historical elements are mixed with non historical ones. This organization forms the support of a pre-service training session developed for future primary school teachers. This session aims to provide future teachers with elementary cosmological knowledge (parallelism of Sunrays, 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).

1 Introduction

Many primary school teachers in most of countries do not teach science, partly because they have a low confidence level in science and also because they have limited science background knowledge.[1] As Corrigan and Taylor (2004) say:

[1] See Appleton (2002), Harlen and Qualter (2004) and Jarvis et al. (2005).

C. de Hosson (✉) · N. Décamp
LDAR (EA 4344), Physics Department, Université Paris Diderot-Paris 7, PRES Sorbonne-Paris-Cité, Bât. Condorcet, 4 rue Elsa Morante, 75013 Paris, France
e-mail: cecile.dehosson@univ-paris-diderot.fr

Published online: 02 August 2013

> A considerable body of literature, across a number of countries, has addressed primary teachers' dislike of science and their low confidence levels in teaching in this subject area. In certain instances, the effect of low confidence may be so extreme that primary level teachers continually postpone teaching science and technology or even avoid it altogether. More commonly, low confidence and a dislike of science and technology simply impact adversely on teaching styles with the result that teaching strategies consistent with contemporary science curricula are frequently not used (Corrigan and Taylor 2004).

In France, a report published by the National Assembly (Assemblée Nationale) in 2006 mentions that two thirds of primary school teachers hold a literary high school diploma; These do not follow any further mathematics nor sciences courses after the end of the 11th high school grade. Furthermore, the pre-service training in science for prospective primary school teachers dedicates only a few hours to science teaching and learning. Consequently, science teaching is rather poor in French primary schools and when science is taught, it is due to marginal and innovative teachers (Report of the French National Assembly 2006). This tendency seems identical in most of the European countries (Rocard 2007). As science has a key-role in primary education (Harlen and Qualter 2004; Rocard 2007), pre-service training for prospective primary school teachers has to provide them with both confidence and science knowledge. It also has to help them develop professional skills connected with the features of inquiry-based teaching that forms the framework for primary science education in France today (French National Curriculum for Primary School–BOEN 2008).

The low confidence of primary school teachers for teaching science is often due to inappropriate views concerning the Nature of Science (NoS).[2] In this context, history of science (HoS) seems to play a significant role in helping teachers develop more adequate conceptions of the scientific enterprise.[3] Nevertheless, the research carried out by Abd-el-Khalick and Lederman shows that the use of HoS to enhance teachers' NoS views operates under certain conditions (Abd-el-Khalick and Lederman 2000). In particular, they claim that only an explicit instructional approach that targets certain NoS aspects can enhance teachers' NoS views:

> Science educators cannot simply assume that coursework in HoS by itself is sufficient to help prospective science teachers develop desired understandings of NoS (Abd-el-Khalick and Lederman 2000, p. 1088).

Considering NoS as an expression that refers to "the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge" (Lederman 1992), our intention is to provide prospective primary school teachers with few NoS facets such as: formulating hypotheses, elaborating and manipulating models and measuring.

This research deals with a pre-service training session for prospective primary school teachers that aims to make the historical approach useful for learning science and elements of the scientific process. The training session consists of a conceptual pathway where historical elements are mixed with non historical ones; it focuses on the teaching of elementary astronomy. Our training session is elaborated through an adaptation of the "didactical engineering" framework as described by Artigue (1994) for teaching and learning sequences (Méheut and Psillos 2004). Consequently, our engineering is supported by a "preliminary analysis" governed by the characterization of elements of different nature:

[2] See Brickhouse (1990), Lederman (1992), Lunn (2002) and Appleton (2003).

[3] See Matthews (1994), Lin and Chen (2002) and Maurines and Beaufils (2012).

1. Elements of an institutional nature linked to the institutional functioning of the training (training context, scientific context involved…)
2. Elements of a cognitive nature linked to the group targeted by the training
3. Elements of an epistemological nature linked to the scientific knowledge involved, to the characteristics of its development, and its current way of functioning, as well as to its history

From these elements, the training session is elaborated and implemented as a pilot training in a real pre-service course for primary school teachers.

2 Elaboration of a Training Session for Prospective Primary School Teachers in Astronomy: Preliminary Analysis

2.1 Institutional Elements

The training session does not take the form of a "homological" one (Kuzniak and Houdement 2002). This means that its aim is not to be replicable in the classroom with primary school children but to make prospective primary school teachers feel more confident in teaching science, to bring them new scientific contents and method, to know more about the modeling process as part of the science enterprise. The training session promotes an experimental approach also valued in French National science Curricula. It is included in a three-hour ordinary training session in the context of an optional course devoted to science teaching.[4]

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–BOEN 2008). Nevertheless in France (as in most part of the World) primary school teachers lack knowledge concerning elementary astronomy and hold many misconceptions concerning the phases of the Moon, the season phenomenon, the day and night cycle, etc. (Frede 2006). Consequently, training sessions usually embed scientific content updated from the one promoted by the primary science curriculum.

In that context, a current astronomical activity in primary school in France (carried out in both mathematics and science courses, see for example, di Folco and Jasmin 2003; Kuntz 2006) consists in exploiting the procedure supposedly used by Eratosthenes in the 3rd century BC in order to measure the perimeter of the Earth. This procedure leans on two observations: (1) A gnomon located in Alexandria (northern Egypt) at noon the day of the summer solstice casts a shadow of a certain length, (2) At the same time a gnomon located in Syene (middle Egypt) casts no shadow since the Sun appears at the zenith. Assuming that: (1) Alexandria and Syene are located on the same line of longitude, (2) The distance between Alexandria and Syene is 800 km, (3) The Sunrays are parallel, (4) The angle at the top of the gnomon of Alexandria and the angle subtending Alexandria-Syene arc of circle are identical, Eratosthenes computed the Earth perimeter (see Fig. 1). The usual teaching supports generally put the emphasis on the experimental replication of Eratosthenes's procedure and on the calculation itself. Such pedagogical choice does not take into account

[4] This optional course is proposed to prospective teachers during the second year of their master degree in education.

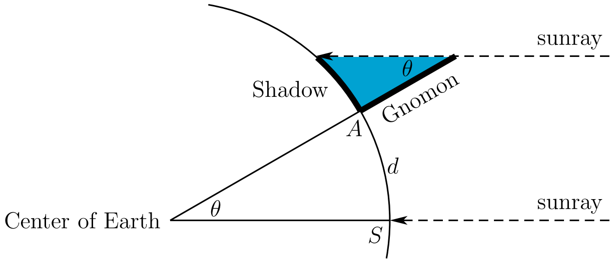
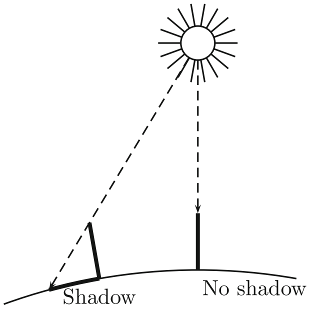


Fig. 1 Usual illustration of Eratosthenes' measurement. Using the angle θ at the top of gnomon located in Alexandria(which is the same as the angle subtended by Syene (S, Syene's Arabic name is spelled "Aswan" in English) and Alexandria (A) at the center of Earth = 7.2°) and the distance between Alexandria (A) and Syene (S) (= 800 km), children can find that the perimeter of the Earth is 360 × 800/7.2 = 40,000 km

Fig. 2 Prototypical drawing made by some children and some primary school teachers who were asked the following statement: why during summer solstice at noon, the same gnomon casts a shadow in Alexandria and not in Syene? Two rays starting from the same point located on the Sun reach the top of the two gnomons



a major conceptual difficulty: the geometrical modeling of the propagation of solar rays into straight parallel lines which appear to be the key for implementing this procedure successfully (Décamp and de Hosson 2012).[5]

2.2 Cognitive Elements

From the pedagogical use of Eratosthenes procedure, some researchers questioned children's difficulties while modeling the Sunrays (Merle 2000; Farges et al. 2002; Feigenberg et al. 2002, see Fig. 2). Children are asked first to explain why during summer solstice at noon, a gnomon located in Alexandria (northern Egypt) casts a shadow while another (identical to the previous one) located in Syene (middle Egypt) casts no shadow. As an explanation (of what we will call the "shadows observations"), some children draw non-parallel rays coming from a sketched Sun down onto a curve (or a plane) surface of the Earth. This drawing is also typical of those proposed by most of the primary teachers explaining the same observation (Merle 2000).

According to Feigenberg et al. (2002), this type of drawing can be interpreted by the difficulties of some children and teachers in understanding large dimensions and the

[5] In some teaching tools, the assumption of parallel rays is constructed on the basis of local observations (e.g., across a sheet of paper and two little wood sticks located on it) considering parallel shadows cast by two vertical sticks very near to each other (see for example: http://www.lamap.fr/eratos). This activity implies that the assumption of parallel rays elaborated by students from experiments locally performed remains relevant for the large scales observations they are given, which is far from being obvious.

relationship between various parameters: the distance to the Sun, the dimensions of the Earth, their impact on observed phenomena. As noted by Feigenberg et al. (2002) it is impossible to show on the same picture the curvature of the Earth and the distance between Earth and Sun preserving correct ratios. These difficulties seem unconnected to a lack of scientific knowledge such as the distance of the Sun or the curvature of the Earth. This said, we assume that even if primary school teachers know about the Earth-Sun distance they do not connect this distance and its consequences when drawing the Sunrays propagation. In other words, the very large Sun-Earth distance (with respect to the Earth dimension) does not imply a representation of sunlight in parallel lines. Moreover, the persistency of such a representation by both children and teachers is probably due to the fact that Eratosthenes observations are efficiently explained by the "spontaneous" model chosen. As Duhem would say this representation appears very powerful in "saving the phenomena" (Duhem 1969), it thus has no reason to be modified.

2.3 Epistemological Elements

The "epistemological elements" are specified by analyzing how the "shadows observations" has been used in both Greek and Chinese cosmologies.

2.3.1 Chinese Cosmological Model

The Chinese text presented hereafter (Doc. 1) is taken from the *Chin Shu,* a book written around 635 A.D. The astronomical part of this book has been written by Li Shun-fêng. The proposed excerpt refers to the astronomical knowledge under the Zhou dynasty that began about a thousand year B.C. Another historical text, the *Zhou bi* (namely, the gnomon of the Zhou) gives similar elements to those found in this *Chin Shu*. The proposed excerpt presupposes children and teachers main type of explanation of the "shadows observations" and based on it, computes some measurements: the shadow of a vertical eight chi long gnomon (2.86 m) located in Yangchen is 15 tsun (53.7 cm) long, at noon, on the day of the summer solstice. The same day at the same time, an identical gnomon located 1000 li (560 km) south of Yangchen will cast a 14 tsun (50.1 cm) long shadow, and if it is located 1000 li (560 km) north of Yangchen, this gnomon cast a 16 tsun (57.3 cm) long shadow. The texts presented hereafter deduce from these measurements that the Earth-Sun distance is 80,000 li (44,800 km). Figure 3 helps us to understand this result. In the Zhou chinese cosmology mentioned in this text, the Earth is flat: whenever one moves 1000 li (560 km)

Doc. 1 The Chin Shu, Ho Peng Yoke (1966), p.65

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 5 tsun 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 1 tsun for every change of 1000 li in the horizontal distance (north or south). Since the length of the shadow is 1chi 5 tsun, 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"

Units of length: 1chi = 10 tsun = 35.8 cm; 1 tsun = 3.58 cm, 8chi = 2.86 m and 1Li = 560 m. Figure 3 illustrates Wan Fan piece of work (Doc. 1) south, the shadow of the gnomon goes down by 1 tsun (3.58 cm); As in Yangchen the gnomon's shadow is 15 tsun (53.7 cm) long, it is then necessary to move 15,000 li (8,400 km) south of Yangchen to be directly under the Sun. Considering that in Yangchen the shadow of an 80 tsun (2.86 m) long gnomon is 15 tsun (53.7 cm) long, the distance to the Sun must be 80,000 li (44,800 km).

A student may obtain this result today using Thales' theorem while it is not the method used in the ancient chinese astronomy (Cullen 1996; Chemla 2004). Note also that this value of 1000 li (560 km) between two successive gnomons does not seem to result from an accurate measurement but to be somewhat mythical (Kalinowski 1990). Finally, the naively inductive extrapolation of what happens 1000 li south and 1000 li north of the Yangchen's gnomon to what happens 15,000 li (8,400 km) south is very debatable. There is no evidence that a linear law for small displacements would remain valid for greater displacements. In fact, not only the value of 1000 li is not valid, but it is the unwritten law of linear variation of shadow length with gnomon displacement which is the most refutable.

2.3.2 Greek Cosmological Model

The original writings of Eratosthenes (2 books) were lost. We have access to his work only through authors of antiquity such as Cleomedes, Pliny, Strabo. The most detailed among these writings is a short review by Cleomedes. We are told by Cleomedes (see the translation of *On the circular motion of the celestial bodies*, book 1, Chap. 7, by Weir 1931) 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 (located at 5000 *stadia* −800 km- at the north of Syene) 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. 4). 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. 3) and then to compute this measurement. The method Eratosthenes used to compute the distance between Syene and Alexandria has been subject to debate. It seems to be based on maps of Egypt or on accurate distance estimations made by bematists. These men were trained to make regular paces when marching from one place to another and to record their number (Dutka 1993).

There are many similarities between the Chinese and Greek chosen measures. In both cases, the astronomers have chosen noon of the summer solstice to make their measurements. This is probably not by accident: midday (solar time) of the summer solstice corresponds (in the Northern hemisphere) actually to the moment at which the shadow of the gnomon is the shortest during the year. In both cases, they also computed a terrestrial surface measurement and derived from it a vertical measurement using a strategy based on proportionality. Both used a sundial but an interesting difference is the fact that Chinese and Greek instruments are not exactly the same. The Greek *scaphe* and its gnomon are an hemispherical sundial. It gives direct access to the searched portion of the circle (we would say to the angle in modern terms) and this is the useful measurement in a spherical Earth cosmology. The Chinese "bi" is on the contrary a flat sundial which gives access to the angle tangent, a more adapted measure for a flat Earth cosmology. This is an interesting illustration of Bachelard's thought:

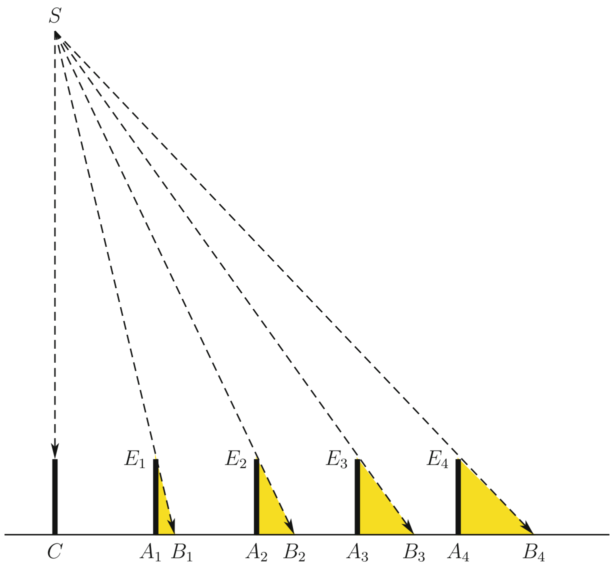


Fig. 3 According to the Zhou cosmology, every displacement of 1000 li on the Earth surface produces a 1 tsun length change in the shadow cast by the gnomon

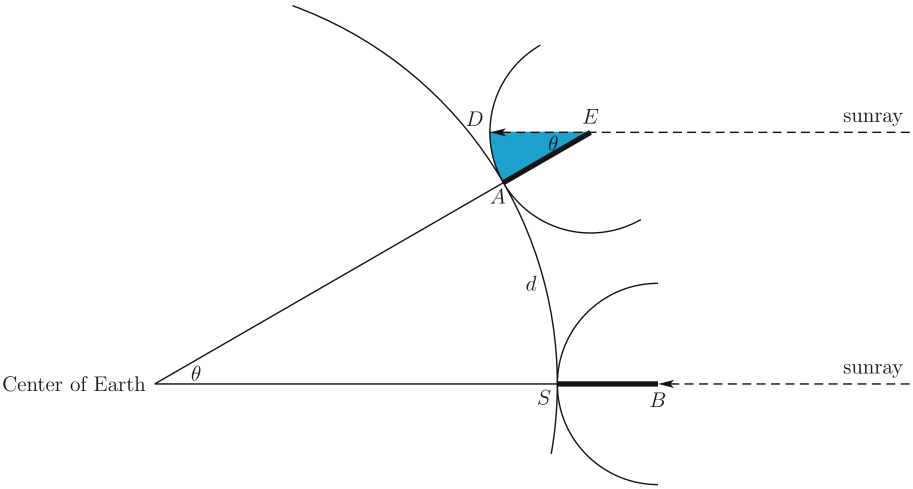


Fig. 4 Illustration of Eratosthenes' procedure as described by Cleomedes in *On the circular motion of the celestial bodies*, book 1, Chap. 7 (Weir 1931). The shadow AD cast by the gnomon in the hemispherical sundial reaches an arc equal to 1/50th of a circle of radius AE. The ratio of 1/50th of the circumference of the Earth corresponds to the distance AS between Alexandria and Syene (Weir 1931)

> A measuring instrument always ends up as a theory: the microscope has to be understood as extending the mind rather than the eye. (Bachelard 2002, p. 240).

Another interesting difference between the two procedures is the fact that Eratosthenes uses only two sundials and the Chinese texts mention at least three. Here we have to note

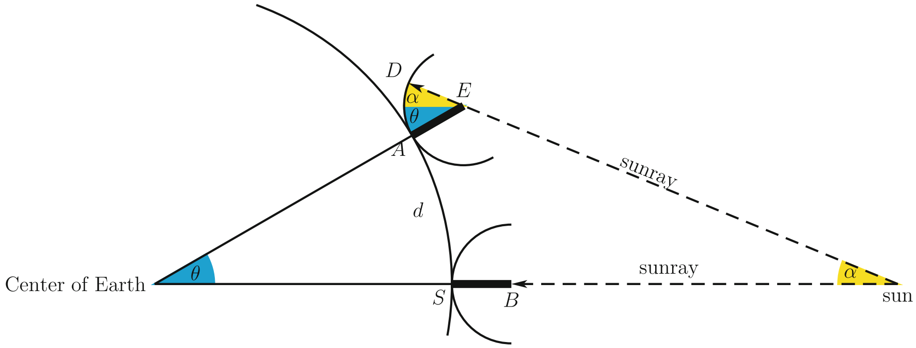


Fig. 5 Two gnomons (AE and SB) are placed at two points A and S on the Earth's surface. The gnomon SB cast no shadow, while the shadow of the gnomon AE makes an angle AED. The value of this angle AED is the sum of the angle θ (at the center of the Earth) and the angle α (at the center of the Sun). With this measure only it is impossible to know the angle's portion corresponding to α and that corresponding to θ. According to Eratosthenes, the Sun is sending parallel rays (this assumption is considered as a valid approximation as the Earth-Sun distance is much larger than the distance AS), the angle α is then almost zero and angle AED can be entirely attributed to the angle θ at the center of the Earth. In the excerpt chosen for the ancient Chinese science, the assumption is that the Earth is flat; the angle θ is then zero and the angle AED is fully attributed to the angle α in the center of the Sun

that, in order to derive a vertical distance from a land survey and from the measurement of an angle, a cosmological model is absolutely necessary. For the same observations, the conclusions may be different depending on the cosmological model adopted. For our observation, the angle difference observed between the two shadows of the gnomons located at two different points on the Earth can be interpreted as the sum of two angles: the difference in latitude between the two gnomons (thêta) and the angle at which someone will "see" the same two gnomons from the center of the Sun (alpha, see Fig. 5). There is no way to know the ratio alpha/thêta from an experimental device that comprises only two gnomons. The Chinese cosmological and the Greek one are the two limit cases of this general pattern: in the Greek model the angle alpha at the center of the Sun is zero (the sunrays are parallel) when in the Chinese case it is the angle thêta at the center of the Earth which is zero (as the Earth is flat). In order to eliminate the unknown (ratio alpha/thêta) by some measurement, a series of gnomons is need. Nevertheless, it is necessary to make the measurements accurately. The inaccuracy of the measurements given in the Chinese text that we described before did not allow the Chinese astronomers to correct their flat Earth cosmological model. In our proposition we were still interested by the idea of using more than two gnomons and we adapted this idea to the *scaphe* of Eratosthenes. It leads us to the situation presented in Fig. 6. This adaptation is not historical but is thought to be of didactic interest.

3 Elaboration of a Training Session in Elementary Astronomy for Prospective Primary School Teachers

Our training session is elaborated in order to respond to specific training goals:

- Make prospective primary school teachers be aware of the difficulty connected with astronomical representation (e.g. parallelism of the Sunrays *versus* divergent rays)

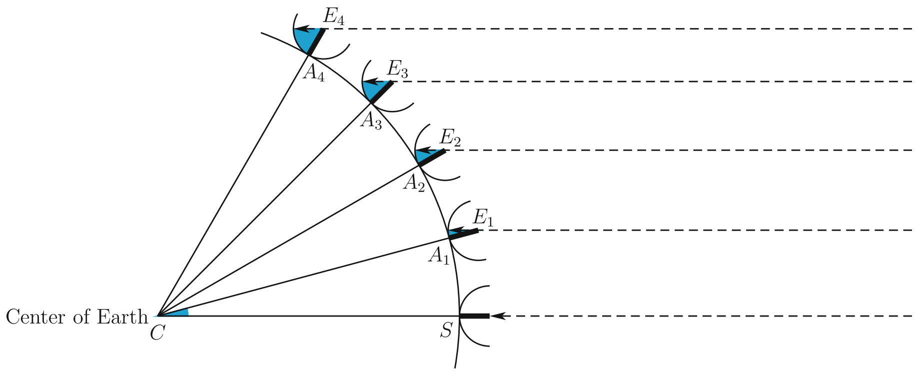


Fig. 6 The angle at the top of the gnomon evolves according to a progress of type α, 2α, 3α… for every movement of the *scaphe* of an angle α measured at the center of the Earth. This information is not historically based but is added for educational needs and according to educational constraints

- Favor the conceptual change (from divergent rays to parallel ones)
- Provide prospective primary school teachers with elements of the modeling process as part of the science enterprise using elements of HoS
- Involve prospective teachers in experimental activities

It takes the form of a didactical reconstruction based on historical grounds. The term didactical reconstruction (Mäntylä 2012) underlines two important aspects behind its construction and purpose. Firstly, the didactical reconstruction is meant for didactical purposes. Secondly, it is a reconstruction using the research in the history of science as well as in cognitive science. The reconstruction includes historical and an-historical elements. The idea is not to provide prospective teachers directly with history of science but to identify learning levers from a specific historical inquiry involving Greek and Chinese written sources. These levers are articulated and completed with an-historical elements chosen and organized according to specific educational and conceptual constraints that include the construction of the parallelism of solar rays and the difficulty in modeling of the propagation of Sunlight. The general framework of a training pathway is divided in six steps (Table 1):

Step 1: The idea is to start from teachers' prior knowledge in order to make teachers be aware of this evolution all along the training session. The first step thus consists in asking them what explains the difference in the length of the shadows cast simultaneously in Syene and in Alexandria. It considers teachers' prior knowledge as an anchoring conception (Clement et al. 1989).
Step 2: A Chinese text using a specific cosmological model (flat Earth, close Sun and divergent rays, see Doc. 1) is provided to teachers. We searched for an historical text that could correspond to teachers' ideas in order to take advantage of this proximity, in particular in terms of motivation (de Hosson and Kaminski 2007). Moreover, we assume that this text will activate prospective teachers' prior knowledge (Alvermann et al. 1985) and allow them to be engaged in step 3 (experimental activity).
Step 3: A small-scale reenactment of this ancient Chinese experiment is carried out by the teachers.
Step 4: This Chinese experiment leads to an inadequate value of the Sun-Earth distance. The prospective teachers suggest that it is due to the incorrect assumption that the Earth is flat.

Table 1 This table presents the 6 steps of our sequence. For each step, we describe prospective teachers expected activity

Steps of the training pathway	Prospective teachers' activities
Step 1: Presentation of a phenomenon linked with shadow observations in order to elicite prospective teachers' ideas	Prospective teachers answer the following question: "Can you explain why during summer solstice at noon, a gnomon casts a shadow in Alexandria and not in Syene?" Prospective teachers should provide explanations involving divergent rays (associated with a curve or a straight line connecting Alexandria and Syene)
Step 2: Historical study involving Wan Fan text	Prospective teachers are given a Wan Fan text (see Doc. 1) and the following information "the Chinese procedure is conducted in the framework of a flat Earth and the measure of the Earth-Sun distance corresponds to the measure of the distance between the Sun and the gnomon that casts no shadow". From these informations, prospective teachers are asked to understand how Sun-Earth distance can be found from both procedures and measures reported in the text Prospective teachers are expected to find that the use of several shadow measurements allows the discovery of the location of a gnomon that would cast no shadow, that is, a gnomon located directly under the Sun. They can use Thales' theorem (see above) or the fact that the change in the shadow length l is linked to the distance d between a given gnomon and a gnomon that casts a shadow measuring 1chi 5 tsun (e.g. 15 tsun) through the following relation: $1 = 0.0001 \times d + 15$
Step 3: Implementing Wan Fan experiment and findings	With simple material (punctual light source, sheets of paper, rulers) Prospective teachers are asked to check the validity of Wan Fan procedure A light source is located at a given position and identical objects (used as gnomon) are regularly arranged in order to form a straight line. By means of shadow measurements, teachers predict the rough position of the light source (that corresponds to both SC and CA_i distances in Fig. 2)
Step 4: Discussing Wan Fan hypotheses and formulating new assumptions	Prospective teachers are given the following information "using this method", ancient Chinese astronomers from the 3rd century BCE found that Earth-Sun distance is 80 000 Li (e.g. around 5000 km). Compare this value with the present value of Earth-Sun distance. How can the difference between both values be explained?" Prospective teachers are expected to question Wan Fan hypotheses concerning the shape of the Earth and to link the flat Earth hypotheses to the "surprising" small value of Earth-Sun distance
Step 5: Toward the parallelism of the Solar rays…	Prospective teachers are introduced to the *scaphe*, an instrument that was probably used by Eratosthenes in order to measure the Earth perimeter in the 3rd century BC (see Cleomedes). Then, 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. Explain this with a drawing" Drawing allows prospective teachers to "discover" the parallelism of the Solar rays which is the only way to model the given situation with the corresponding data (see Fig. 6). A discussion takes place in order to understand the reasons why the Solar rays can be considered and thus drawn as parallel

Table 1 continued

Steps of the training pathway	Prospective teachers' activities
Step 6: Calculating the perimeter of the Earth according to Eratosthenes procedure	Prospective teachers are asked to find a way of calculating the perimeter of the Earth using the observations introduced in step 1. The distance between Alexandria and Syene is given as well as the length of the shadow cast within the *scaphe* of Alexandria (a circular segment of 1/50 of the whole *scaphe* perimeter) Prospective teachers provide a drawing similar to the one presented in Fig. 4 and connect the angle at the top of the gnomon of Alexandria with the angle at the center of the Earth. Both angles define the same circular segment, thus the distance between Alexandria and Syene represents the same circular segment of the whole Earth as the one defined by the shadow of Alexandria's *scaphe*

Step 5: The failure of this experiment reveals that the assumption in step 2 is inadequate due to the inadequate answer in step 1. The use of an-historical data (e.g. the linear evolution of the angle at the top of the gnomon for a regular displacement of a same *scaphe*, see Fig. 6) justifies the fact that we decided to use a multiple-*scaphe* experiment as a new pedagogical lever. Indeed, we know from Fig. 5 that the use of two gnomons is not sufficient to prove the assumption of the parallelism of the Sunrays. This step focuses on the ratio of the distances involved in the explanation of the shadows observations. It aims to make the prospective teachers understand the reason why the Sunrays arriving at Syene and Alexandria can be considered as parallel.
Step 6: A more careful study of Eratosthenes' experiment (according to Cleomedes) will provide the teachers with an adequate astronomical model, which answers the original question in step 1 and allow the teachers to calculate the perimeter of the Earth from the following values:

- The distance between Syene and Alexandria is 5000 *stadia* (800 km)
- The shadow cast by the gnomon located in Alexandria corresponds to a ratio of 1/50th of the *scaphe*

4 Implementation of the Training Session and Elements of Evaluation

A pilot study concerning five pairs of prospective teachers (named "teachers" in the following) is presented. It takes part in a gradual research-based evolutionary process aiming to link the scientific and prospective teachers' perspective (Nurkka 2008). It aims to provide elements concerning the feasibility and acceptability of the training session, to build, test and evaluate lesson materials and guidance notes for transfer to other training sessions. Here, the researcher (one of the authors of this paper) worked as a trainer. The training sequence was audio-recorded and transcribed.

The concerned teachers[6] (N = 10) had studied the apparent movements of the Sun across the horizon through the use of a gnomon. They studied the phenomenon of seasons;

[6] Two of the prospective teachers have a bachelor degree in physical education, two in English, three in French literature, one in economy, one in sociology and one in history of art. The training session was performed in April 2012.

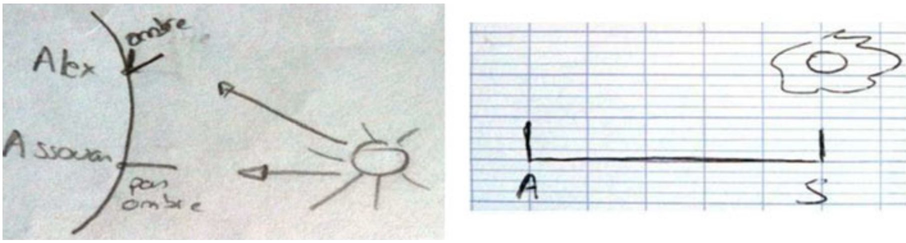


Fig. 7 Two examples of teachers' drawings proposed in order to answer the following question: "Can you explain why during summer solstice at noon, a gnomon casts a shadow in Alexandria and not in Syene (Aswan)?". "Pas d'ombre"/"ombre" means "no shadow"/"shadow"

it means that they know about "equinox" and "solstice"; they also built a small equatorial sundial. The sequence lasted 3 h and was organized according to the steps presented in Table 1. Teachers were working in pairs.

The shadows observations (step 1) led to interpretations all involving divergent rays (see Fig. 7). This step also revealed difficulties that differ from the one linked to the modeling of the propagation of Sunrays:

- 8 teachers drew a straight line between Alexandria and Syene
- 5 teachers failed in drawing a vertical gnomon, e.g. a segment leaning on a straight line passing through the exact centre of the Earth (see Frede 2006).
- 3 teachers had difficulties in proposing a two-dimensional drawing (e.g. a cut-plane drawing). This led to drawings where the shadow located at the bottom of the Alexandria's gnomon seems to exist outside of the Earths' surface.

To sum up, this first step revealed difficulties of different natures (using a cut-plan representation, using an appropriate idea of what means "vertical", knowing about scale ratios, etc.) not only associated with the representation of light coming from the Sun. Considering these difficulties some time was devoted to help teachers (1) represent a relevant cut-plane of the situation using a curved line between Alexandria and Syene (2) draw appropriate vertical gnomons in both Alexandria and Syene. The modeling of the propagation of Sunrays was not commented nor modified.

Wan Fan text was then provided to teachers and discussed (step 2). All teachers were able to explain Wan Fan's experiment and observations but they failed in finding the way to access the distance between the Sun and the Earth from the provided historical data. Thus, we decided to pass directly from step 2 to the experimental step (step 3) assuming that the experimental device will help teachers' reasoning. During the experimental step teachers were asked to check the validity of Wan Fan's procedure using simple material (punctual light source, sheets of paper, rulers). One of the difficulties encountered by teachers was to make identical "gnomons" with the provided material that could lead to relevant measurements (the sheets of paper was the only material provided but it could be replaced by flat-headed screws positioned on the head). The sheets of paper were folded and regularly arranged in order to create shadows oriented in the same direction. This phase appears as very delicate since the consistency of the measurements is absolutely linked to both position and orientation of the set of folded papers (see Fig. 8).

Performing the experiment all teachers seemed more confident than during the study of the Wan Fan text (step 2) and they all found that the value of the shadow length regularly

Fig. 8 A set of folded papers located in order to reproduce Wan Fan experiment

decreases when the papers are put closer to the light source (see Fig. 8). Nevertheless, the experimental strategies developed by the different pairs of teachers were not the same.

- Two groups intended to calculate the successive positions of the papers located between the first one (the one casting the smallest shadow) and the one that should be located at the upright position of the light source. This appeared to be very difficult as the length of the smallest shadow was not a multiple of the decreasing value (e.g. one group found a 9.7 cm smallest shadow-length and a 2.3 cm decreasing value and successively obtained: 7.4/5.1/2.8/0.5 cm shadow-length for each displacement of 30 cm of the paper). They finally found a way of connecting the decreasing value of the shadow length, the distance between two paper sheets, the "new" smallest shadow length and the location of a paper casting no shadow using a cross-multiplication (see below).
- Three groups made a cross-multiplication using the decreasing value of the shadow length, the distance between two paper sheets, the shadow length of the nearest paper sheet and the unknown location of a paper casting no shadow (e.g. one group inferred that if a 30 cm displacement creates a 1.8 cm decreasing of the shadow length, a "d" movement should thus lead to a complete disappearance of the shadow).
- One of the five groups reported its measurements (shadow length/distance between a given gnomon and a gnomon considered as a reference) in a spreadsheet program and obtained a diagram connected with Table 2. A linear fit[7] allowed them to find the gnomon location corresponding to a value of the shadow length equal to zero (107 cm from the nearest paper sheet in that case)

Finally, no group had difficulties in finding the distance between the upright point of the light source and the light source itself using the property of the "similar triangles" (see Fig. 9). The value obtained was then compared for each group to the effective position of the light source and the likely causes of the differences between the two values were discussed. All teachers were then able to come back to Wan Fan procedure and to

[7] $f(x) = 0.00763x + 7.3378$.

Table 2 Experimental data obtained by teachers during this activity and corresponding linear fit of the experimental data

x = Distance to the first sheet of paper (cm)	f(x) = Shadow length (cm)
0	7.5
20	8.7
40	10.4
60	12
80	13.4
100	14.9
120	16.4
140	18
160	19.7

understand how he calculated the distance between the Earth and the Sun. The difference between the value of 80 000 Li and one AU (astronomical unit) was spontaneously explained by teachers through the assumption of a flat Earth that sustains Wan Fan's procedure.

The new information concerning the evolution of the angle at the top of *scaphe* regularly arranged according to a defined angle considered at the center of the Earth allowed (or "forced" in a certain extent) all teachers to propose a drawing involving parallel lines. Nevertheless, this step required strong support in terms of explicitation. We thus provided teachers with a ready-made pattern (Fig. 10) were they just had to draw the lines responsible for the linear evolution of the angle at the top of the *scaphe* (corresponding to the linear evolution of the angle at the center of the Earth). We also pointed out that the evolution of the angle tends to linearity as the source-point is taken away from Earth.

The teachers succeeded in drawing the parallel lines that support the linear evolution of the angle at the top of the gnomon of each *scaphe* but they had difficulties in interpreting parallelism. Specifically, the majority did not understand how a single point could send parallel rays:

[T] I still don't understand why the light sent by a single luminous point can be modeled using parallel rays[8]

[R] Actually, the Sunrays are not exactly parallel. But if I stretch out two long strings from the same mooring, their extremities can be considered as parallel lines under certain conditions? Which one?

[T] Hum… if it is nearly parallel it is very different!

[R] Why?

[T] Because in the case of nearly parallel lines from a single point it is obvious that they can have the same origin, whereas if they are really parallel they will never cross each other; they cannot come from the same point

[R] Ok. But what could allow considering these two lines having the same mooring as parallel?

[T] If the extremities are very close

[R] Do you think Syene and Alexandria are close enough to consider the Sunrays reaching them as parallel lines?

[8] [T] indicates one of the prospective teachers; [R] is for the trainer (one of the author of this paper).

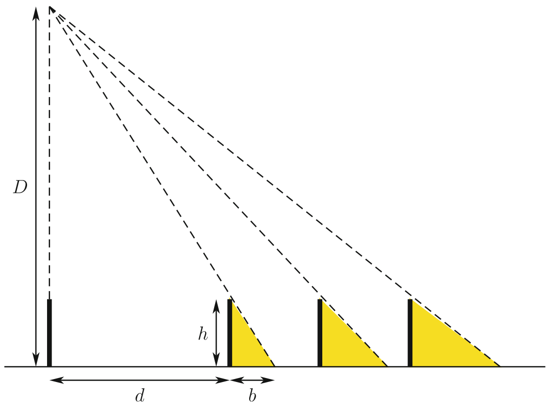


Fig. 9 After distance d is computed, the distance D between the upright position of the sheet casting no shadow and the light source position is obtained using the property of the "similar triangles"

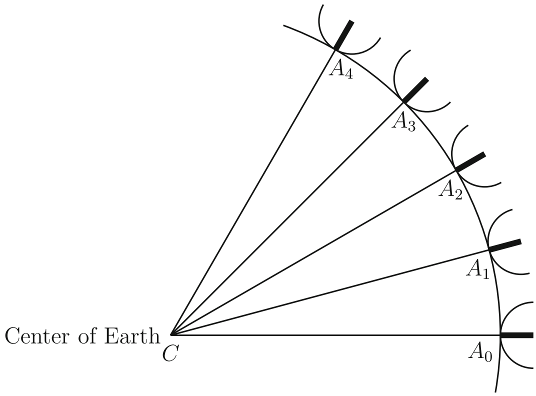


Fig. 10 Pattern used by teachers in order to draw Sunrays corresponding to the linear evolution of the angle at the top of the gnomon of the *scaphe*

[T] Well… oh… ok… Yes, since the Sun-Earth distance is much larger than the distance between the two towns! The distance between the extremities of the Sunrays should be very very small

The calculation of the Earth's circumference was conducted by the teachers using the diagram presented in Fig. 4. The relation between the shadow as a circular portion of the *scaphe* located in Alexandria and the distance between Alexandria and Syene as a circular portion of the whole Earth became easy. With the given data, teachers found that the Earth perimeter is 40,000 km.

The training session ended with a foreseeable discussion which focused on two main points: the modeling process and the measurement uncertainty. The teachers were very surprised by the longevity of the Chinese cosmological model and still more by the fact that this model relied on no real measurements. This allowed us to evoke the validation procedure of knowledge creation at different times and in different geographical locations. We also discussed the criteria of a scientific model (Justi and Gilbert 2002). The adequacy of the measurement instrument (*scaphe*/gnomon) to the cosmological model (a spherical instrument for a spherical Earth model/a flat instrument for a flat Earth model) was

Fig. 11 A small *scaphe* is built from a table tennis ball in order to respond to some teachers' comments. Here, we can clearly see the portion of the half table tennis ball delimited by the shadow of the nail

discussed too. The precision of the measurement obtained by Eratosthenes was the most dazzling aspect of the session according to the teachers. This led us to point out the rigor of the science enterprise when it involves experiments. These aspects formed explicit elements of NoS that spontaneously emerged from the training itself.

At the very end of the session we asked the teachers to anonymously comment the positive and negative points of the training session (what drew their attention). The general opinion expressed can be resumed by the following answer: "Because I was asked to draw my own explanation in response to the given initial statement [the shadow situation] and because I remarked that the explanation evolved through the sequence, I am sure that I will remember the knowledge involved and that I will perform this activity with my own students". Three teachers asked to build a *scaphe*. We thus decided to try to build one with simple material using a table tennis ball and a nail (see Fig. 11).

5 Discussion and Perspectives

The usual teaching supports of the Earths' perimeter measurement procedure via the history of science generally puts the emphasis on the experimental replication of the supposed procedure led by Eratosthenes in the 3rd century BC and on the calculation itself (often by the anachronistic use of trigonometrical tools, as an example see Bekeris et al. 2011). Such pedagogical choice does not take into account a major conceptual difficulty: the geometrical modeling of the propagation of Sunrays into straight parallel lines.

In comparison, this research focuses on the construction of the parallelism of Sunrays. It is a didactical engineering adapted for pre-service teachers training. We explicitly consider as a starting point the spontaneous divergent rays drawings that govern most of the explanations provided by prospective primary school teachers while explaining the shadows observation (e.g.: during summer solstice at noon, a gnomon casts a shadow in Alexandria and not in Syene). The didactical engineering aims at making this explanation evolve through the use of a six-step conceptual pathway that takes the form of a didactical reconstruction based on historical grounds. This reconstruction involves historical and an-historical elements organized to respond to learning and training requirements such as:

- making prospective teachers recognize their spontaneous explanation in an historical text in order to make them more confident while providing scientific explanations
- using different cosmological models in order to make prospective teachers aware of certain aspects of the modeling activity in the science enterprise

- favoring a conceptual path in order to make prospective teachers pass from a divergent ray representation to a parallel one and connect the parallelism of the Sunrays to the large Sun-Earth distance (compared with the Earth radius).

Consequently, we sought for existing ideas close to the prospective teachers' ones within the history of cosmology. An historical inquiry led us to search for reliable historical sources evoking Anaxagoras work but we failed to find satisfying writings. Nevertheless this historical inquiry within the Greek world soon led us towards a less known history: that of the Chinese cosmology where a very constructed cosmology based on hypothesis very close to prospective primary teachers' ideas about the propagation of the Sunrays was found. This cosmology (flat Earth/close Sun sending divergent Sunrays) was chosen as an anchoring situation that would echo their prior knowledge. Prospective teachers were then engaged in operating this cosmology through an experimental activity. By confronting the Chinese data (e.g. the Sun-Earth distance) with the actual one, they were prepared to elaborate an alternative way of modeling the shadows situations.

The pilot training session provided crucial information for a further implementation that could involve some changes in the progress of the pathway offered to prospective teachers. In particular the difficulty in modeling the rays emitted from a single point using parallel lines requires a more steady support. Actually, step 5 could be divided in two subparts. The first one (a technical subpart) would consist in connecting the linear progression of the angle at the top of the gnomon of the *scaphe* regularly arranged at the surface of the Earth with parallel Sunrays through the systematic use of a pattern (Fig. 10); the second subpart (a conceptual subpart) would help prospective primary teachers to determine the conditions that allow parallel rays to be emitted from a single luminous point. For this subpart, the use of two threads stretched out from the same mooring seems to favor this step of conceptualization that involves the connection between the Sun-Earth distance and the size of the Earth.

The pilot training session also leaned on hypotheses (in terms of learning both science and NoS) that could be precisely tested in further implementations:

1. The prospective teachers provide a divergent Sunray model when explaining the shadows observations
2. The prospective teachers identify themselves with the Chinese astronomers in step 2 and actively participate in the experimental activity in step 3
3. The conflict between the Chinese Sun-Earth distance and the actual one leads the prospective teachers to reject the Chinese cosmology and experiment in step 4
4. The use of the linear progression of the angle at the top of *scaphe* regularly disposed at the surface of the Earth and the use of an analogy involving two strings having the same mooring make the prospective teachers conceptualize the link between the Sun-Earth distance and the parallelism of the Sunrays in step 5
5. The use of two models to explain the same observation provides information concerning elements of NoS

We also could investigate the way the trainees would reinvest what they learnt in terms of NoS (concerning the modeling and the measurement activities for instance) during another training situation involving the same type of aspects. Because the training session was not designed in order to be transferred such as in the classroom, it could be interesting to examine later to what extent the trainees would use elements of this training in the context of an astronomical sequence in primary school.

References

Abd-El-Khalick, F., & Lederman, N. G. (2000). The influence of history of science courses on students' views of nature of science. *Journal of Research in Science Teaching, 37*(10), 1057–1095.

Alvermann, D. E., Smith, L. C., & Readence, J. E. (1985). Prior knowledge activation and the comprehension of compatible and incompatible text. *Reading Research Quarterly, 20*, 420–436.

Appleton, K. (2002). Science activities that work: Perceptions of primary teachers. *Research in Science Education, 32*, 393–410.

Appleton, K. (2003). How do beginning primary school teachers cope with science? Toward an understanding of science teaching practice. *Research in Science Education, 33*(1), 1–25.

Artigue, M. (1994). Didactical engineering as a framework for the conception of teaching products. In R. Biehler (Ed.), *Didactics of mathematics as a scientific discipline* (Vol. 13, pp. 27–39). Dordrecht: Kluwer.

Bachelard, G. (2002). *The formation of the scientific mind* (Mary McAlister Jones, Trans.). Manchester: Clinamen Press.

Bekeris, V., Bonomo, F., Bonzi, E., Garcia, B., Mattei, G., Mazzitelli, D., et al. (2011). Eratosthenes 2009/2010: An old experiment in modern times. *Astronomy Education Review, 10*, 1.

Brickhouse, N. W. (1990). Teachers' beliefs about the nature of science and their relationship to classroom practice. *Journal of Teacher Education, 41*(3), 53–62.

Bulletin Officiel de l'Education National, hors-série n°3 du 19 juin 2008, Ministère de l'Education Nationale, France.

Chemla, K. (2004). Les neuf chapitres: le classique mathématique de la Chine ancienne et ses commentaires (p. 204). G. Shuchun (Ed.). Paris: Dunod.

Clement, J., Brown, D. E., & Zietsman, A. (1989). Not all preconceptions are misconceptions: Finding 'anchoring conceptions' for grounding instruction on students' intuitions. *International Journal of Science Education, 11*(5), 554–565.

Corrigan, G., & Taylor, N. (2004). An exploratory study of the effect a self-regulated learning environment has on pre-service primary teachers' perceptions of teaching science and technology. *International Journal of Science and Mathematics Education, 2*(1), 45–62.

Cullen, C. (1996). *Astronomy and mathematics in ancient China: The Zhou Bi Suan Jing*. New York: Cambridge University Press.

de Hosson, C., & Kaminski, W. (2007). Historical controversy as an educational tool: Evaluating elements of a teaching-learning sequence conducted with the text "Dialogue on the ways that vision operates". *International Journal of Science Education, 29*(5), 617–642.

Décamp, N., & de Hosson, C. (2012). Implementing Eratosthenes' discovery in the classroom: Educational difficulties needing attention. *Science and Education, 21*(6), 911–920.

Di Folco, E., & Jasmin, D. (2003). Mesurer la terre avec un bâton: Sur les pas d'Ératosthène. *Aster, 36*, 163–167.

Duhem, Pierre. (1969). *To save the phenomena, an essay on the idea of physical theory from Plato to Galileo*. Chicago: University of Chicago Press.

Dutka, J. (1993). Erathostenes' measurement of the earth reconsidered. *Educational Studies in Mathematics, 46*(1), 55–66.

Farges, H., Di Folco, E., Hartmann, M., & Jasmin, D. (2002). *Mesurer la Terre est un jeu d'enfant: sur les pas d'Erathosthène*. Paris: Le Pommier.

Feigenberg, J., Lavrik, L. V., & Shunyakov, V. (2002). Space scale: Models in the history of science and students' mental models. *Science & Education, 11*, 377–392.

Frede, V. (2006). Pre-service elementary teacher's conceptions about astronomy. *Advances in Space Research, 38*, 2237–2246.

Harlen, W., & Qualter, A. (2004). *The teaching of science in primary schools* (4th ed.), London, David Fulton.

Ho Peng Yoke. (1966). *The Astronomical chapters of the Chin shu*. Paris: The Hague, Mouton & Co.

Jarvis, T., McKeon, F., & Taylor, N. (2005). Promoting conceptual change in pre-service primary teachers through intensive small group problem-solving activities. *Canadian Journal of Science Mathematics & Technological Education, 5*(1), 21–39.

Justi, R. S., & Gilbert, J. K. (2002). Modelling, teachers' views on the nature of modelling, and implications for the education of modellers. *International Journal of Science Education, 24*(4), 369–387.

Kalinowski, M. (1990). Le calcul du rayon céleste dans la cosmographie chinoise. *Revue d'histoire des sciences, 43*(1), 5–34.

Kuntz, G. (2006) Mesurer la Terre est un jeu d'enfant ! *MathemaTICE, 1*.

Kuzniak, A., & Houdement, C. (2002). Pretty (good) didactical provocation as a tool for teachers' training in geometry. In *Proceedings of CERME*, vol. 2, 292–304.

Lederman, N. G. (1992). Students' and teachers' conceptions of the nature of science: A review of the research. *Journal of Research in Science Teaching, 29*(4), 331–359.

Lin, H. S., & Chen, C. C. (2002). Promoting preservice chemistry teachers' understanding about the nature of science through history. *Journal of Research in Science Teaching, 39*(9), 773–792.

Lunn, S. (2002). 'What We Think We Can Safely Say…': Primary teachers' views of the nature of science. *British Educational Research Journal, 28*(5), 649–672.

Mäntylä, T. (2012). Didactical reconstruction of processes in knowledge construction: Pre-service physics teachers learning the law of electromagnetic induction. *Research in Science Education, 42*(4), 791–812.

Matthews, M. (1994). *Science teaching: The role of history and philosophy of science*. New York: Routledge.

Maurines, L., & Beaufils, D. (2012). Teaching the nature of science in physics courses: The contribution of classroom historical inquiries. *Science & Education*, pp 1–23.

Méheut, M., & Psillos, D. (2004). Teaching-learning sequences: Aims and tools for science education research. *International Journal of Science Education, 26*(5), 515–535.

Merle, H. (2000). Proposer les mêmes situations: Problèmes aux maîtres en formation qu'aux élèves de cycle 3: Est-ce possible et avec quels objectifs de formation ? *Tréma, 18*, 22–36.

Nurkka, N. (2008). Use of transfer teachers in developing a teaching-learning sequence: A case study in physiotherapy education in Finland. *NorDiNa, 4*(1), 9–22.

Rapport d'information de l'Assemblée Nationale Française, n°3061 du 2 mai 2006.

Rocard, M. (2007). *Science education now: A renewed pedagogy for the future of Europe*. Office for Official Publications of the European Communities.

Weir, J. (1931). The method of Eratosthenes. *The Journal of the Royal Astronomical Society of Canada, 25*, 294–297.