From geocentric to heliocentric model of the universe, and the alternative perspectives

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Abstract

A recent study (Liu, 2005a, 2005b) revealed a limited number of alternative models of the universe held by young students in Taiwan and in Germany. In line with the previous findings, these alternative models frequently fall into two groups: earth-centred and sun-centred views, which draw a correspondence to the ideas in the European history of astronomy. However, the data also show that students do know the universe is infinite but only discuss an "observational" universe, whose centre is either the sun or the earth. This way of inquiring into the sky has also its analogy in the history of Chinese science. It seems that students' models share a common place with the historical ideas, and moreover, show alternatives to geocentric and heliocentric views of the universe. This seems to consequently convey an accessing point where the pre-scientific models may be operated to assist students in the learning process towards understanding the targeted subject.

Introduction

It is well acknowledged that students hold various alternative conceptions prior to, during and even after formal science instruction (for an extensive literature see Duit, 2004). These conceptions are, moreover, commonly recognized as a key to students' learning processes. Many research efforts have been made to discovering the characteristics of these alternative conceptions and the mechanism of their development (Wandersee *et al.*, 1994). Especially, the attention has been given to their structure form, such as (mental) models (Vosniadou and Brewer, 1992; Vosniadou and Brewer, 1994; Gilbert, 1998; Harrison and Treagust, 2000).

Along this research line, the author conducted a study (Liu, 2005) in Taiwan and in Germany, which was intended to reveal young students' ideas in the domain of observational astronomy and to find out whether these ideas rest upon a model. The results of the study confirmed that students make sense of the heavenly bodies, the earth and their relations based on a model of the universe, which is often different from the accepted scientific model. It is worth noting that the findings support the use of historical material for assisting students' science learning for there seems to be a common place shared by the students' alternative models and the historical ones. First of all, like the early scientists, young students make sense of the world based on their models of the universe, which yield a small scope of the questions and phenomena as opposed to the modern scientific model. Secondly, students' models of the universe frequently fall into two groups: earth-centred or sun-centred view, and seem to correspondently have a common feature with the pre-scientific models in Europe. However, the data also showed that students actually conceive of the "real" universe as infinite space and only discuss an "observable" universe where the earth and the heavenly bodies reside. Also worth-noting is that this way of inquiring into the sky is well documented in the history of Chinese astronomy: The early Chinese believed that there exists the vast cosmos which lies beyond the "researchable" world - in the Chinese term, "the heavens and the earth (天地)". Thus, it is argued that historical models harbour valuable instructional implications for they share some common place with the ideas presented by today's young students.

The present paper first gives an outline of Liu's investigation on German and Taiwanese students' alternative models of the universe (for detailed information on the research design, see Liu, 2005a), and goes on to discuss the main features of the revealed models with a view of the historical ones from the cultural contexts of the two targeted countries. Based on the common features of the two conceptual domains, the conclusion is drawn in connection to science instruction by suggesting the use of historical models in the science classroom that are in line with the students' perspectives: They can be operated as intermediate models in the learning process, assisting students to move from the perspective on the surface of the earth towards beyond, and, moreover, to form a structural view of nature.

Students' Alternative Models of the Universe

Previous studies on children's concepts about the earth revealed their "egocentric" view which leads to notions such as the flat and static earth, absolute up-and-down direction in space, horizontal sky, etc. (Klein, 1982; Nussbaum, 1985; Baxter, 1989). These findings indicated that children tend to interpret reality based on their perceptive experience. The fact that the sun, for example, rises on one side of the horizon, travels through the sky, and sets on the other side, while the landscape does not move, often leads the child to the conclusion that the sun is orbiting the static

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earth. This kind of egocentric view may resist to change because it is compatible with everyday experience.

Liu's recent study on students' conceptions of the universe conformed the previous findings and uncovered several types of models, based on which students described and explained the earth and the heavenly bodies and events. The investigation was conducted with sixty-four third to sixth graders (8-13 years old) in Taiwan and in Germany by means of interviewing in a story form. Students were asked to play the role of the earth child and to have a conversation with an alien child who accidentally fell onto the earth during navigation. The questions presented in the interview concern the earth (its shape, motion, relative positions to the obvious celestial bodies, etc.) and the heavens (its meaning, characteristics of the heavenly bodies and reasons for day/night cycle and moon phases). They were intended to reveal not only verbal responses but also students' drawing, clay model making and demonstration using the clay. The same analysis technique as described in Vosniadou and her colleagues' several investigations (Vosniadou and Brewer, 1992; Vosniadou and Brewer, 1994; Diakidoy et al., 1997) is used in the study. The main results of the study are summarized in the following (also see Table 1)

Common features	1. Elicited knowledge shows a model-like pattern. 2. The student's model exhibits an either earth-centred or sun-centred view. 3. The earth and the heavenly bodies seem to be confined in an "observable universe". 4. A more scientifically correct model generally demonstrates a higher level of explanatory power.
Differences between German and Taiwanese students	1. For the Taiwanese students, "reasoning" the phenomena in question does not seem to be always significant or necessary. 2. Earth-centred view is dominant among the Taiwanese, whereas sun-centred view is mostly presented by the Germans.

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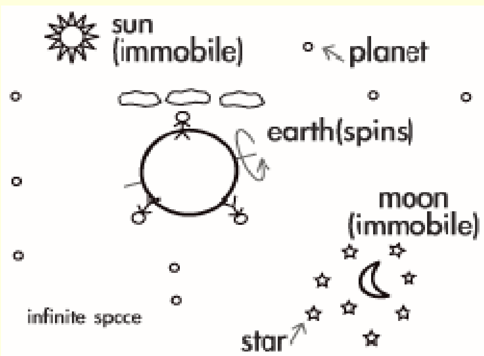
	3. German students generally provide more accurate explanations to day/night cycle and moon phases than Taiwanese ones.

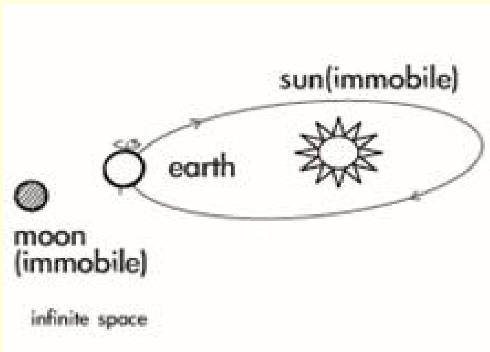
Table 1. Students' ideas about the earth and the heavens

A child's elicited knowledge appeared to be rooted in a model of the universe, which is often different from the accepted scientific one. Students conceive of the universe as being infinite, but, nevertheless, confine the basic astronomical objects - the sun, moon, earth, planets and sometimes stars - to an observable (or imaginary) space that has a centre of either the sun or the earth.

<table>
<tr><th>Group 1: Earth-Centred View</th><th>Group 2: Sun-Centred View</th></tr>
<tr><td>Model 1: Static heavens with spinning earth



</td><td>Model 4: Static sun with orbiting earth



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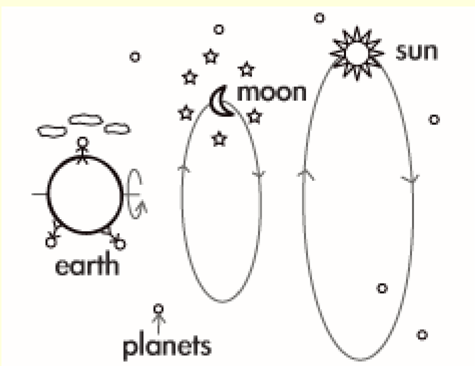
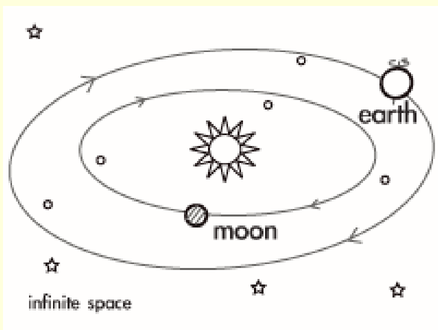
<tr><td>Model 2: Cone heavens



</td><td>Model 5: Static sun with orbiting earth and moon



</td></tr>
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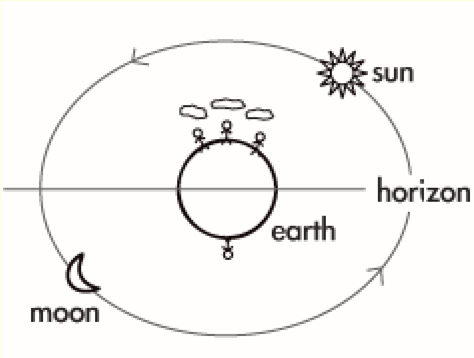
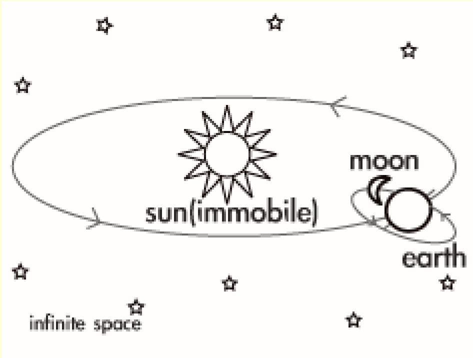
Model 3: Earth-orbiting heavens	Model 6: Present-day model with static sun
	

Figure 1. Students'models of "the heavens and the earth"

It seems that these alternative models exhibit different levels of explanatory power (Thagard, 1992); the more advanced the model is, the higher explanatory power it exhibits. A considerable number of students, for example, in the group of "Model 6: present-day model with static sun" explained, in various levels of precision, the moon phases as a result of its movement and the consequent change of its illuminated area visible from the earth, whereas students in the group of "Model 3: earth-orbiting heavens" often believed that the earth's shadow is the reason for the same phenomenon.

The interview data also revealed that children's epistemological positions about reasoning play a significant role in the construction of their alternative models. Several students who specifically cited that there was no (physical) reason for the changing phases of the moon all presented relatively primitive models, where an imaginary horizon and an absolute up-and-down direction predominated. It can be argued that when a child does not seek to explain reality, her/his interpretation of that reality remains at a descriptive level.

Some differences between the students of the two cultural settings were also observed. First, the majority of the Taiwanese presented the earth-centred models, whereas their German counterparts held mostly the sun-centred models. Secondly, the explanations of the day/night cycle and the changing moon phases given by the German children are generally more (scientifically) accurate than those by the Taiwanese. Thirdly, it

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seemed that to reason the phenomena under study was a more "natural" or "legitimate" task for the German students than for the Taiwanese ones; that is, the former seemed to answer readily the why-questions, no matter the answer was correct or not, while the latter often puzzled in the first place, and sometimes even did not hold that there was a reason at all.

The following discussion does not go into detail with the cultural difference, but rather focuses on the model-like structure of the elicited knowledge from both the Taiwanese and German young students. Based on students' alternative conceptions as revealed, it is argued that there is a potential for the use of pre-scientific models in helping students distinguish and improve their own views.

Historical Models in the European and Chinese Contexts

Before the seventeenth century, astronomy had developed differently in China and in Europe. The similarities of these two lines of scientific development are that, first, both focused on the study of the heavens (the order of the heavens as a major preoccupation), and that, second, both dealt with the calendar, cosmography (sometimes along with the study of the movements of the planets), and what we call today "astrology." The intellects in the two early worlds paid great attention to the sky and believed the heavens to be organized in order. Regulating the calendar, drawing the sky map, and investigating omens are the same tasks they undertook.

However, the early Chinese and Greek astronomy have fundamental differences: first, Greek astronomy highlighted planetary motions; as the apparent irregularities threatened the very notion of celestial order itself, the Greeks sought to geometrize them and in doing so turn irregularities into regularities. In contrast, the Chinese were more confident in the inherent order of the heavens and more open minded about its possible messages for the earth. Chinese theories seem to have "imposed far less rigid patterns on the order they expected, and they would no doubt have been amazed at the Greek ambition to prove celestial regularities" (Lloyd, 1999).

Secondly, the early Chinese and Greeks developed very different models of the universe: the former primarily with a flat earth, round heaven, free heavenly bodies and infinite cosmos, and the latter with a round earth centred by layers of round heavens, bound heavenly bodies and finite cosmos/heavens. The motions of heavenly

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bodies were, for the Greeks, the consequence of the rotation of the concentric celestial spheres on a common axis, and, for the Chinese, generated by vapour with each having its own path around the earth (Chen, 1996). For the ancient Greek scientists, their aim was to provide a tempo-spatial model of the universe for explaining the apparent motions of the heavenly bodies - the sun, moon, planets and stars - as seen from the earth (Sun, 2000). In contrast, early Chinese cosmological theories did not give detailed descriptions of the movement of the heavenly bodies, as they are viewed as independent entities from one another, moving freely.

As perceiving virtually the same phenomena, why did the Chinese and the Greeks come up with fundamentally different world pictures? It may, as Needham (1959) commented, have something to do with the fact that the Chinese appeared to concentrate on the polar star (based on their keen observation to the sky) while the Greeks emphasised on the earth (or rather, where man is located) and, much later on, the sun. Furthermore, according to Lloyd (1999), despite the same subject matter of the both enquiries, the early Chinese and Greeks developed and presented very different theories and concepts, which are associated with the questions they chose to study and, consequently, the answers they chose to give to them.

In ancient China, three main theories of cosmology (Figure 2) can be distinguished. The most archaic Chinese cosmological model, *Gai Tian* (蓋天), consists of a flat earth and umbrella-like heavens, whereas its centuries-long opponent, *Hun Tian* (渾天)model, was presented through the analogy of "egg" The flat earth was situated in the middle of the egg yolk and surrounded by water, while the heavens were like the egg shell. It should be noted that the heavens, no matter in which form, were always filled with *Chi* (氣;vapour) and accommodated the freely floating heavenly bodies, and therefore have nothing to do with the solid celestial shells as presented in Greek astronomy. For the Chinese, the heavens and the earth altogether form an observable and researchable world, beyond which is the infinite cosmos. The third model, *Shuen Ye* (宣夜), is said to be more a philosophical notion than a scientific theory. It did not discuss the forms of the earth and the heavens, but merely

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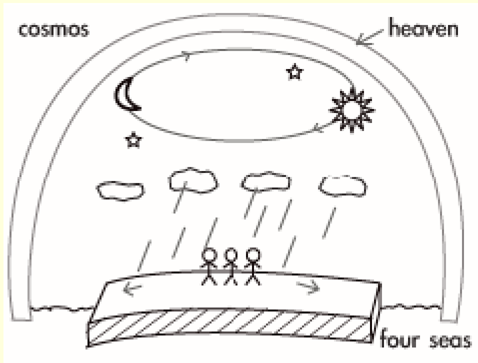
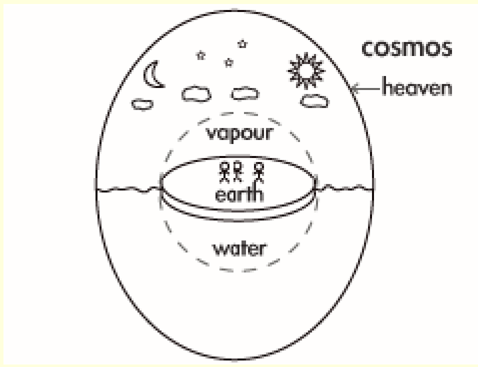
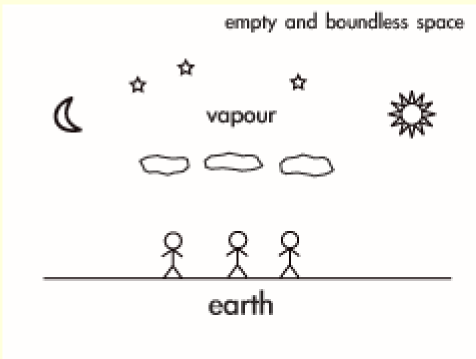
concentrated on the free moving objects in the sky and the empty and boundless space.



The *Gai Tian* Model (Hemispherical Dome)



The *Hun Tian* Model (Celestial Sphere)



The *Shuen Ye* Model (Infinity)

Figure 2 Three early Chinese models of the universe

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It is worth noting that the shape of the earth had not been a problem for either of the early Chinese and Greeks before the seventeenth century when missionaries arrived in China. For the Chinese the earth had been always flat, whereas the Greeks had taken for granted the earth was spherical. This seemed to be, at least at the outset, associated with what they considered as "ideal" form. That is, for the Chinese, the word of flat or square -*fan* -is associated with the much valued virtue of being righteous and robust, and in contrast, the Greeks considered spherical to be the "perfect" form, as evident in Plato's text. Yet, more distinguishing is that the Greeks went further to seek evidence by conducting experiments, while the Chinese simply kept to premise the flat earth in their astronomy (Chu, 1999).

It is argued that the lack of emphasis on "reasoning" gave rise to the standstill of Chinese theories. Chinese science is fundamentally influenced by the Confucian model of cognition which tends to use personal experience to make rational inductions. As a result, Chinese scientific theories dwell on direct experience and technology. The Chinese scientists considered their tasks as "discovering" and "following" the natural rules, rather than "reasoning" because of the confines of human intellectual comprehension. As late as in the *Qing* (清) dynasty (1644-1911), the eminent scholar Ruan Yuan (阮元) still complained that Western astronomers successively changed their theories in explaining astronomical phenomena: "The laws are always changing ... I don't know where the real reason lies." He then concluded that "heavenly laws are so profound and subtle that they lie beyond human ability". Theories should therefore express certainties rather than search for reasons. Only in this way can theories "last forever without error". Consequently, the Chinese did not establish a structural view of nature that substantially requires "reasoning" as embraced in the Western science. In other words, the Chinese did not attempt to make systematic connections between natural principles that people had in mind; they "had sciences but no science, no single conception or word for the overarching sum of all of them"(Sivin, 1995)

Briefly, the main characteristics of the ancient Chinese models of the universe can be listed as follows:

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1. The phrase, "the heavens and the earth" was used to refer to their researchable universe, which is an observable space based in the earth; beyond the heavens there is unknown infinite cosmos. That is, for the Chinese, the universe was in fact infinite, but they confined their models to a space called "the heavens and the earth".
2. The earth is flat.
3. The heavens are round; the heavenly bodies are floating, unattached to the heavens, and moving freely.
4. There is a lack of emphasis on reasoning and consequently the structural view of nature.

These features interestingly are distinguished from those of the Greek cosmological models:

1. The universe is finite, where "the heavens and the earth" are located.
2. The earth is round (spherical).
3. The heavens are layers of solid spheres; the heavenly bodies are attached to the layers respectively.
4. Efforts are made to search for reasons and to establish a structural view of nature.

The Common Place for Students' Models and their Historical Counterparts

Based on the students' and historical accounts, there seems to be some common features to be observed. Most evident is that the students construct for themselves a model of the universe, which organizes a limited scope of information, like early scientists did. Furthermore, the alternative models among students appear to embrace the Western geo- and heliocentric views and in the same time demonstrate the Chinese way of enquiring into the sky, separating the observable world and beyond. On the one hand, students did not have solid spheres of heavens in mind, and instead believed the universe to be infinite vastness in space. They construct, on the other hand, a model of the "universe" confined to an observational area, where either the earth or the sun occupied the centre and had the dominant power over the movements of other celestial bodies.

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At this point, we may argue that the pre-scientific models may harbour the valuable information about the ways children may move out of their previous conceptions towards the more scientifically accepted view. More precisely, by discovering what are the things that establish and support a model, that differentiate one model from another, and that make one model "more scientific" more successfully explaining reality, than another, we may gain insight into the keys of cognitive process in its rational domain.

It should be noted that the alternative models from the both sources are easily seen as inconsistent if examined without taking into account what questions it speaks to or what phenomena it is intended to account for. If the student's alternative model, for example, does not speak to the question about phases of the moon, it is understandable that (s)he explains the phenomena as a result of clouds or whatever moving across the moon. That is to say, this kind of explanation avoids confronting the model to a crisis of being insufficient or incorrect. Similarly in history, the scientist addressed a limited number of questions to construct a self-sufficient model of the universe. The ancient Greeks, for example, persisted in earth-centred views and concentric celestial spheres because they did not question whether the earth was actually placed in the centre of the universe, but instead focused on the question about the ways in which celestial bodies move around the earth. For, above all, their models were informative enough for them regarding the phenomena in their concern. It seems to us that alternative models are consistent to the eye of their beholders.

Historical Models for Science Teaching and Learning

It is a common goal for science education practitioners to locate instructional approaches that can foster students' conceptual change in their science learning processes. To stimulate conceptual change, as generally agreed, a primary stage where students come to recognise and further scrutinize their own conceptions is required. The common place between students' and historical models, as discussed in the last section, can be specially meaningful for this stage. Namely, historical models can be operated in the science classroom as intermediate models in the learning process (Clement, 2000), providing alternative views that have common features with the student's initial conceptions and have also cognitive connections to the intended scientific knowledge. The sequential feature of historical models can function as a

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reflective tool to help students locate their own ideas and proceed to understand the scientific ones. It should be noted that the models should not be clarified merely by its descriptive explanations, but instead the causal relations among concepts and the constraints lying behind them should be emphasized. As the student's knowledge is often in conflict with modern scientific ideas, it could be valuable to use historical models, presented with its developmental features, as the bridge for the student to move from one end to another. The highlight of the inclusion of historical models shall be the changing perspectives from on the surface of the earth to beyond as illustrated in the historical transition from Ptolemaic to Copernican universe, where the children find analogies to their ideas. The Chinese alternative view on the universe may similarly serve to stimulate students' reflection and furthermore convey some aspect of the nature of science -the role of "reasoning".

Changing the perspective from on the surface of the earth to beyond

1. *Models of the universe*

Students' elicited models of the universe fall into two groups: earth-centred and sun-centred views. The analogous models can be found in history, as the geocentric and heliocentric models characterized the astronomical development in Europe. At this point, historical models find their positions in instruction - as a means of intermediate models in the learning process from the student's alternative conceptions to the intended scientific model. The students can project their conceptions onto these views in history. As the essential difference between the geocentric and heliocentric views is the perspective taken on the surface of earth and beyond, it should be therefore a high point for instruction to use the historical models. To be more precise, the geocentrism and heliocentrism of historical models can be introduced to students in relation to the understanding of the perspective on the surface of the earth and beyond.

As a matter of fact, scientific progress often involves a change in the perspective man takes. For the learner, the change of perspective is significant, too, in the process of conceptual development. The transition from a geocentric to a heliocentric view is typically a change in man's perspective; the former is constrained by the experience and observation based on the surface of the earth, whereas the heliocentric view was

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regarded as the first step that man goes beyond the surface of the earth to view the universe. This is indeed the point upon which we should lay stress while using the historical models. Students do have similar difficulty to take a different perspective beyond where they are located. When they are able to move from the perspective on the earth to that beyond the earth, they are on the way towards understanding the intended scientific knowledge in instruction, and, moreover, of the nature of science.

2. *Models of the earth*

Students' difficulty in relating the flat earth as viewed on the surface of the earth to the spherical earth as explained by other people is also derived from the perspective students take from where they locate. To understand the sphericity of the earth, the student must first realize there is a difference between what is seen on the surface of the earth, while the observer is a tiny point as opposed to the whole earth, and outside the earth, while the earth can be fully captured in the view. The historical models of the earth can be therefore placed in the students' learning process for understanding the perspective beyond the earth. For example, the historical intuitive ideas about the shape of the earth, such as Homer's shield-like earth, Anaximander's cylindrical earth, and the disk- or plate-like earth held by early Chinese scientists for centuries, are those that can be understood as the perspective taken on the earth surface. In contrast, a spherical model of the earth was established in the Greek antiquity as early as in the six century B.C. The arguments scientists put forward to this model can be illustrated in the teaching the sphericity of the earth in relation to the perspective beyond the earth.

Furthermore, the contrasting development of this subject in Europe and China before the 17th century, if introduced carefully, can convey that, first, people at different parts of the world actually held different "truths", and, second, ideas are bound to the cultural context. Students could reflect on their own thoughts in the light of the historical examples.

Conveying the Structural View of Nature

Liu's study revealed that the students who did not take for granted the necessity to physically reason the astronomical phenomena consequently presented more primitive (or more descriptive) models than the others. This is to some extent similar to the

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fundamental difference between the perspectives of early Chinese and European scientists and the sciences they accordingly demonstrated: the former devalued reasoning in their scientific enquiry while the latter gave much importance to it. It is argued that this is closely associated with a "structural view of nature" (logically coherent theories) that determines scientific progress.

A structural view of nature was claimed to be the driving force, by which European astronomy was moving towards a more coherent view, and in contrast, in absence of this view the early Chinese astronomers failed to progress their models. Without a structural view of nature, natural phenomena cannot be regulated into a whole and all bits in scientific theories cannot be summed up into certain rules or fundamental hypotheses, from which one can make logically consistent deductions by means of formal logic. To point it out again, what is essential to establishing such a structural view of nature is the why-question - If one only seeks to describe, not to explain causally, the physical world, the accordingly constructed theories or models would not exhibit logical, causal interrelations.

Thus, the contrasting views on "reasoning" from the early Europeans and Chinese can be helpful in assisting students in forming a structural view of nature. The ancient Chinese astronomers, unlike their Greek counterpart, did not give emphasis to efforts on regulating celestial phenomena, despite a different perspective they provide, and consequently on testing the derived regularities. As a consequence, their models of the heavens and earth were prevailing without significant improvement for about two millenniums until the Western scientific concepts became known in the seventeenth century. This aspect indicates how significant it is to establish a structural view of nature and an understanding of the function of experiment in scientific theory (for reasoning) that should have much implication to students' conceptual development.

Apart from the Chinese historical models, the Copernican Revolution can serve as another example to teach about this, as Copernicus was the first in written history to single out the form of a theory, and to argue for a systematic, harmonic, and logically coherent astronomy. He criticized Ptolemaic astronomy as being "fundamentally hypothetical" within which everything is isolated and independent and thus can be freely changed whenever a need emerges. This historical chapter can not only tell students something about the nature of science but also help them reflect upon their own views in terms of structure.

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Final Remarks

In spite of its potential advantageous information, the historical material, like all other instructional tools, should be analysed carefully. The analysis must, in accordance with the instructional model proposed by the German science educators, Kattmann, Duit, Gropengiesser and Komorek (1996), make direct references to and further integrate the perspectives from students, experts of the subject matter, and science and general educators. More precisely speaking, to tackle, select and divert the historical and philosophical accounts to a form ready to be used in school science, one has to have in mind the ideas students hold (as a starting point in learning process), the clarification of the subject matter (as the end product of the process) and the theories regarding learning and instruction (generally and domain-specifically). In this way, the material can be analysed based on a specified outset, goal, and issues necessary to be considered.

To profit in the learning process, it may be worth taking into account the authentic arguments behind the pre-scientific models and their comparative levels of explanatory power. By doing so, students may come to realize what makes them think the way they think and to further distinguish their own ideas from others' including the scientific ones. Yet, what do we mean by authentic arguments? It is the original texts of the scientist's work that we assume to be an effective means to understanding why and how (s)he thought about something. These early scientific arguments could be plausible to the student due to the similar conceptual tools and levels. Ptolemy's and Copernicus' arguments, for example, of the earth-centred and sun-centred universe (respectively), can genuinely illustrate their reasoning and the philosophical propositions beyond. The preface in De Revolutionibus which reveals Copernicus' motives for innovation is another good example of involving students in the thoughts of early scientists and as well those of their own. Text from *De Revolutionibus* can be interesting and also meaningful, as the student is faced with questions in relation to the nature of science, such as: Given the limitations of traditional astronomical tools and cosmological beliefs imposed to him, what led Copernicus to believe an innovation is necessary? To what extent beyond this innovation is he still bound to the old tradition? To be sure, the reading of the original texts would require the guide of the teacher, not only to select the appropriate texts (as many early astronomical works

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focused on complicated mathematical forms) but also to communicate them based on the student's cognitive status.

It is also worth noting that the early astronomical models were basically established through sky-gazing, as technological instruments were actually the modern products as late as in the seventeenth century. Astronomers in different places of the world observed and documented the sky carefully and thereby developed their visions of the universe. It should be reasonable that students may revise their concepts and models if watching the sky carefully. Activities such as observation of the sun, moon and stars, from different angles, may demolish some naive preconceptions and, in addition, develop a sense of spatial relations of heavenly bodies and the earth. As ancient Greeks, for example, argued for a spherical earth based on the evidence that ships coming towards the shore appear first with their masts, children may learn to revise their alternative earth concept through observing the same phenomenon. Moreover, when they make direct contact with the phenomena instead of being merely told, children may discover more than the intended concept.

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