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An Experimental Plan: Teaching of Astronomical Clock Tower under View of New Liberal Arts Perspective

Jianguang Yao (Corresponding author)

School of History, Culture and Tourism, Yulin Normal University

1303 Edu. Dong Road, Yulin, Guangxi, China

Tel: 86-186-9081-9679 E-mail: 466705309@qq.com

Lingfei Chen

College of Foreign Languages, Yulin Normal University

303 Edu. Dong Road, Yulin, Guangxi, China

Tel: 86-188-9959-5378 E-mail: 16368516@qq.com

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Abstract

At the end of the 11th century, the "Astronomical Clock Tower" developed by Su Song's team involved many scientific knowledge, advanced and complex technologies, and created many world firsts. It played an important role in the history of science and technology in China and even the world. It was the best test sample for exploring the teaching method of the history of science and technology content in the teaching reform of the undergraduate history (normal) major "Ancient Chinese History" course under the guidance of the new liberal arts and science concept. The experimental plan focuses on the common characteristics of this type of content, closely adheres to teaching objectives, fits the actual learning situation, and is based on general teaching conditions. Within the limit of class hours, it introduces the background, structure, and function, explains the principle and process of key components, analyzes ideas and methods, highlights the key points and difficulties, and strives to be interesting, easy to understand, and memorable, so that students can feel the outstanding wisdom and innovation of the sages, clarify its position and influence in the history of science and technology in China and the world, and accumulate knowledge and methods for future teaching of this type of historical content.

Keywords: New liberal arts perspective, Astronomical clock tower, History-teaching reform, Experiment scheme

1. Introduction

Constrained by historical tradition, teacher impart and inherit as well as other factors, for a long time, the teaching content of the course "Ancient Chinese History" for undergraduate history (normal) majors has been based on the agricultural regime of the Central Plains, with Political history as the bulk. The history of economy, culture, thought and social life, especially the history of science and technology, is seriously inadequate (Shaohou, 2010), so that intellectuals, including many Chinese scholars, know little about the achievements of ancient China in science and technology and its contributions to mankind, becoming a common historical blind spot and teaching void. This situation not only distorted historical education, but also made the public, including many Chinese people, mistakenly believe that ancient China was lacking in science and technology, and that Western countries had much higher scientific and technological achievements in ancient times than China, making much greater contributions to human development and progress than China (McClellan III & Dorn, 2020).

When the idea of new liberal arts has gradually become the consensus of the educational community and has been put into practice, the improvement and upgrading of the "Ancient Chinese History" course has become an urgent task that brooks no delay. The most important part is to vigorously promote the status and weight of the achievements and contributions of ancient Chinese science and technology in this course.

The teaching object of the History (Normal) major is undergraduate students majoring in history, and its teaching goal is to cultivate qualified secondary school history teachers. Therefore, the history-teaching of this major not only aims to cultivate graduates who are familiar with the various historical knowledge，achievements and contributions of ancient China, but also to cultivate secondary school history teachers who are able to teach relevant knowledge.

For this reason, it is necessary to actively explore the updating and upgrading of teaching concepts, content, and methods. In terms of teaching concepts, what we should do is to resolutely abandon the outdated view (which are bound by traditional ideas, that is, the history of Ancient China is the history of emperors, politics, struggles, and wars), and establish the awareness that history covers all aspects of society, history teaching should include the achievements and contributions of the ancients who did not enter the classroom in many disciplines into the focus of learning, understand the principles, build a basic cognitive system, and focus on interpretation, practice or understanding on the important knowledge points. More importantly, it is important for students to truly understand their wisdom, feel their superb and ingenious reason, understand the greatness of their achievements, and admire their tremendous contributions.

In terms of teaching content, content updates are the key to improving this course. The achievements and contributions of ancient economy, culture, ideology, and social life history,

especially the history of science and technology, should be included in the teaching focus. Through high-dose and high-frequency exposure and learning, students' scientific and technological awareness can be significantly improved, relevant knowledge can be enriched, and basic interpretive abilities can be formed.

In terms of teaching methods, the main approach is to enable students to engage in participatory and operational teaching such as learning, thinking, doing, comparing, feeling, and understanding. They can examine and interpret these achievements and contributions like science popularization workers, and be able to compare and analyze them on the world stage to understand their international status and influence. Therefore, new types of courses such as field exercises, hands-on experience and experiments, and expert lectures will rise to a very important position and should account for no less than 40% of the total. More importantly, the allocation of class hours, selection of class types, and effectiveness testing should be determined based on specific content and teaching objectives

Su Song (1020-1101), a prime minister scientist and naturalist of the Northern Song Dynasty, was undoubtedly very important one among many outstanding figures in the world during the Song Dynasty. The Shuiyun Yixiang Tai (SYYXT. It meanings an instrument and phenomenon platform droved by water, is also called "Astronomical Clock Tower") developed by the research team led by him was the most advanced in concept, the most sophisticated in technology, the most powerful in function, the most accurate and diverse in timing and chiming, the most accurate demonstration of celestial phenomena, the most comprehensive astronomical observation, the most ingenious design concept, the most complex internal structure, the most condensed disciplinary knowledge and manufacturing skills, the highest degree of automation, the largest size, and the most expensive water droved astronomical clock (Tuotuo, Yuan Dynasty a, Yuan Dynasty d).

It is a typical representative of China's ancient science and technology leading the world, and also a peak that surpassed the past and future in the history of history of science of human medieval timing, chiming, punctuality and issuing almanac (Needham, 1976; Jiaxi, 2000, 2023). But such an important and representative achievement, in the most influential "Ancient Chinese History" textbook (Shaohou, 2010) for undergraduate history majors in China's universities, only 360 words are used to introduce Su Song's life, his team members, the structure, and function of SYYXT. There is no outline drawing or sectional view, and its working principle and process, its positioning in the history of Chinese and world science and technology are all not clear. So, students cannot recognize its importance, historical status, and value when reading textbooks. The importance of the content targeted by the training objective, as well as the arrangement of credits, class hours and learning methods determined by the importance, cannot help these freshmen who are less than 20 years old, have many difficulties in reading ancient books, and know little about the history of Chinese astronomy, history of mathematics, time science, and the manufacturing process of astronomical instrument to build an accurate, clear and three-dimensional brain diagram of this national important utensil that integrates the high, sophisticated, and cutting-edge technologies of the world at that time. It is difficult for them to understand its essence, appreciate its profundities, and realize its value. Therefore, it is necessary to use this typical problem as a sample for

improving history teaching under the guidance of the new liberal arts concept, and conduct teaching reform experiments in order to achieve teaching objectives.

2. Teaching Experiment of SYYXT under the Guidance of New Liberal Arts Idea

2.1 Setting of Teaching Elements

2.1.1 Elements of Teaching Noumenon

Elements of teaching noumenon include seven aspects, as shown in Table 1.

Table 1. List of seven elements of teaching noumenon

Primary Elements	Secondary Subitem	Specific Information
	Content	Su Song's Life
		Team composition, Division of responsibilities, Development background，Process and cost
		Dimensional specifications and internal structure
		Function and utility
		Working Principles, Processes, and Related Disciplinary Knowledge
		Processing, manufacturing, and technique of core components
		Historical status and international influence
		Fate and restoration
	Important points	Astronomical and Mathematical Knowledge as well as Manufacturing technique of Important components
		Status in the History of Science and Technology in China and the World
	Difficult points	The mathematical principle of gear transmission ratio conversion in SYYXT
		Shaping process of "Shu Wheel" spokes
Objective	Knowledge and Skills	Understand the research and development background of SYYXT, comprehending its basic working principles, especially the transmission ratio conversion of parallel, vertical, and inclined gear driving, celestial tracking and demonstration, observation of star positions and movements, knowledge of timing, chiming mechanisms, and assembly devices.
	Process and method	Understand its internal structure, the relevant knowledge, material processing technology and process of key parts such as escapement mechanism, Shu Wheel, hydrodynamic circulation device, Shaft-driving motion, chain-driving motion, gear-driving motion, etc.
	Emotions, Attitudes, and Values	Familiarize oneself with its functions and understand its status in the history of astronomy, timing, and chiming technology in China and the world. Understand the importance of valuing and learning science and technology, and establish the concept that science and technology are the primary productive forces.
	Method	Explanatory method
		Q&A method
		Discussion method
		Audiovisual method
		Comparative method

2.1.2 Teaching Guarantee Factors

Guarantee factors include five elements, as shown in Table 2.

Table 2. List of five teaching guarantee factors

Primary Elements	Secondary Subitem	Specific information
Duration	80 minutes	Explaining: 45:40
		Q and A: 10:00
		Discussion: 10:00
		Viedo: 14:20
Resource	Literature that must be read	[Song] Su Song. *New Yixiang Fayao*. Shanghai Ancient Books Publishing House, 2007, pp. 1-15, pp. 130-135.
		Lu Jiaxi. *History of science and technology in China·Mechanical Volume*. Science Press, 2000, pp. 297-312.
		Joseph Needham. *History of Chinese Scientific Civilization* (Volume 4). Shanghai, Shanghai People's Publishing House, 2003, pp. 235-246.
		Wang Zhenduo. *A Collection of Scientific and Technological Archaeology*. Cultural relics publishing house, 1989, pp. 238-274.
	Video	(a) https://v.qq.com/x/page/o0399wqk0yk.html?ptag=qqbrowser
		(b) https://v.qq.com/x/page/u0144oozljx.html?ptag=qqbrowser
	PPT	The Power Point "*Su Song and SYYXT*" created for learning the content of this lesson
	Site and equipment	Smart Classroom 609

2.1.3 Placement of Desks and Chairs

As shown in Diagram 1, In front of the smart classroom is the main screen, with two screens on both sides that can be synchronized with the main screen, and can also display different content separately. I can control all equipment from the podium or remotely control all equipment from any location in this classroom. To facilitate eye and emotional communication between students and I, establish a democratic and equal teacher-student relationship, and ensure that students' vision is not obstructed when I teach and write on the blackboard in front of the main screen, desks and chairs are arranged in a trapezoidal manner. When playing a video image, students on both sides can turn 90 degrees to see the information displayed on both sides' screens more clearly.

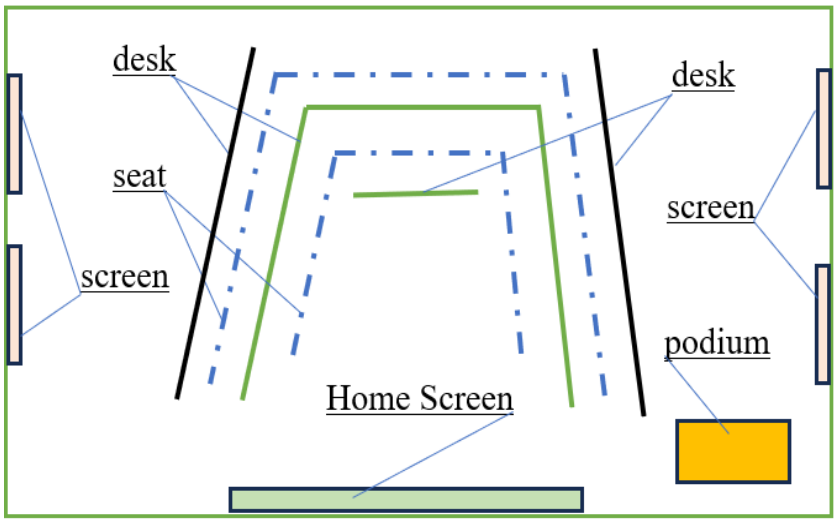


Diagram 1. Schematic diagram of the putting method for desks and chairs

2.2 Preparation before Class

Arrange students to read the relevant content in Table 2 "Literature that must be read" one week in advance.

2.3 Teaching Implementation

The teaching implementation process is divided into three consecutive paragraphs: leading-in; Learning new content; summary.

2.3.1 Leading-In

Play Video a to enable students to have a more intuitive and vivid understanding of SYYXT based on preview. Before starting to play the video, ask the students the following questions to help them capture key information and deepen their impression during the viewing process.

Q1: What are the main components of SYYXT?

Q2: What are the main functions of SYYXT?

Q3: Whom are the main members of the R&D team for SYYXT?

Q4: What fate had SYYXT suffered?

Q5: Since the 20th century, who did study SYYXT at home and abroad?

Q6: What are the main reference materials for restoring SYYXT?

After watching, choose students to answer these questions according to gender ratio and their enthusiasm for speaking, and record grades into the "Classroom Questions" section of "Daily Performance" based on the accuracy of the answer.

2.3.2 Learning New Content

2.3.2.1 Su Song's Life

Su Song (Dec. 10, 1020-Jun. 18, 1101), literary name Zirong, was born in Tong'an County, Quanzhou Prefecture, Fujian Province (today's Tong'an District, Xiamen City). At the age of 22, he got the highest degree title "Jinshi". He passed away at the age of 82. Throughout his life, he experienced six dynasties, namely, Zhensong, Rensong, Yingzong, Shenzong, Zhezong, and Huizong, he was an official in five dynasties from Renzong to Huizong, served as all level local leaders and court officials for 55 years, and twice served as a special envoy of the emperor to the Liao Dynasty. Officially appointed as Minister of Justice, Minister of Personnel and concurrently serving as Minister of Attendance, Imperial Scholar Chengzhi of Hanlin, Left Minister, and then Prime Minister of Zhezong. He was a clean and honest official, diligent and pragmatic, with considerable achievements, and widely respected among the people. After Emperor Huizong ascended the throne, he was conferred the position of Taizitaibao and was honoured with the title "Duke of Zhao County". After his death, he was bestowed the title of "Sikong", "Shangzhu State" becouse of his achievements, and was conferred the title of "Duke of Wei". The posthumous title of "Zhengjian" was granted by the Emperor Lizong of the Southern Song Dynasty. He was outstanding astronomer, mathematician, expert in astronomical instrument manufacturing, pharmacologist, naturalist, politician, and writer of the Song Dynasty. Yinyang, Five Xing, Astrology, Algorithm, Geography, Mountain Classic, Materia Medica, Exegesis, Rhythm and Lyrics, Characters, Figures and weft are all well understood, and especially proficient in historical decrees and regulations. Joseph Needham called him "one of the greatest naturalists and scientists in ancient China and the Middle Ages. He was a prominent scholar who attached great importance to scientific laws" (Su Song, Song Dynasty c; Tuotuo, Yuan Dynasty b). He has authored "*Luwei Xinlu*", "*Bencao Tujing*", "*Lue Ji*", "*Suweigong Documents Collection*", 72 volumes, "*New Yixiang Fayao*", "*Jin Yixiang Zhuang*", "*Zhuying Yaolan*", "*TanXun*", etc. The latter five are still passed down to the world. In short, Su Song can be regarded as "an encyclopedia like knowledge giant in 11th century China" (Tuotuo, Yuan Dynasty a, Yuan Dynasty d).

2.3.2.2 R&D Origins of SYYXT

The origin of R&D can be summarized in seven aspects: firstly, due to Xining Instrument cannot be used anymore and non-automatic instruments require manual operation, which can result in significant errors; secondly, the need to revise the calendar; thirdly, the requirement for accurate positioning of constellations in navigation; fourthly, the emperor's most concerned "astrology" task cannot be achieved without advanced and accurate equipment; fifthly, at that time, agricultural production developed, handicrafts and commerce flourished, and the government attached great importance to technological inventions, providing political and economic conditions for the frequent construction of expensive large-scale astronomical instruments; sixthly, there is a talent team represented by Su Song, Han Gonglian, and others who understand technology and are skilled in research; finally, the fact that the astronomical and calendar level of the Song Empire at that time was lagging behind that of the Liao

Dynasty brought a great sense of humiliation to the Emperor of Song. The combination of the seven major reasons mentioned above led to the birth of SYYXT, which is indispensable. Below is a supplementary introduction to the last one, article 7.

In ancient China, the emperors of the Central Plains dynasties regarded themselves as the co-owners of the world and had a strong sense of superiority, unable to tolerate being surpassed by others. Ye Mengde (Song Dynasty), who was contemporary with Su Song but a little later, recorded in his book *Shilinyanyu*:

> During the Yuanfeng period, Su Song gent to the Liao Dynasty as the special envoy of the Song Dynasty, coinciding with the "Winter Solstice" festival. The winter solstice of the Liao calendar was one day earlier than that of the Song, so the Liao requested the envoy of the Song to congratulate them. Due to the fact that the Liao Dynasty did not prohibit the dissemination of astronomy among the people, many people understood this kind of knowledge. In fact, the calendar of the Liao was correct, but the great Song missions, who regarded themselves as the Celestial Empire, could not admit that their country's calendar was incorrect. For this reason, the erudite Su Song talked extensively about calendar to the Liao people, demonstrating rich knowledge. The Liao people were difficult to distinguish right from wrong, let alone refute it. Then, Su Song calmly gave an "explanation" to save the face of the Liao people. He slowly said: "This small mistake is not worth considering, it is just an accumulated 15 minutes error. Taking midnight as an example, an extra quarter of the winter solstice is today, and a quarter less of the winter solstice is tomorrow. Your calendar errors are just accumulating some extra quarters". Upon hearing this, the Liao people, although not convinced, were powerless to oppose. After returning, the members of the mission reported Su Song's rich knowledge and eloquent eloquence to the emperor, who was delighted and immediately asked: "Which of the two calendars is right?" Su Song had to tell the truth. The emperor was furious and all the "Taishi" were punished for this. In the early year of Yuanyou (actually referring to the second year of Yuanyou, 1087), the emperor ordered Su Song to rebuild the armillary sphere… (Mengde, 2004; Xin, 2004).

2.3.2.3 The Creation Process of SYYXT

- In 1086, Su Song was ordered to decide to use old instrument or make new one, he proposed the opinion of SYYXT that integrates the three instruments of the armillary sphere, Hunxiang sphere, and time servicing into one machine. He found the capable technician Han Gonglian who could achieve this idea, and officially proposed to establish a specialized agency.

- In Aug.1087, Su Song was granted permission to "form a R&D team" and officially established the department of "Xiangding Zhizao Hunyi Suo" (Research Institute for Manufacturing of SYYXT). The chief clerk of Yuanwu County, Zhengzhou, and the professor of Shouzhou state studies, Wang Yanzhi, was appointed as Creative Director and responsible for inspecting income and expenditure officials. Summer Guanzheng Zhou Riyan, Autumn Guanzheng Yu Taigu, and Winter Guanzheng Zhang Zhongxuan from the Taishi Bureau, along with Han Gonglian, served as "System Officers (equivalent to the current

engineering project leader). Bureau students Yuan Weiji, Miao Jing, Zhang Duan, Jieji Liu Zhongjing, and students Hou Yonghe, Yu Tangchen, and others were responsible for testing the position of the sun shadow and the scale of the clepsydra, Yin Qing, a technician from Duzuoyuan (the Bureau of supervising manufacturing), was responsible for guiding and planning work.

- R&D steps: small wooden models—large wooden models—metal objects.

- In May 1088, a small wooden model was built and placed Du Hall of Shangshu Sheng for check.

- In Dec.1088, a large wooden model was built and placed in the Jiying Hall. Zhou Riyan, Miao Jing and others debugged it day and night to make it run "in line with the operation of the sky" (Su Song, Song Dynasty a).

- In Apr. 1089, Xu Jiang,a scholar from Hanlinyuang, conducted an experiment and the results were "No mistakes made day and night". The model test was successful. So the emperor issued an edict to make of copper. Xu Jiang proposed to combine Hunyi and Hunxiang inside one machine, which was consistent with Su Song's initial idea. The emperor approved the R&D plan of "three instruments make up one machine".

- In 1091, the development of copper SYYXT was officially started.

- In 1092, copper SYYXT was successfully developed, and the emperor issued the edict that "The three Sheng and Shumiyuan (the Bureau of Military Affairs) officials check it". The entire project used 20,000 kilograms of copper (approximately 12,000 kg today), with a cost of 50,000 guan (approximately 35 million RMB today), accounting for 1/1000 of the national fiscal revenue at that time (Needham, 1976; Jiaxi, 2000).

2.3.2.4 Overall Composition, Subsystems, Working Principles and Processes of SYYXT

Playing Video b, serves as a foreshadowing and foundation for teaching new knowledge, facilitating students to understand the structure of SYYXT, clarifying the specific parameters of each component, understanding the working principle and basic process, and helping students understand relevant terminology and professional and abstract knowledge points. During the video playback process, when introducing the composition, function, working principle, and process of each subsystem, pause the playback for necessary emphasis, supplementation, explanation, questioning or replay.

Before playing, ask the following questions, and require students to take notes while watching the video and listening to my explaining.

Q1: What are the main components of SYYXT?

Q2: How do the various components work?

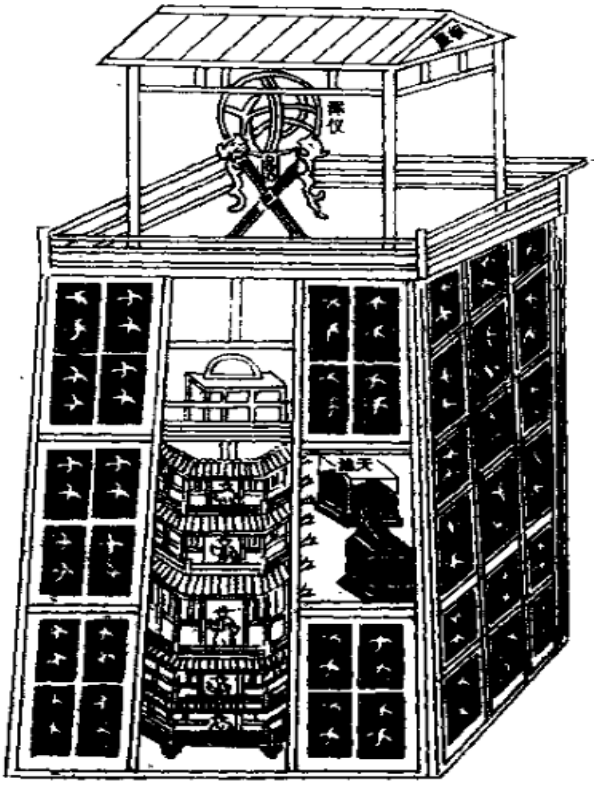
Q3: What have you already understood? What else have you not understood?

Q4: What question are you curious or interested in but the video did not discuss or clarify it clearly?

The above questions are answered through Q&A and discussion to further identify the key and difficult points, in order to allocate time reasonably.

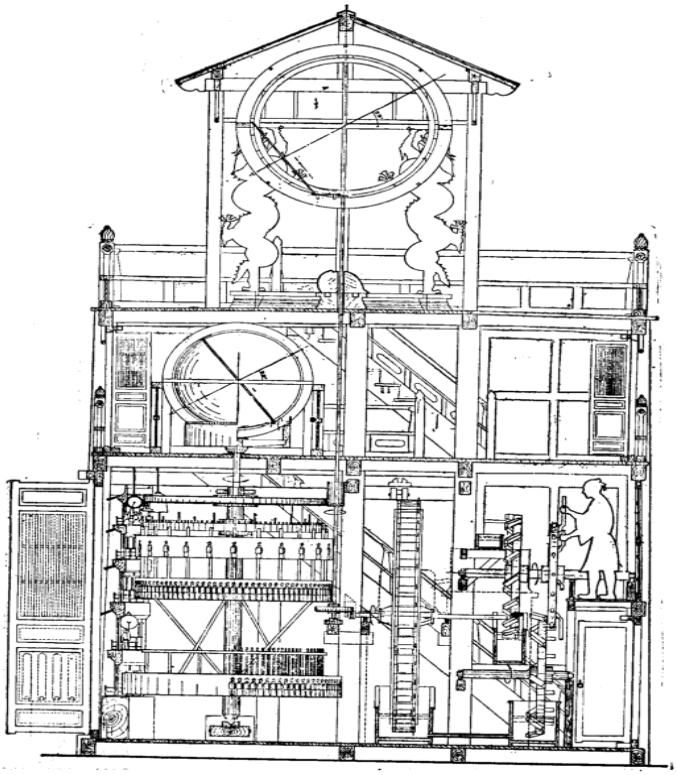
2.3.2.4.1 Overall Composition

SYYXT is a stacked three-dimensional square astronomical building with a narrow top and a wide bottom, with a magnificent momentum. The total height is 12 meters, and the outer platform is seven meters high. The main structure is divided into 3 layers (as shown in Picture 1 and Picture 2).



Picture 1. SYYXT outline drawing

Source: Lu (2007).

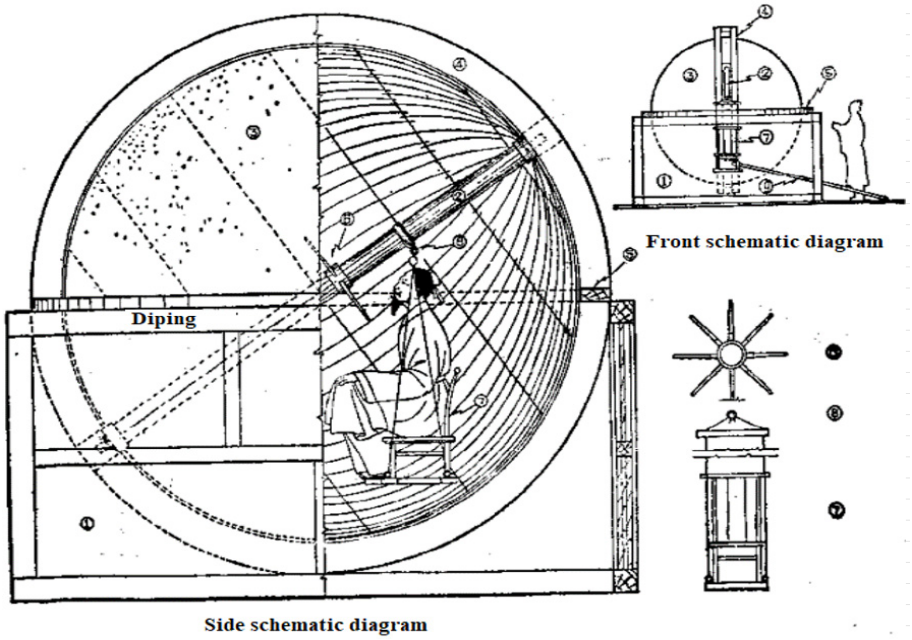


Picture 2. SYYXT restoration perspective

Source: Wang (1989).

➢ The lower layer is where the driving mechanism is located, and there is a set of precise timing and chiming device “Sichen”. a person can enter the building through the door opened to the south. The Sichen mechanism is composed of five wooden pavilions, each of which has a set of driving motion system behind it.

➢ The middle layer is a closed structure chamber with a 1.4-meter-diameter Hunxiang Sphere. It is an astronomical model that operates synchronously with the celestial phenomena. The main part is composed of the “Tianqiu” (celestial sphere) and the “Diping” (closed roof), half of which appears above the Diping and half of which is hidden under the Diping (as shown in Picture 1 and Picture 2). A person can enter the celestial sphere and watch the celestial phenomena from the inside out, just as we look up at the sky at night (as shown in Picture 3).



Picture 3. Hunxiang sphere

Source: Guo (1988).

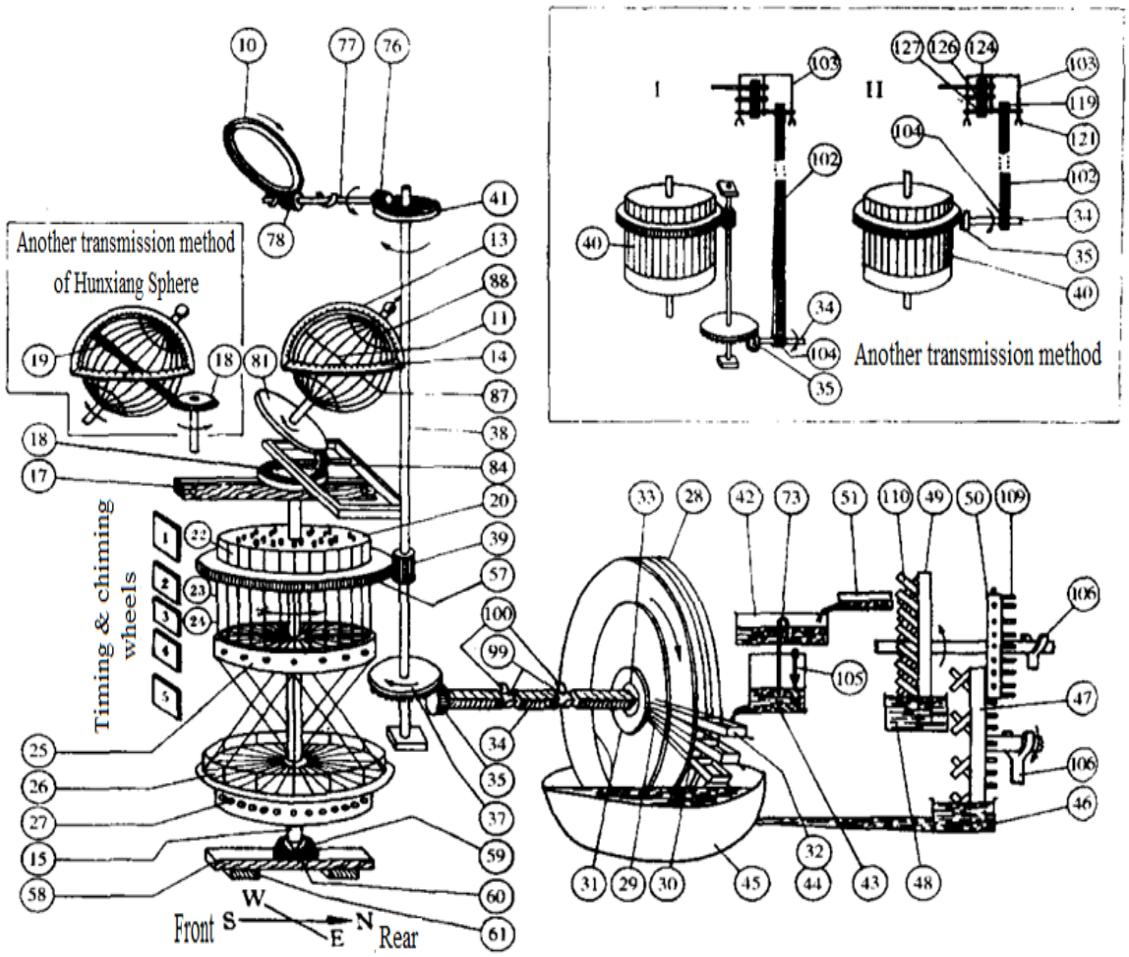
The motive power transmitted from the main driving shaft drove the celestial sphere to rotate, simulating the alternation of day and night, which was newly created by the R&D team according to the records of *Suishu·Astronomical records* (Shengchi, 1988).

2.3.2.4.2 Six Subsystems and Specific Composition

The subsystems mainly include: circulating water motive power generation system, motive power control system (Water bucket linkage escapement device), motive power transmission system, timing-chiming system, celestial phenomena demonstration system, and astronomical observation system. Identify one by one in combination with PPT pictures (Xianzhou, 1962; Needham, 2003; Video c & d).

2.3.2.4.3 Working Principle and Process of Each Subsystem

(a) Circulating water motive power generation system: when the “Boya” 109 (This number is the part number on the corresponding picture, the same below) on the “Heche” 50 in Picture 3 is manually rotated, because it is meshed with the “Shengshui xialun” 47 and coaxial with the “Shengshui shanglun” 49, the 3 wheels 50, 47 and 49 rotate at the same time, and the water in “Shengshui xiahu” 46 is lifted to “Shengshui Shanghu” 48. “Shengshuilun” works in the same principle as the “waterwheel”. At the same time, the water in “Shengshui Shanghu” 48 is lifted to the “Tianhe” 51. Under the action of gravity, the water in “Tianhe” 51 naturally flows into



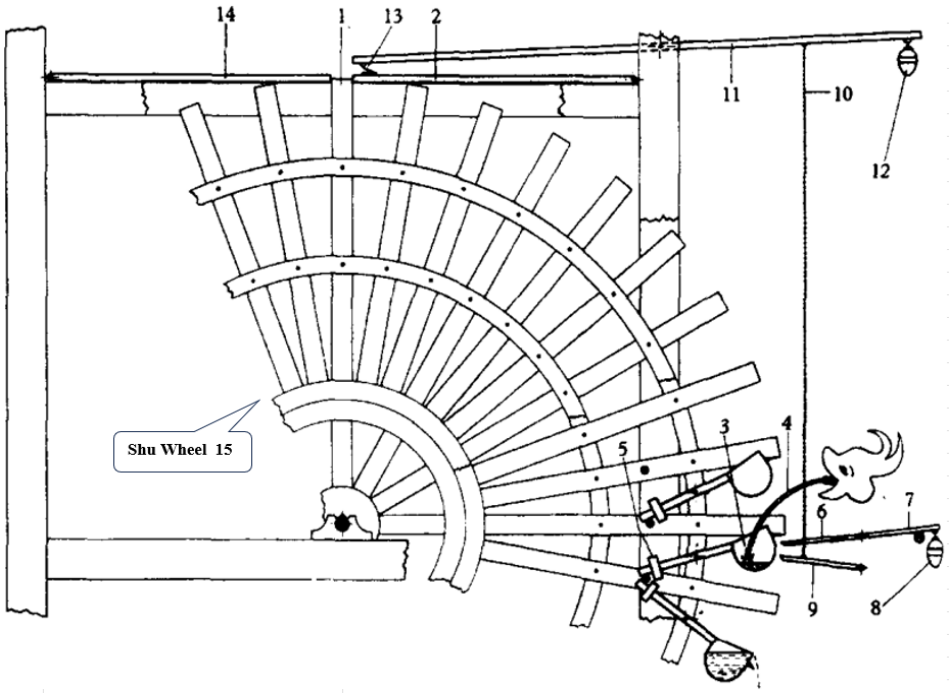
Picture 3. Distribution and connection diagram of subsystems of SYYXT

Source: Needham (2003).

the reservoir “Tianchi” 42, but at this time, the water flow is unequal in speed, quantity and pressure, and the water flow driving the “Shu Wheel” 28 must be equal in speed, quantity and pressure to ensure that the “Shoushuihu” 32 is filled at the same time. Therefore, the water in “Tianchi” 42 flows into “Pingshuihu” 43 through “Kewu” 73 (siphon method), and then flows into “Shoushuihu” 32 through another “Kewu” 105. After the “Shoushuihu” 32 is filled, its gravity overcomes the resistance force of the “Gecha” 6 in Picture 4 and rotates clockwise, triggering the operation of the “Water bucket linkage escapement device”, so that the “Shu Wheel” 28 rotates clockwise to generate motive power. During rotation, part of the water in the “Shoushuihu” 32 will overflow into the “Tuishuihu” 45, and then return to the “Shengshui Xiahu” 46 through the return pipe, completing a cycle and preparing to start a new cycle. The tooth meshing transmission, siphon technology and water lift technology in this system were all advanced technologies in the world at that time, although they had been widely used in China for a long time (Xianzhou, 1962; Needham, 2003; Chunhui, 2004; Shengchi, 1988).

(b) Motive power control system (Water bucket linkage escapement device): This is one of

the most ingenious innovations in SYYXT, and is the earliest escapement known in the world. It is not only the focus of learning, but also a major difficulty. Although its working principle is to "weigh" the weight of water from the "Pingshuihu" 43 by means of regular weighing to convert it into the required time interval, its way of time performance is similar to that of the mechanical clock, and the motive power control system formed by the linkage of the "Shoushuihu" 32, the "Guanshe" 9 in Picture 4 and the "Left Tiansuo" 2 has the same effect as the anchor shape escapement invented by Clemente, an Englishman (Weijia, 1994; Encyclopedia Britannica Company in US, 2011; Nai, 2009). In this sense, the set of "Water bucket linkage escapement device" (named by Chinese scholar Hu Weijia in 1994) developed by Su Song's team should be regarded as the originator of mechanical watch escapement.



Picture 4. Motive power control system (Water bucket linkage escapement device)

Source: Needham (2003).

Its specific working principle and process is that when the "Shoushuihu" 3 in Picture 4 is not filled with water, due to the self-weight of the "Shuquan" 8, the "Gecha" 6 will automatically tilt up against the "Shoushuihu" 3 to keep it in the normal position to accept water injection and not fall. This is the balance state of the device before operation. When the "Shoushuihu" 3 is filled with water and its weight is greater than the "Shuquan" 8, this balance is broken. The "Shoushuihu" 3 drops and contacts the "Guanshe" 9 and drove it to fall. At the same time, pull the connected "Tiantiao" 10 to fall, and the fall of "Tiantiao" 10 pulls the fall of "Tianheng" 11, so that the "Tianguan" 13 is lifted and the "left Tiansuo" 2 connected to "Tianguan" 13 is lifted at the same time. The"Shu Wheel" 15 that loses resistance rotates

clockwise under the action of gravity from the "Shoushuihu" 3. This process is called "Zong", which aims to turn the "Shu Wheel" 15. But the "Shu Wheel" 15 will not keep turning.

Because when the water in the "Shoushuihu" 3 overflows, the weight will be reduced until it is unable to overcome the weight of the "Shuquan" 8, forcing the "Gecha" 6 to tilt up again and return to its original position. At the same time, the "Guanshe" 9, "Tiantiao" 10, "Tianheng" 11, "Tianguan" 13 and "Left Tiansuo" 2 will all return to their original position under the action of gravity due to the loss of downward pull force, and return to the original equilibrium state. After the "Left Tiansuo" 2 is reset, it will again resist the spoke "Lunfu" 1, and the "Shu Wheel" 15 attempting to continue rotating will immediately stop rotating. At this time, the "Shu Wheel" 15 that rotates one spoke to the right is still the highest when it is located at the position of spoke "Lunfu" 1. The "Right Tiansuo" 14 falls under the action of its own weight and blocks the spoke "Lunfu" 1 from the left to prevent the Shu Wheel" 15 from reversing. This whole process is called "Qin", which aims to stop the "Shu Wheel" 15 from rotating. Such isochronous rotating and pausing, pausing and rotating again, cycle continuously, and its function is exactly the same as that of the escapement of the modern mechanical clock (Su Song, Song Dynasty c; Weijia, 1994; Su Song, Song Dynasty b).

(c) Motive power transmission system: this system is not difficult to understand, but it is a system with great technical difficulty. We now know that it once had some change. The initial design was the two longitudinal long shaft transmission method as shown in Picture 3. This method used a 6m long wooden shaft "Tianzhu" 38 as the main transmission shaft. The motive power from the "Digu" 35 was transferred to the main driving shaft "Tianzhu" 38 after the transmission ratio and direction were changed by the meshing gear "Tianzhu lower wheel" 37. Then it is transmitted to the gear "Boyajilun" 57 on the secondary driving shaft "Yilunzhou" 15 through the "Tianzhu middle wheel" 39 on the "Tianzhu" 38, and the "Boyajilun" 57 drove the timing-chiming system as well as the celestial phenomenon demonstration system. Because the "Tianzhu" 38 is too long and the transmission torque is too large, this design puts forward very high requirements for wood and processing technology. The requirements were so high that it directly affected the stability and accuracy of the whole machine's operation. Therefore, it was later changed to a transmission mode combining two short shafts driving and one chain driving. The specific method is shown in the "Another transmission method" in the upper right corner of Picture 3. The original main driving shaft "Tianzhu" 38 only drove the timing-chiming system and the celestial phenomena demonstration system. The 10-20-ton armillary sphere on the top floor was driven by a chain "Tianti" 102. The lower end of the "Tianti" 102 was connected to the newly added gear 104 on the "Shu Wheel" 28, and the upper end was connected to the lower gear "Tianxiagu" 127 of the gearbox "Tiantuo" 103. In this way, not only the length of "Tianzhu" 38 was shortened a lot, but also the load was greatly reduced, which ensured the normal and accurate operation of the whole machine. This design was the chain-driving technology was applied to large astronomical instruments again after Zhang Sixun (Needham, 1976; Jiaxi, 2000; Su Song, Song Dynasty c; Xianzhou, 1962).

(d) Although the timing-chiming system had six major turntables, they were all synchronously driven by the "Boyajilun" 57. Here was equipped with a set of cam control

mechanisms that operate according to a predetermined program and could also be converted into another action program according to seasonal changes. There were paddles on each wheel. When these wheels rotate to a certain position, the corresponding paddles would toggle the puppet arm fixed in the outer wooden pavilion to perform actions such as ringing the bell, drumming, shaking small bell, chiming the zheng, and hitting geng. At the same time, the other wheels would also display with corresponding puppet figures, Chinese characters, or pictures by toggling corresponding paddles (Su Song, Song Dynasty d).

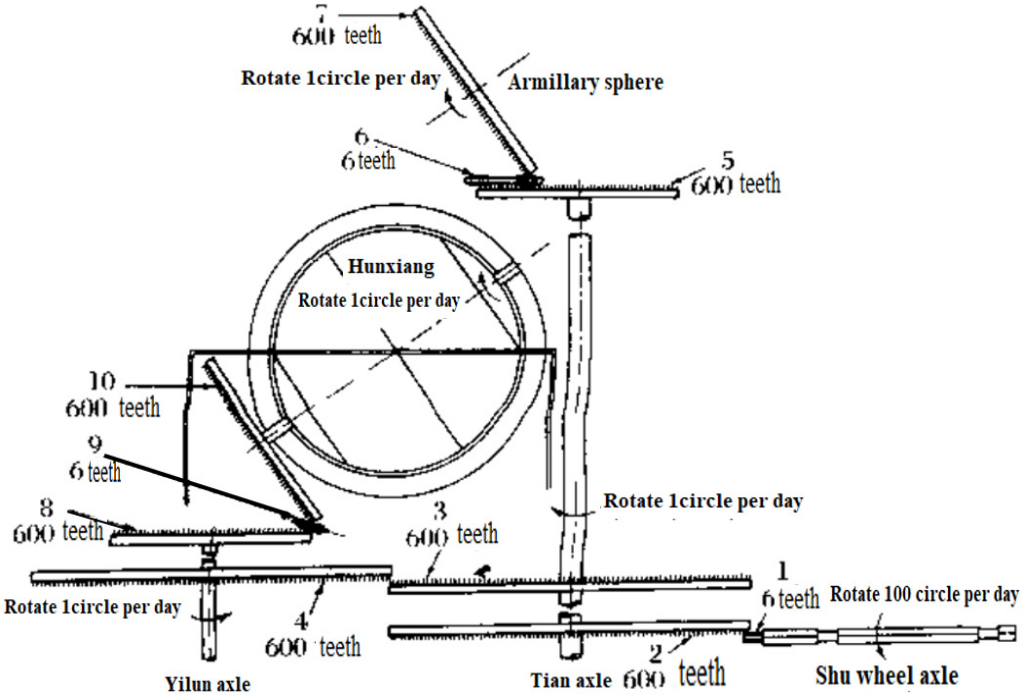
The transmission of the celestial demonstration system had two designs that were likely to had been actually used. From Picture 3, it can be seen that one design was to install the gear "Hunxiang Tianyun Wheel" 81 at the southern end of the North and south polar axis, which was meshed with the intermediate gear "Tietian Shaft" 84. The "Tietian Shaft" 84 changed the direction of rotation and transmission ratio, and received motive power from the gear "Tianlun" 18 at the top of the secondary transmission shaft "Yilunzhou" 15. Another design was that the "Tianlun" 18 directly engages with the teeth of the equatorial ring on the Hunxiang "Hunxiang Equatorial Teeth" 19. There were also two designs available for astronomical observation systems, namely the transmission of the celestial sphere was also two designs. As shown in Picture 3, one type was the "Rear Tiangu" 76 of the "Hengtian axis" 77 meshed with the "Tianzhu Upper Wheel" 41, and the "Front Tiangu" 78 meshed with the "Tianyun Ring" 10 on the armillary sphere to achieve motive power transmission. The other type was that the "Tianti Shanggu" 119 of the chain "Tianti" 102 was coaxial with the lower gear "Lower Tiangu" 127 of the gearbox "Tiantuo" 103. It meshed with the intermediate gear "Middle Tiangu" 126 and also meshed with the upper gear "Upper Tiangu" 124. The "Upper Tiangu" 124 meshed with the "Tianyun Ring" 10 on the armillary sphere (Jiaxi, 2003; Su Song, Song Dynasty c; Zhenduo, 1989; Shengchi, 1988; Nai, 2009).

The working principle and process of the last three subsystems involve complex astronomical knowledge. It is impossible and unnecessary to explain astronomy in detail in this lesson，just clarify the timing and chiming methods through video data and discussion, the process and accuracy of the celestial phenomena demonstrated by the Hunxiang Instrument, and what precise astronomical observations can be made by the armillary sphere. In order to understand this part more easily, two aspects of knowledge need to be added. The first is the knowledge of astronomical mathematics to calculate the transmission ratio of each gear, and the second is the key technology of "Shu Wheel" spoke manufacturing that has been lost. The following is a brief description.

(e) The precise calculation of astronomical mathematics in the 11th century: as early as 470 million years ago, the earth's rotation speed had slowed down to about 23 hours and 56 minutes, which was not much different from today. The ancient Chinese recognized the law of day and night time variation determined by this speed very early, and made division and calculation with Chinese characteristics. They founded Chinese astronomical mathematics and made great achievements leading the world for a long time.

The research on SYYXT of Joseph Needham, Liu Xianzhou, Wang Zhenduo and others provided us with a simple and easy explanation to understand. China divided a day into 12

shichens (1 shichen = 2 hours), a total of 100 Kes (1 ke = 1 quarter), and each shichen contains 8 and 1/3 kes. 1 ke was divided into 60 equal parts, each one was called 1"fen". Then, there were 20 fens in each shichen. In this way, each Ke is equivalent to 14 minutes and 24 seconds of today's time. As shown in Picture 5, in order to realize the "Sichen Wheel" of SYYXT display



Picture 5. Astronomical mathematics of SYYXT

Source: Needham (2003).

and report the time synchronously by combining the sound with distinct characteristics (such as bell, drum, Zheng, bell, etc.) with the puppets, Chinese characters and pictures according to the shichen, the beginning of the shichen, integral point, every quarter, sunrise, sunset, the middle of the day, midnight and 5Geng[1], so the day and night must be divided into two kinds of equal parts of 24 and 100, and the least common multiple of the two is 600. So, 7 large gears are all 600 teeth, 3 pinions are all 6 teeth. Therefore, every time the timing gear moves 1 tooth, it needs to escapement 6 times, 36 times every quarter, 300 times every shichen, 3600 times every day (Zhenduo, 1989; Needham, 1956, 2003; Shengchi, 1988; Nai, 2009).

(f) Key technologies for manufacturing Shu wheel spokes: During the SYYXT restoration process, experts encountered significant technical challenges in selecting Shu wheel spoke wood[2] and how to process it to remove moisture and deformation characteristics of wooden spokes. After experiencing multiple failures, they learned an ancient technique that was about to be lost by visiting old craftsmen in folk shipbuilding workshops, this problem was solved. The method is: the spokes are made of teak wood. After processing, heat tung oil to 160 °C,

immerse the spokes in tung oil, maintain this temperature, soak continuously for 24 hours, take them out, lay them flat, and expose them to sunlight for several hours, evaporate the water completely, and then soak and expose them again using the same method. Repeat this process more than three times until the tung oil saturates the spoke, expelling all moisture and forming a uniform and thick tung oil film on the surface, moisture in the air cannot enter the interior of the spoke again. Both experiments and facts have shown that after such shaping and determining the nature, the entire spoke can no longer be damped, inflated, distorted in the event of any changes in temperature or humidity. This also ensures that the part of the spoke immersed in water, like the part exposed to air, will not undergo deformation and decay (Zhenduo, 1989; Chunhui, 2004; Video c & d).

2.3.2.5 Historical Status and International Influence

Review the relevant content in the video and introduce it to students:

Su Song's team was an outstanding representative of scientific and technological workers in the Song Dynasty and even in the ancient history of China. The SYYXT developed by them was the earliest and most advanced large-scale astronomical observatory in the Middle Ages in the world. It integrated astronomical observation, celestial phenomena demonstration, timing, tracking and other functions. It is a comprehensive application and innovative achievement of many technologies in China at the end of the 11th century, such as astronomy, mathematics, Statics, dynamics, optics, timing science, iron and steel technology, hydraulic conversion technology, sectional driving technology, lever principle, siphon technology, engineering technology, timing and chiming technology, automatic control technology, etc. It is a manifestation and witness of the national scientific and technological strength, a symbol of the comprehensive national power of the Northern Song Dynasty, and created many world firsts (Jiaxi, 2000; Needham, 1976).

The water bucket linkage escapement device[3] is the pioneer of modern mechanical clocks and watches, which is at least 210 years ahead of the world, and the timing technology is at least more than 100 years ahead of the world. The rotating device of the armillary sphere is the embryonic form of the transfer clock of the modern observatory. The Hunxiang instrument is the ancestor of the modern stellarium. The movable roof "detachable roof" on the top of the armillary sphere is the ancestor of the automatic opening and closing dome of the modern observatory, which is more than 400 years ahead of the west, the monograph of mechanical drawings, *New Yixiang Fayao*, is the representative of the astronomical level of the Song Dynasty. It is the earliest and most complete mechanical blueprint known in the world. In its 5 star-atlas, 283 guans and 1464 stars are the earliest complete scientific star-atlas in China and the earliest and most detailed scientific star-atlas in the world. The 1464 stars in the star-atlas are 442 more than those drawn by Western Europeans 400 years later (Jiaxi, 2003; Lin, 2014). the orthographic cylindrical projection method used in the guan-star-atlas in the East and North of Hunxiang and the guan-star-atlas in the West and south of Hunxiang was first used by Mercator to draw the world map more than 450 years later[4] (Jiaxi, 2000; Weijia, 1994). The polar isometric projection method used in the Arctic and Antarctic atlas of the Hunxiang sphere is also a great initiative, which is 4 centuries earlier than the similar zenith

isometric projection method in the West (Nai, 2009). In addition, the *Bencao Tujing* (Atlas of Meteria Medica) written by Su Song is the first monograph on engraving pharmaceuticals, medicine and atlas in China, and also the first engraving medicine atlas in the world. It promoted the nature of Materia Medica from simple pharmacology to natural history, created a new era of development of Materia Medica, and made Chinese materia medica occupied an important position in the history of world science and technology (Tuotuo, Yuan Dynasty a, Yuan Dynasty d; Su Song, Song Dynasty d).

After the introduction, guide students freely discuss and the whole class exchange experience in order to deepen the understanding and emotion of this scientific and technological achievement.

2.3.2.6 Fate and Restoration

After SYYXT was put into use, it suffered many misfortunes and even was almost destroyed due to political struggle, ideological concepts and its own room for improvement. Fortunately, it survived with the strong support of Lin Xi (Tuotuo, Yuan Dynasty c; Temple, 1995). At the end of the Northern Song Dynasty, the Jin army captured Bianjing (today's Kaifeng), and SYYXT was disassembled and transported to Yanjing (today's Beijing). Because no one can repair damaged Sichen components caused by transportation, the timing and chiming function lost. Due to the difference in longitude and latitude between Yanjing and Bianjing, no one can recalibrate it, which made it unable to accurately demonstrating and observing celestial phenomena. The Jin people abandoned it in Yanjing City, and was struck by lightning and the armillary sphere fell. The Jin Dynasty was destroyed by the Yuan Dynasty. SYYXT, which had survived for more than 120 years, was completely destroyed.

After the founding of the Southern Song Dynasty, Emperor Gaozong issued an edict to re-make SYYXT. But neither Yuan Weiji, Su Song's student, nor his son Su Xie, had the skills to rebuild. Later, important officials such as Qin Hui and Zhu Xi also attempted to do this job, but all failed. As time went by, people completely forgot this great masterpiece, until the last century, British scholar Joseph Needham published his research achievements on SYYXT, professor Liu Xianzhou of Tsinghua University published 2 research papers. Wang Zhenduo, an expert in the history of Chinese machinery, put forward the proposal of restoration in 1956, but failed to realize this desire. Later, folk technologist Chen Kaige succeeded in restoring according to Wang's last wish. At present, China's Taiwan, Suzhou, Beijing, Xiamen, Shanghai, Kaifeng, Kunming etc. have various proportions of restored objects for public visit, study and research (Tuotuo, Yuan Dynasty a; Video e).

2.3.3 Summary

Guide students to review the main content learned in this lesson, use collective question and answer methods to help them summarize the key and difficult knowledge they need to master, and form a textual outline of the important items and key points for the whole class to share.

3. Conclusion

This part of teaching content is a supplement to the content of the textbook used now. It aims

to change the situation of emphasizing Political history, imperial history, and ignoring science and technology and the history of relevant figures from the perspective of the new liberal arts, and to broaden the cognition of history (normal) major undergraduates—future secondary school history teachers—on the great contributions and outstanding achievements made by ancient China in the long journey of the development and progress of human science and technology, so as to stimulate their awareness and interest on these important figures, events and achievements, as well as their enthusiasm for learning, enhancing their knowledge of science and technology history and discipline literacy, preparing them for future related teaching in secondary school classrooms. Due to the limited teaching time allocated in the teaching plan of this course and the scarcity of restored SYYXT physical objects, this course can only be implemented through a combination of historical materials, videos, explanations and discussions. So, the content arrangement mainly focuses on basic knowledge and a general understanding of key components and technologies.

Through this part of studying, students will have a basic understanding of this world leading achievement in the Northern Song Dynasty, which is very helpful to view the scientific and technological level and comprehensive national power of the Bei Song in history, and can also accumulate necessary knowledge and methods for future history teaching in the Song Dynasty. Due to the focus of this article being on improvement of teaching content and methods rather than the history of science and technology itself, controversial issues are not discussed and are either explained separately or simply ignored. All pictures are also directly selected from various trustworthy resources based on intuitive, clear, and convenience for teaching. The structural design and content arrangement of this article are not a standardized and complete teaching design, but rather an experimental plan that highlights the key and difficult points of teaching, serving the teaching motivation and goals, aiming to throw bricks and attract jade.

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Notes

Note 1. Ancient China, one night was divided into 5 gengs, each geng lasting 2 hours. The start and end times for gengs were 19:00 and 5:00 respectively.

Note 2. There are 72 spokes and 96 spokes recorded in different editions of the existing "*New Yixiang Fayao*". Accordingly, the number of "Shoushuihu" had also two kinds of data: 36 and 48.

Note 3. The earliest record of the escapement mechanism in ancient China is about 723 A.D., which was invented by Yixing monk and Liang Lingzan. See Joseph Needham's *History of science and technology in China·Astronomy and meteorology volume*, p. 443.

Note 4. Hu Weijia, a Chinese scholar, once objected to this theory in his paper "*On the "Escapement" and star-Mapping in the XIN YIXIANG FAYAO*", but the mainstream view was that Joseph Needham's view was tenable. Pan Nai also adopted this view in History of stellar observations in China, so this view was adopted in this course.

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Authors contributions

Dr. Jianguang Yao was responsible for study design and revising, and drafted the manuscript. Prof. Lingfei Chen collated research materials and proofread English expression.

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