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THE SCIENTIFIC HERITAGE OF ABU RAYHAN BIRUNI AND ITS ROLE IN THE DEVELOPMENT OF WORLD SCIENCE

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ABOUT ARTICLE

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Abstract: This article analyzes the life, scientific activities, and immense contribution to world science of Abu Rayhan Beruni-a brilliant encyclopedic scholar and prominent representative of the Eastern Renaissance in Central Asia during the 9th-12th centuries-based on modern scientific and methodological approaches. Furthermore, it scientifically substantiates the contemporary relevance of studying the scholar's heritage and its role in the upbringing of the younger generation.

Introduction. Significant progress is being made in Uzbekistan toward building a democratic state governed by the rule of law and a free civil society, liberalizing all spheres of public life, implementing comprehensive reforms, modernizing the country, and ensuring its deeper integration into the international community. In this process, the rich and ancient cultural, educational, philosophical, and scientific heritage of our people, which constitutes an important part of the treasury of universal human civilization, holds particular significance.

President Shavkat Mirziyoyev has repeatedly emphasized that an in-depth study of the rich scientific legacy left by our ancestors—including manuscripts in mathematics, astronomy, medicine, physics, literature, and philosophy—serves as a vital foundation for strengthening the New Uzbekistan. He has also underscored that the lives and achievements of great scholars represent an exemplary school for shaping the worldview of young people and fostering their intellectual maturity. As he stated: “Every nation takes pride in its history. However, nowhere

else is there a history as rich as ours or scholars as great as our ancestors. We must study this heritage profoundly and present it to our people and to the world."[1].

Among the outstanding representatives of the early medieval scientific tradition, Abu Rayhan al-Biruni occupies a unique position as one of the greatest scholars in the history of world civilization. Possessing an extraordinary intellectual legacy, he made fundamental contributions to the advancement of global science and significantly influenced the development of numerous branches of knowledge. An objective study and critical analysis of al-Biruni's vast scholarly heritage, together with the translation and interpretation of his works and the systematic investigation of his philosophical and natural-scientific ideas, remain among the most important priorities of contemporary academic research.

Renowned for his encyclopedic scholarship, Abu Rayhan al-Biruni (973–1048) made remarkable contributions to virtually every major field of science of his time. He occupied a distinguished place within the Khwarazm Ma'mun Academy, where his exceptional intellectual achievements played a pivotal role in the advancement of scientific inquiry and the flourishing of the academy's scholarly tradition.

The theoretical and methodological foundation of this study is based on the rich scientific and philosophical legacy of Abu Rayhan al-Biruni, as well as a wide range of primary and secondary sources devoted to examining his outstanding contributions to the development of world civilization. To provide a comprehensive understanding of the research topic, relevant historical sources and scholarly literature were systematically reviewed and comparatively analyzed. The study employs a comparative-historical approach, textual analysis, and critical interpretation to evaluate al-Biruni's intellectual heritage within its historical context and to assess its significance from the perspective of contemporary scholarship.

Primary Sources and Historical-Documentary Foundations. Primary historical sources constitute the principal basis for examining the life, scholarly activities, and personal qualities of Abu Rayhan al-Biruni. In particular, Abu al-Fazl Bayhaqi's Tarikh-i Mas'udi was employed as a primary source, as it provides valuable contemporary evidence of al-Biruni's exceptional intellectual abilities. The work highlights the high esteem in which he was held by his contemporaries for his profound knowledge of geometry, philosophy, and his ability to comprehend the essence of natural phenomena. In addition, the biographical accounts of Yaqut al-Hamawi were analyzed using a historical-retrospective approach to examine al-Biruni's lifelong commitment to scientific inquiry, his way of life, and his remarkable perseverance in pursuing knowledge until the final moments of his life.

Contemporary Approaches to the Study of the Early Medieval Eastern Renaissance and al-Biruni's Legacy. The present study also draws upon the works of both Uzbek and international scholars devoted to the encyclopedic legacy of al-Biruni and his contributions to the natural sciences. Particular attention was given to G. K. Masharipova's monograph The Scientific Heritage and Philosophical Views of Abu Rayhan al-Biruni, which provides a comprehensive analysis of the integration of philosophical thought and the exact sciences in al-Biruni's intellectual system. Furthermore, P. Shermukhamedov's The Birth of a Genius, or the Fate of Abu Rayhan al-Biruni, A. Otokhojayev's Abu Rayhan al-Biruni, and H. Hasanov's Scholar-Travellers were extensively utilized as secondary scholarly sources. These studies offer valuable interpretations of al-Biruni's geodetic measurements, geographical predictions, and scientific expeditions, thereby contributing to a deeper understanding of his role in the development of medieval science.

Methodology. To ensure the scientific rigor and objectivity of the study, the following methodological principles and research methods were employed:

- Historical-comparative analysis. Al-Biruni's geodetic measurements for determining the Earth's dimensions were comparatively analyzed alongside the achievements of prominent scholars of antiquity, including Pythagoras, Aristotle, Archimedes, and Eratosthenes, as well as those of leading representatives of the Islamic Renaissance, such as Muhammad al-Khwarizmi, Khalid al-Marwarrudi, and Abu ibn Isa al-Asturlabi. This comparative approach made it possible to evaluate the originality and scientific significance of al-Biruni's methodology within the broader historical development of geodesy and mathematical geography.

- Mathematical and quantitative analysis. Al-Biruni's calculations based on the angle of the visible horizon depression and the length of one degree of the meridian, obtained during his observations at the Nandana Fortress, were examined in parallel with modern geodetic parameters. Their degree of accuracy was assessed through logical and quantitative analysis by comparing the historical calculations with contemporary scientific measurements and determining the corresponding margin of error.

- Systematic and objective approach. In accordance with the principles of source criticism, the available historical and scholarly evidence was critically evaluated and systematically synthesized to identify the distinctive features of al-Biruni's scientific methodology, epistemological principles, and worldview. This approach ensured a comprehensive and unbiased assessment of his contribution to the development of medieval science and the history of scientific thought.

Results. The Eastern Renaissance and the Scholarly Environment of the Khwarazm Ma'mun Academy. The socio-cultural and intellectual revival that took place in Central Asia between the ninth and twelfth centuries is widely recognized as the first phase of the Eastern Renaissance. During this period, the Khwarazm Ma'mun Academy emerged as one of the leading centers of scientific scholarship in the Islamic world. According to historical sources, Abu Rayhan al-Biruni served as the Academy's principal scientific leader. Within this vibrant intellectual environment, he conducted pioneering research and produced groundbreaking achievements in the natural and exact sciences, many of which significantly influenced the subsequent development of scientific knowledge.

Foundations of Geodesy and High-Precision Measurements. One of al-Biruni's most remarkable scientific achievements was the composition of his celebrated treatise Geodesy, which is widely regarded as a foundational work in the development of geodesy as an independent scientific discipline. Among its most significant contributions are his calculations concerning the length of one degree of the Earth's meridian.

- Modern geodetic measurements: approximately 110,275 m per degree of the Earth's meridian.

- Al-Biruni's calculation: approximately 110,895 m per degree.

The difference between al-Biruni's estimate and the currently accepted value is only about 620 m, corresponding to an error of less than 0.6%. Considering the absence of modern measuring instruments and computational techniques in the eleventh century, this level of precision represents an extraordinary scientific achievement and demonstrates the exceptional accuracy of his observational and mathematical methods.

Geographical Discoveries and Scientific Predictions. Theoretical Anticipation of the American Continent. One of the most remarkable aspects of al-Biruni's geographical thought is his theoretical assumption that a vast landmass must exist in the Western Hemisphere to maintain the balance of the Earth's known continents. This hypothesis, formulated in the eleventh century, preceded the European voyages of exploration by nearly five centuries and is regarded by many historians of science as an outstanding example of scientific reasoning based on geographical and mathematical principles. Historical accounts also suggest that the works of Eastern scholars, including al-Biruni, were known to European intellectual circles and may have been consulted during the period preceding Christopher Columbus's transatlantic expeditions.

Construction of a Terrestrial Globe. For many years, the prevailing view in the history of science held that the first terrestrial globe in Europe was constructed by the German

cartographer Martin Behaim in 1492. However, historical evidence indicates that approximately five centuries earlier, in 995, al-Biruni had already designed and constructed a scientifically grounded terrestrial globe. This achievement reflects not only his advanced understanding of the Earth's geometry but also his outstanding contributions to cartography, mathematical geography, and geodesy.

Discussion. Al-Biruni's extraordinary scientific talent became evident at an early age. From his youth, he devoted considerable time to systematic observations of natural phenomena and astronomical events. Historical records indicate that, while still a child, he designed and constructed astronomical instruments and later undertook the determination of the geographical coordinates of various locations in Khwarazm. Between 995 and 996, he carried out a series of astronomical observations in the city of Kath (Kot) using a circular observational instrument with a diameter of 15 zira (approximately 7.35 m, based on one zira being about 49 cm) together with other precision instruments. These early investigations laid the foundation for his later achievements in astronomy, geodesy, and mathematical geography.

A total of 152 works are attributed to al-Biruni, although only about 30 have survived to the present day. His scholarly output demonstrates an exceptional breadth of intellectual interests: approximately 70 works concern astronomy, 20 mathematics, 12 geography and geodesy, 4 mineralogy, 1 physics, 1 pharmacology, 15 history and ethnography, 4 philosophy, and 18 literature. His encyclopedic scholarship was further strengthened by his remarkable linguistic abilities. At the age of fifty, he mastered Sanskrit in order to study Indian scientific and philosophical texts in their original language. In addition, he possessed a command of Persian, Arabic, Hebrew, and Greek, enabling him to engage critically with diverse intellectual traditions and significantly expanding the scope of his comparative scientific research [4:10].

The concept of a spherical Earth had been proposed long before al-Biruni by eminent scholars of antiquity, including Pythagoras, Aristotle, Archimedes, and Eratosthenes. Among them, Eratosthenes of Cyrene made the first known scientific attempt to determine the Earth's size in the third century BCE. By estimating the distance between Alexandria and Syene (modern Aswan) from caravan travel times and comparing it with the difference in the solar zenith angle observed at the two locations, he calculated the Earth's radius to be approximately 6,840 km. On this basis, he estimated the Earth's meridional circumference to be close to 39,500 km, an achievement that represented one of the greatest scientific accomplishments of the ancient world.

Following Eratosthenes, scholars in Egypt, China, and Greece continued refining methods for measuring the Earth's dimensions. During the Islamic Golden Age, Central Asian

scholars made particularly significant contributions to this field. Among them, Muhammad al-Khwarizmi demonstrated that the length of one degree of the Earth's meridian is approximately 111.8 km, thereby providing a more refined estimate that influenced subsequent developments in geodesy and mathematical geography [10].

The House of Wisdom (Bayt al-Hikma) in Baghdad, widely regarded as the foremost scientific institution of its time, brought together leading scholars from across the Islamic world. Among the distinguished Central Asian scientists associated with the institution were Muhammad al-Khwarizmi, Ahmad al-Farghani, Habash al-Hasib, and Khalid al-Marwarrudi, all of whom made significant contributions to mathematics, astronomy, and related sciences. According to historical accounts, Abu Rayhan al-Biruni was also affiliated with the House of Wisdom, where he conducted scholarly research for approximately seven years. Al-Biruni records that, under the orders of the Abbasid Caliph al-Ma'mun, the Academy's scholars were divided into two research teams to determine the Earth's dimensions by measuring one degree of the meridian in the Sinjar Plain, west of Mosul (present-day Iraq). One expedition was led by Khalid al-Marwarrudi, while the other was headed by Abu ibn Isa al-Asturlabi. Each group independently calculated the length of one degree of the Earth's meridian based on its own field measurements.

The first expedition obtained a value of approximately 111.815 km for one degree of the meridian, whereas the second produced a result approximately 1.315 km smaller. Al-Biruni attributed this discrepancy to differences in measurement techniques and expressed his intention to verify these results independently. He selected the Dehistan Plain, located in the southeastern region of the Caspian Sea, as a suitable site for conducting his own geodetic survey. However, due to the lack of financial support and qualified assistants, he was unable to carry out the proposed expedition [10].

Al-Biruni recognized the practical limitations of the traditional degree-measurement method, which required extensive flat terrain, long-distance surveying over several tens of kilometers, considerable financial resources, and lengthy preparation. Consequently, he proposed an innovative alternative based on trigonometric and astronomical observations. As he explained:

“The circumference of the Earth can be determined without traversing vast deserts. One should ascend a high mountain located near a plain or the seashore and, at sunrise or sunset, when half of the solar disk is visible above the horizon, measure the angle of the visible horizon's depression using an armillary instrument.”

He further demonstrated this method through geometric diagrams and mathematical formulas, showing that the angle formed between the observer's horizontal line of sight and the apparent horizon could be used to calculate the Earth's radius with remarkable precision.

One of al-Biruni's greatest scientific achievements was the development of this original method for determining the Earth's size. Applying trigonometric principles, he calculated the length of one degree of the Earth's meridian to be approximately 111.16 km and estimated the Earth's meridional circumference at about 40,183 km. For the scientific instruments and mathematical techniques available in the eleventh century, these results represent an extraordinary level of precision.

During one of Sultan Mahmud of Ghazni's military campaigns to the Indian subcontinent, al-Biruni accompanied the royal expedition and temporarily resided near Multan. Taking advantage of this opportunity, he conducted a series of geodetic observations at the Nandana Fortress, located approximately 400 km west of Multan in present-day Pakistan. He first determined the geographical latitude of the site (approximately 32°00′ N) and subsequently measured the angle of the horizon's depression from the summit of a nearby mountain. Al-Biruni described the observation as follows:

“While residing at the fortress of Nandana in India, I observed a high mountain to the west and an extensive plain to the south. There I decided to test this method. From the summit, I clearly observed the point where the Earth appeared to meet the azure sky. The line of sight was depressed by 0°34′ below the horizontal. I then measured the height of the mountain, which amounted to 652.055 gaz, according to the local unit of measurement” [10].

Using these measurements, al-Biruni calculated the Earth's radius to be 12,803,337.036 gaz. Assuming one gaz equals approximately 0.4933 m, this corresponds to an Earth radius of approximately 6,315.9 km. Compared with the currently accepted mean value, the error is less than 1%, demonstrating the remarkable accuracy of his calculations. He further determined that the length of one degree of the meridian at the latitude of 32°00′ was approximately 223,550.329 gaz, or 110.277 km. When compared with the modern geodetic value of approximately 110.895 km, the difference amounts to only 618 m. Achieving such a high level of precision nearly one thousand years ago stands as one of the most outstanding accomplishments in the history of medieval geodesy and mathematical geography [10].

The determination of the Earth's circumference, as proposed by al-Biruni, represented a more accurate and practical approach compared with the traditional method of measuring meridian arcs through extensive land surveys. By applying trigonometric principles to

determine mountain elevations and astronomical distances, al-Biruni achieved results that surpassed the accuracy of many earlier astronomers.

Regarding the calculation of the Earth's circumference, al-Biruni explained his method as follows:

“To determine the length of the Earth's circumference, in all cases it is sufficient to double the obtained radius and multiply it by 22. Then divide the resulting product by 7, and the length of the Earth's circumference will be obtained in the units used for measurement.”

Applying the procedure described by al-Biruni, the circumference of a circle can be calculated according to the formula $L = 2\pi R$, where the fraction 22/7 represents an approximation of the mathematical constant π (pi).

Through his own observations and calculations, al-Biruni determined the geographical latitudes of numerous cities. For example, he calculated the latitude of Ghazna as 33°35′, Kandahar as 33°55′, and Dumpar as 34°20′. According to his calculations, the latitude of Bukhara was determined as 39°20′, while the modern value is approximately 39°46′. Thus, the difference between al-Biruni's calculation and the contemporary measurement is only about 26 arc minutes, demonstrating the remarkable precision of his astronomical and geodetic methods [10].

Therefore, the study and dissemination of the scientific and cultural heritage of the great scholar Abu Rayhan al-Biruni represent an important continuation of the intellectual values and traditions inherited from our ancestors. As noted by President Shavkat Mirziyoyev: “It is extremely difficult to fully assess the unparalleled discoveries created through the scientific genius of the great encyclopedic scholar Abu Rayhan al-Biruni. Although only 31 of his more than 150 scientific works have survived to the present day, even these incomplete manuscripts provide clear evidence of the extraordinarily diverse and profound legacy he left behind” [2].

The socio-cultural and intellectual development that took place in Central Asia during the ninth–twelfth centuries should be regarded as one of the most remarkable and productive manifestations of the early stage of the Eastern Renaissance. Indeed, contemporary scholars from both Eastern and Western academic traditions identify the prominent representatives of this Renaissance primarily among the scholars who emerged from this region and made outstanding contributions to global science and culture.

Historical sources indicate that Abu Rayhan al-Biruni served as the scientific leader of the Khwarazm Ma'mun Academy. His scholarly activities within this institution constituted a crucial stage in his intellectual development. Alongside other distinguished scholars of the

Academy, al-Biruni made groundbreaking discoveries in both the natural and social sciences, thereby becoming one of the most influential figures in the history of world scholarship.

Al-Biruni authored his renowned work Geodesy, which laid the foundation for the scientific discipline of the same name. One of his remarkable achievements was his anticipation of the existence of an unknown landmass in the Western Hemisphere—later identified as the American continent—as early as the eleventh century, approximately 450 years before European explorers. He repeatedly discussed this possibility in his writings based on mathematical and geographical reasoning. Historical studies suggest that Christopher Columbus, during his long preparations for his transatlantic voyages, was familiar with the works of Eastern scholars and travelers, including those of al-Biruni [6:21].

For many years, European scholars maintained the view that the first terrestrial globe was created by the German scholar Martin Behaim in 1492. However, historical evidence demonstrates that approximately five centuries earlier, in 995, Abu Rayhan al-Biruni had already constructed a scientifically based model of the Earth [8:49].

It should be emphasized that, during this period, the Karakhanid dynasty had firmly established its authority in Transoxiana (Mawaraunnahr). Meanwhile, in the territories between the Amu Darya River and India, the power of Mahmud of Ghazni was expanding rapidly, creating political instability and posing a threat to the Abbasid Caliphate, the Karakhanids, and the Ma'munid state of Khwarazm. In 1017, Mahmud of Ghazni (998–1030) conquered Khwarazm, brought an end to the Ma'munid dynasty, and appointed his own governors to administer the region. In the same year, al-Biruni, together with other prominent scholars, was taken to Ghazna under these circumstances [9].

Thus, al-Biruni spent the final and, at the same time, one of the most productive periods of his life in Ghazna. Historical sources indicate that during the early years of his residence there, he experienced considerable difficulties but demonstrated remarkable resilience and intellectual perseverance. Subsequently, al-Biruni gradually resumed his scientific investigations, producing many of his most significant works during the reigns of Mahmud of Ghazni's successors, Mas'ud (1030–1041) and Ma'dud (1041–1048).

Al-Biruni's scientific achievements and written works received high recognition even during his own lifetime. For instance, the renowned historian Abu al-Fazl Bayhaqi stated:

"Master Abu Rayhan possessed such profound knowledge in oral traditions, understanding the essence of things, geometry, and philosophy that no one of his time could be considered his equal" [3].

Similarly, numerous scholars from both Eastern and Western academic traditions—including J. Reynaud, E. Sachau, G. Suter, E. Wiedemann, C. Nallino, G. Sarton, R. Wright, M. Meyerhof, S. H. Nasr, M. Kozim, S. Baraniy, M. Nizamuddin, and Sh. Yaltkaya—highly evaluated al-Biruni's intellectual legacy. The American historian of science George Sarton gave one of the highest assessments of al-Biruni's contribution, describing him as one of the greatest scientific minds of his era and considering him among the foremost scholars of the medieval world. The distinguished Orientalist Ignaty Krachkovsky, while evaluating al-Biruni's heritage, emphasized the extraordinary breadth of his knowledge by stating that "it is easier to list the fields of science in which he was not interested than those in which he was interested" [5:109].

Beyond the study of al-Biruni's scientific and intellectual heritage, his personal life and way of living also provide valuable lessons for contemporary generations. His dedication to scientific inquiry until the final moments of his life, his authorship of more than one hundred scientific and philosophical works, and his ability to overcome numerous hardships through patience, determination, and perseverance represent an exemplary model of intellectual commitment.

Particularly noteworthy are al-Biruni's interactions with Mahmud of Ghazni, including the intellectual challenges imposed by the ruler and the scholar's ability to respond to such situations with exceptional wisdom and ingenuity. These episodes demonstrate not only his scientific knowledge but also his extraordinary analytical thinking and practical intelligence.

One such example is the well-known intellectual challenge posed by Sultan Mahmud. According to historical accounts, the ruler once attempted to test al-Biruni by asking: "I have hidden something in my mind; tell me what it is. The palace has twelve doors—through which one will I leave and through which will I enter?" After careful consideration, al-Biruni wrote his answer on a sheet of paper and folded it without revealing its contents. The Sultan then ordered a new opening to be created in the palace wall, exited through that newly constructed passage, and later returned through a door of his choice. When he opened al-Biruni's written response, he found the following words:

"The palace wall will be opened, a new door will be created, and the ruler will exit through it and return through whichever door he chooses."

According to the account, the Sultan became even more frustrated by al-Biruni's intelligence and ordered his vizier to throw the scholar from the palace roof. However, Khwaja Hasan, who deeply respected al-Biruni, secretly prevented the execution and saved his life. Several days later, Sultan Mahmud regretted his decision and expressed remorse. Khwaja Hasan then informed the Sultan that if al-Biruni were granted pardon, he would return to the

court. Following his reinstatement, al-Biruni resumed his scholarly activities at the palace [7:54–55].

Another remarkable example demonstrating al-Biruni's lifelong devotion to knowledge is related to his final days. According to historical accounts, his friend Qadi al-Walwaliji once discussed with him a complex issue concerning al-Jaddat al-Fasida, a branch of Islamic inheritance law dealing with the distribution of inheritance. However, their conversation remained unfinished for certain reasons. Several years later, when al-Walwaliji visited al-Biruni, who was already on his deathbed, the scholar—despite suffering from severe weakness, difficulty breathing, and physical exhaustion—asked his friend to explain that same unresolved issue. When his friend suggested postponing the discussion due to al-Biruni's critical condition, the scholar refused, stating:

"O fortunate companion! Everyone who comes into this world must eventually depart from it. I am now leaving this world. Is it not better for me to depart knowing the answer to this question rather than leaving it unresolved?"

After receiving the explanation from his friend, al-Biruni expressed his own scholarly opinion on the matter and continued the discussion until his final moments before passing away [7:56].

The examples presented above demonstrate that al-Biruni remained devoted to intellectual activity and scientific inquiry throughout his entire life. Describing al-Biruni's later years, Yaqut al-Hamawi noted that the scholar was never seen without a pen in his hand, without contemplation in his eyes, or without intellectual reflection in his mind. According to al-Hamawi, al-Biruni made no distinction between periods of rest and labor, day and night, except on two annual occasions—Nowruz (the spring New Year celebration in March) and Mihrjan (the autumn harvest festival)—when he would prepare only enough food and clothing for his basic needs.

By 1048, during the final period of his life, al-Biruni's health had significantly deteriorated, and his eyesight had weakened. Nevertheless, his scientific achievements and discoveries had already transformed the intellectual landscape of his era. His works contributed greatly to the advancement of numerous scientific disciplines and later played an important role in awakening and enriching European scientific thought through the study and translation of his writings. Each of al-Biruni's works was created with a unique intellectual spirit, profound enthusiasm, and an unwavering commitment to scientific truth. Consequently, his writings continue to inspire admiration and intellectual curiosity among readers and researchers.

Conclusion. In conclusion, the encyclopedic scientific heritage of Abu Rayhan al-Biruni and his unwavering commitment to the pursuit of knowledge represent one of the most remarkable achievements of the early medieval Eastern Renaissance. His continuous scientific investigations until the final moments of his life and the extensive written legacy he left behind demonstrate his exceptional sense of responsibility toward science and humanity.

The analysis conducted in this study shows that al-Biruni's contributions to the natural sciences—particularly his foundational role in the development of geodesy, his highly accurate determination of the Earth's meridian measurements, and his advanced geographical theories—surpassed the scientific boundaries of his time and provided a strong foundation for the subsequent development of modern science.

Furthermore, al-Biruni's perseverance, intellectual dedication, and ability to continue creative scientific work despite severe historical challenges and personal hardships represent a profound example of moral strength and scholarly commitment. His life and achievements remain an enduring model of intellectual integrity, determination, and devotion to knowledge.

A comprehensive study and dissemination of al-Biruni's scientific-philosophical legacy among younger generations remains highly relevant in the contemporary era of globalization. It serves as an important means of promoting the principle of "enlightenment against ignorance", fostering critical thinking, strengthening intellectual awareness, and cultivating a sense of responsibility and patriotism among future generations.

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