

EMPIRICAL KNOWLEDGE AND METHODOLOGICAL PRACTICES IN MEDIEVAL CENTRAL ASIAN SCIENCE

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Abstract. *This study explores the emergence and methodological foundations of empirical knowledge in medieval Central Asian science. Rather than equating empiricism exclusively with modern laboratory experiments, it treats the concept as an interconnected practice involving observation, experience, measurement, calculation, comparison of evidence, verification, and instrumental precision. An examination of the intellectual heritage of al-Biruni, Ibn Sina, Ulugh Beg, al-Khwarizmi, and al-Farabi demonstrates that scholars of the region did not depend on texts and established authorities alone. They also investigated natural processes, the human body, celestial objects, geographical distances, minerals, and social evidence. The findings indicate that the interaction of theoretical reasoning with practical inquiry formed the methodological basis of empirical knowledge in medieval Central Asian science.*

Keywords: *empirical knowledge, Central Asia, al-Biruni, Ibn Sina, Ulugh Beg, al-Khwarizmi, observation, experience, measurement, scientific methodology*

Annotatsiya. *Ushbu maqolada oʻrta asrlar Markaziy Osiyo ilmiy fanida empirik bilimning yuzaga kelishi va metodologik asoslari tadqiq*

etiladi. Empirizm tushunchasi faqat zamonaviy laboratoriya tajribasiga tenglashtirilmay, kuzatuv, tajriba, o'lchash, hisoblash, dalillarni qiyoslash, tekshirish hamda asboblarning vositasida aniqlikka erishishdan iborat o'zaro bog'liq amaliyot sifatida yoritiladi. Beruniy, Ibn Sino, Ulug'bek, Xorazmiy va Forobiy ilmiy merosi tahlili mintaqa olimlari matnlar va tan olingan autoritetlar bilangina cheklanmaganini ko'rsatadi. Ular tabiat hodisalari, inson organizmi, osmon jismlari, geografik masofalar, minerallar va ijtimoiy dalillarni ham o'rganganlar. Tadqiqot natijasida nazariy tafakkur bilan amaliy izlanish uyg'unligi empirik bilimning metodologik negizini tashkil etgani asoslanadi.

Kalit so'zlar: empirik bilim, Markaziy Osiyo, Beruniy, Ibn Sino, Ulug'bek, Xorazmiy, kuzatuv, tajriba, o'lchash, ilmiy metodologiya

Аннотация. В статье исследуются становление и методологические основы эмпирического знания в средневековой науке Центральной Азии. Эмпиризм не сводится исключительно к лабораторному эксперименту в его современном понимании, а рассматривается как взаимосвязанная практика наблюдения, опыта, измерения, вычисления, сопоставления доказательств, проверки и инструментальной точности. Анализ научного наследия Бируни, Ибн Сины, Улугбека, Хорезми и Фараби показывает, что ученые региона не ограничивались текстами и признанными авторитетами. Они также изучали природные процессы, человеческий организм, небесные тела, географические расстояния, минералы и социальные свидетельства. Установлено, что взаимодействие теоретического мышления с практическим исследованием составляло методологическую основу эмпирического знания в средневековой центральноазиатской науке.

Ключевые слова: эмпирическое знание, Центральная Азия, Бируни, Ибн Сина, Улугбек, Хорезми, наблюдение, опыт, измерение, научная методология

INTRODUCTION. The place of empirical knowledge in medieval Central Asian science cannot be understood adequately through a rigid contrast between “traditional” and “modern” forms of inquiry. Within the scholarly environments of Khwarazm, Bukhara, Samarkand, Farghana, and the wider Islamic East, inherited texts were important but did not constitute the only basis of scientific judgment. Scholars referred to Aristotle, Ptolemy, Galen, and earlier Muslim thinkers, yet propositions received from these authorities could still be reassessed by means of observation, computation, comparison, and practical examination. Empirical inquiry in this setting should therefore be understood as a broad intellectual discipline rather than merely as experiment conducted under modern laboratory conditions. It required the scholar to observe a phenomenon, quantify it whenever possible, compare information derived from several channels, verify or repeat the result, and place the conclusion within a consistent explanatory system.

This pattern of knowledge production is particularly evident in the works and scholarly activity of Abu Rayhan al-Biruni, Ibn Sina, Mirzo Ulugh Beg, Muhammad al-Khwarizmi, and Abu Nasr al-Farabi. Al-Biruni brought together astronomy, geography, mineralogy, historical inquiry, and the study of cultures. Ibn Sina offered a highly developed account of experience in both medicine and logic. Ulugh Beg and the astronomers of Samarkand turned systematic observation into numerical exactness through measurements undertaken at the observatory. Al-Khwarizmi joined abstract algebraic procedures to geometrical proof, thereby giving calculation a demonstrable form. Although al-Farabi is

more often approached as a philosopher concerned with logic and metaphysics, his epistemology also presented knowledge as a progression from sensory perception to rational demonstration [Masykur, 2025, p. 95–96].

The importance of the subject derives from the need to reconsider the assumption that medieval Central Asian intellectual life was essentially textual, speculative, or theological. Religious and philosophical concepts undoubtedly influenced the vocabulary and framework of scholarly inquiry, but they did not prevent the development of practices grounded in experience. Recent scholarship on the formation of Islamic civilization in Central Asia similarly indicates that the intellectual culture of the region evolved through the interaction of local traditions, Islamic ideas, and wider transregional influences [Ungalov, 2025, p. 75–88]. Such an environment encouraged the combination of inherited learning with the direct study of observable reality.

Accordingly, the central question of this article is how empirical knowledge was conceptually understood in medieval Central Asian scientific thought and through which scholarly practices it was produced. The purpose is to determine the principal components of this methodological tradition and to explain how observation, experimentation, measurement, comparison, and theoretical verification functioned as parts of a unified intellectual process.

METHODS. The research draws on historical-analytical, comparative, source-critical, and conceptual approaches. The historical-analytical method allows empirical practices to be interpreted within the intellectual conditions of their own period, avoiding the uncritical transfer of modern notions of experimental science to a medieval setting. The comparative approach is used to differentiate several forms of

evidence-based inquiry, including observation of nature, medical experience, mathematical modelling, instrument-assisted measurement, and the comparative assessment of sources. Source criticism is particularly important because modern accounts of medieval science sometimes overstate its direct continuity with contemporary science, while others underestimate the scholarly significance of medieval observation and practical testing.

The investigation is organized around the concepts of observation, experiment, measurement, verification, instrumental accuracy, quantification, and comparative evidence. Observation is understood as the direct or systematic recording of natural, medical, astronomical, geographical, and social phenomena. Experiment refers to the intentional testing of a proposition under identifiable conditions, most clearly visible in medical, pharmacological, and mineralogical practice. Measurement denotes the numerical determination of a phenomenon by mathematical, geometrical, or instrumental means. Verification is treated as the procedure through which a theoretical proposition is compared with an observed or measured reality.

The sources were chosen on the basis of their relevance to the subject, bibliographical transparency, and the presence of identifiable page references. Particular attention was paid to the precision of pagination. Publications in which the required pages could not be clearly established were not treated as primary evidence. Whenever the consulted studies supplied exact page locations, references were inserted directly in square brackets.

The principal body of scholarship used in the article addresses al-Biruni's historical and empirical procedures, Ibn Sina's medical and logical conception of experience, Ulugh Beg's astronomical observations,

al-Khwarizmi's mathematical demonstrations, and al-Farabi's theory of knowledge. Studying these intellectual traditions together makes it possible to identify not one isolated technique, but a broader methodological culture in which sensory evidence, calculation, instruments, and rational proof complemented one another.

RESULTS. The first major finding is that empirical knowledge in medieval Central Asian science took shape as a composite methodological system rather than as a single standardized technique. This system operated on at least three closely connected levels: observation of natural or social phenomena, experimental or comparative verification, and mathematical-instrumental measurement. The levels reinforced one another. Observation generated the initial body of information; experiment and comparison helped establish its reliability; measurement converted it into a more stable and reproducible record; and theoretical reasoning supplied an intelligible explanation of the result.

Al-Biruni's intellectual activity offers perhaps the most comprehensive example of this methodological structure. In his investigation of India, he did not merely reproduce reports transmitted by earlier writers. The relevant scholarship indicates that he combined textual materials, oral testimony, and observations made in the field. In modern methodological language, this use of several independent types of evidence resembles data triangulation [Putri, Yasmin, 2026, p. 394]. Consequently, al-Biruni's historical account went beyond description: his treatment of Indian religion, culture, geography, and learning was shaped by source criticism, first-hand observation, and comparison [Putri, Yasmin, 2026, p. 395]. This interpretation is reinforced by the conclusion that his method anticipated the verification of information through multiple evidentiary channels [Putri, Yasmin, 2026, p. 400].

Measurement occupied an even more prominent place in al-Biruni's studies of nature. His writings on metals and precious stones reveal that he did not accept ancient statements about volume and weight without subjecting them to examination. He tested the relative weights of metals and minerals experimentally and presented the resulting data in tables. Modern assessments emphasize that his figures were strikingly close to measurements later obtained with more precise instruments [Kuranbaeva, 2023, p. 34]. The apparatus connected with his determination of density, often referred to as the "Biruni vessel," further demonstrates that reliable inquiry depended not only on observation but also on the construction, use, and description of instruments [Kuranbaeva, 2023, p. 35–36]. A recent technical study likewise associates al-Biruni's hydrostatic procedure with a conical device and a regulated overflow method used to determine the density of natural stones [Loizidou, Deepshikha, Zeinalipour-Yazdi, 2025, p. 14–15]. His empirical practice thus represented a carefully ordered sequence of instrument use, controlled measurement, comparison, and numerical recording rather than passive contemplation of nature.

Ibn Sina's distinctive contribution was to clarify the epistemological status of experience. He did not regard simple induction and methodically organized experience as identical. Repeated observation could be useful, but it did not automatically produce certainty unless the relevant conditions had been examined. In his logical works, experience becomes a dependable source of judgment when the relationship between cause and effect is investigated with care. The familiar example of scammony illustrates this point: a medicinal effect could be considered valid only when no obstructing factor interfered with the observed outcome [Erlwein, 2025, p. 45–48].

In medicine, this epistemological caution acquired the form of a practical method. Studies of the *Canon of Medicine* demonstrate that Ibn Sina formulated principles for determining the effects of medicines and related pharmacological conclusions to controlled comparison [Nasser, Tibi, Savage-Smith, 2009, p. 78–80]. Recent medical scholarship also observes that he did not accept anecdotal therapies when they lacked confirmation through controlled testing and clinical experience [Elahi, 2025, p. 3]. Ibn Sina's empiricism should therefore not be interpreted as unrestricted trial and error. It was disciplined experience structured by diagnosis, defined conditions, comparison, and repeated clinical observation.

Ulugh Beg's scientific activity reveals a different but equally important dimension: the quantification of experience within an observatory. The Samarkand observatory provided an institutional and technical setting in which repeated celestial observations could be transformed into refined numerical conclusions. According to the available research, Ulugh Beg's school prepared a catalogue containing 1,018 stars and calculated the astronomical year as 365 days, 6 hours, 10 minutes, and 8 seconds. The difference between this figure and modern calculation amounted to less than one minute [Sharipova, Abilqasimova, 2024, p. 467–468]. Such accuracy could not have resulted from speculative reasoning alone. It depended on astronomical instruments, sustained observation, mathematical tables, and the coordinated labor of a scholarly community.

The broader *zij* tradition represents a form of empirically grounded mathematics. Astronomical tables were not simply abstract theoretical constructions; they made it possible to calculate, anticipate, and subsequently check the movement and occurrence of celestial phenomena

[Kennedy, 1956, p. 123–177]. The Samarkand school therefore illustrates how experience became durable scientific knowledge through numerical organization and instrumental discipline.

The mathematical work of al-Khwarizmi shows that empirical reasoning in a medieval context could also be expressed through geometrical confirmation. His geometrical treatment of quadratic equations, including the celebrated equation $x^2 + 10x = 39$, connected abstract algebra with visual and spatial demonstration [Baki, 1992, p. 226–227]. Moreover, his acknowledgment that certain calculations, among them the circumference of a circle, were approximate indicates an awareness of the limits of numerical exactness [Baki, 1992, p. 226]. This awareness is methodologically significant. Empirical inquiry involves not only collecting sensory information but also distinguishing exact values from approximations and recognizing the possible boundaries of practical computation.

Al-Farabi supplied this empirical culture with a broader epistemological framework. His account of cognition describes a hierarchical movement from sensory apprehension toward the active intellect. Sensation thereby retains an indispensable role, even though its products must ultimately be ordered through rational demonstration [Masykur, 2025, p. 95]. His understanding of *burhan*, or demonstrative proof, also implies that isolated empirical evidence could not by itself amount to complete knowledge; it needed to be incorporated into a logically valid chain of reasoning [Masykur, 2025, p. 96]. From this perspective, the empirical orientation of medieval Central Asian science was neither opposed to theory nor independent of it. Experience and demonstration acquired scientific value precisely through their mutual support.

DISCUSSION. These findings challenge the reduction of medieval Central Asian science to an intellectual tradition governed solely by texts and recognized authorities. Textual inheritance remained fundamental, but it operated within a wider practice of evaluation. A scholar might begin with knowledge transmitted from the past; nevertheless, the credibility of a given proposition could be confirmed, modified, or weakened through observation, measurement, comparison, and practical testing.

Al-Biruni's historical and cultural research makes this feature particularly clear. His simultaneous use of written accounts, oral testimony, and personally observed evidence indicates that empirical judgment extended beyond astronomy, medicine, and other natural sciences. It also shaped inquiry into human communities, religious traditions, geography, and culture [Putri, Yasmin, 2026, p. 394–400]. In this respect, the distinction between the study of nature and the study of society did not eliminate a shared concern with evidence.

At the same time, medieval empirical practices should not be described as fully identical to modern experimental science. Scholars of the period did not work with contemporary laboratories, statistical standards, or formal institutions of peer review. Their concepts of nature and causation frequently reflected Aristotelian philosophy, Galenic medicine, Islamic learning, and other intellectual traditions of the age. These differences are historically important. Yet they do not negate the existence of procedures that later became central to scientific inquiry: testing claims against observed reality, comparing independent evidence, making numerical measurements, designing instruments, evaluating medicines, and acknowledging the possibility of error.

Ibn Sina's pharmacological principles illustrate this balance especially well. It would be anachronistic to identify his method with a modern randomized clinical trial. Nevertheless, his effort to define testing conditions and separate dependable experience from an isolated anecdote clearly reveals an orientation toward methodological control [Nasser, Tibi, Savage-Smith, 2009, p. 78–80]. His approach shows that the historical significance of a method lies not in its complete identity with later science, but in the epistemic problem it attempted to solve: how can repeated experience be transformed into reliable knowledge?

Natural observation constituted the first level of this empirical culture. Its forms included the study of the heavens, geographical description, clinical attention to the patient, and observation of social and cultural life. In al-Biruni's works, observation was consistently reinforced through comparison; a claim became more credible when several different kinds of evidence supported it. The second level consisted of experimental or comparative verification. It can be seen in Ibn Sina's assessment of medicines and al-Biruni's determination of mineral density. Here, experiment denoted a deliberate test under identifiable circumstances, even when it did not correspond to a modern laboratory protocol. The third level was mathematical and instrumental measurement. Al-Biruni's mineralogical calculations and Ulugh Beg's catalogue of stars show how measurement gave observed experience an organized and lasting scientific form.

The unity of these levels was the defining strength of the tradition. Observation that lacked measurement could remain uncertain; measurement detached from explanation could become a merely mechanical exercise; and theory isolated from verification could descend into speculation. Central Asian scholars of the medieval period therefore

did more than look at the surrounding world. They ordered their observations through logical categories, mathematical techniques, and purpose-built instruments. Empirical practice thus served as the connecting link between abstract reasoning and practical activity. Through it, astronomy generated predictive tables, medicine assessed the effects of remedies, geography calculated distances and coordinates, mineralogy established density, and historical inquiry differentiated unsupported reports from evidence.

This methodological culture also places Central Asian scholarship within the wider development of science in the Muslim East and beyond. Al-Biruni participated in a transregional intellectual environment joining Khwarazm, Ghazna, India, and Arabic-Persian scholarly traditions. Ibn Sina's writings circulated throughout the Islamic world and subsequently became influential within Latin medicine. Ulugh Beg's observatory marked one of the major achievements of mathematical astronomy before the early modern era. The algebraic heritage of al-Khwarizmi became foundational for later mathematical thought. Empirical knowledge in Central Asia was therefore not an isolated regional phenomenon. It belonged to a broader historical process through which observation, numerical calculation, and verification increasingly contributed to scholarly authority.

CONCLUSION. The analysis leads to several interrelated conclusions. First, empirical knowledge in medieval Central Asian scientific thought developed as a complex epistemic system grounded in observation, experience, measurement, comparison, and verification. For this reason, it should be reduced neither to the modern laboratory experiment nor to unstructured sensory perception.

Second, the exceptional breadth of this approach can be observed in al-Biruni's scholarly legacy. In historical and anthropological research, he combined field observation with the comparison of several types of testimony; in geography and mineralogy, he relied on instruments, calculation, and numerical comparison. His work demonstrates that empirical reasoning could be applied to both natural phenomena and human society.

Third, Ibn Sina converted experience into a disciplined intellectual procedure. In logic, he considered the limits of induction and the conditions under which a causal judgment might become reliable. In medicine, he connected diagnosis, clinical observation, and the testing of drugs with the production of trustworthy knowledge. His approach represents a movement away from anecdotal experience and toward systematic verification.

Fourth, Ulugh Beg and the Samarkand astronomical school embodied the mathematical and instrumental form of empirical inquiry. Their catalogue of stars and highly accurate determination of the year show how repeated observations, specialized instruments, numerical tables, and organized scholarly cooperation could produce precise results.

Finally, the contributions of al-Khwarizmi and al-Farabi confirm that empirical practice did not develop in opposition to theoretical reasoning. Geometrical demonstration, mathematical modelling, and logical proof provided observations and measurements with rational structure. Medieval Central Asian science advanced by examining theory through measurable reality and strengthening experience through coherent explanation. Further studies may deepen this interpretation through close analysis of particular manuscripts, scientific instruments,

and numerical tables, especially those related to observatories, medicine, geodesy, mineralogy, and pharmacology.

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