

Mathematics and Astronomy in Ancient India: Contributions of Aryabhata and Successors

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Abstract- Ancient Indian mathematics and astronomy evolved as part of a tightly linked scholarly tradition wherein numbers, geometry, trigonometry, calendars, and planetary astronomy were practiced and theorized simultaneously rather than as distinct and separate activities. In such an intellectual environment, Aryabhata, whose *Aryabhatiya* was written around 499 CE, emerged as the pivotal classical scholar. He provided not only mathematical formulas but also geometrical facts, sine values, solutions to indeterminate equations, models for planetary motion, theories of eclipses, and the remarkable proposition that the observed daily rotation of the stars is due to the rotation of the Earth. But what made Aryabhata influential was more than just his own contributions, since other Indian mathematicians and astronomers such as Bhaskara I, Brahmagupta, Lalla, and Bhaskara II preserved, disputed, modified, and elaborated on his teachings, resulting in one of the most impressive pre-modern mathematical astronomical traditions found anywhere in the world. This paper contends that the accomplishments of Aryabhata and the Indian tradition based on his work can be considered an important scholarly tradition in which mathematics worked for astronomy, astronomy inspired mathematics, and the practice of commentary was a powerful force of innovation.

Keywords: Ancient Indian mathematics, Ancient Indian astronomy, Aryabhata, *Aryabhatiya*, Indian mathematical astronomy, history of Indian science

I. INTRODUCTION

It would not be possible to do justice to the history of science in ancient India if mathematics and astronomy are discussed as different disciplines. In the Sanskrit learned community, works on astronomy always had chapters dealing with mathematics, and mathematics itself was advanced due to considerations of calculating planetary positions, compiling tables for sines, making predictions about eclipses, and managing time according to calendars. The introduction of Indian mathematics in Britannica highlights how, from among the earliest surviving classical texts, one has the *Aryabhatiya* by Aryabhata and the *Brahma-sphuta-siddhanta* by Brahmagupta, and how the "schools" connected with them were not buildings or institutions but textual traditions created through multiple writings and commentaries.

Aryabhata is of central importance within this tradition in that he combined synthesis and originality in his contributions. Aryabhata was by no means the first practitioner in Indian mathematical astronomy, but he may have been one of the earlier practitioners whose works survive in sufficient detail to be able to reconstruct both his contributions and influence on later mathematicians. His book *Aryabhatiya*, written about 499 CE, and comprising

separate chapters on constants, mathematics, calculations relating to time reckoning and spherical geometry respectively, is an important textbook studied extensively in the southern parts of India for centuries after.

II. HISTORICAL AND INTELLECTUAL SETTING

Traditional Indian mathematics originated from the lengthy tradition of ancient Indian astronomy and calendar studies, but the classical age provided a higher level of sophistication for this science. The use of Sanskrit poetry became the main way of transmitting knowledge. Ancient Indian poetry was highly condensed, and it could be easily memorized, yet it still required explanatory prose commentaries. Numerical constants in verse texts needed to be encoded in terms of syllables and words, and Indians created elaborate ways of writing numbers using this language format. Poetry became not only a method of knowledge transmission but also an educational tool used for teaching, interpreting, and developing science further.

The scientific/mathematical developments of this era demonstrate another trend towards adaptation and invention. Britannica mentions that the astronomical knowledge of the Greeks was carried

over to India and modified along with native techniques, whereas a historical survey by Cambridge University highlights how Aryabhata's own system of astronomy employed the concept of geocentric circular paths for the mean planets, epicycles or eccentrics for true planets, and equal linear movement within their paths. However, Aryabhata's model was not a copy of the Greeks' work; there were several key differences between his calculations and theirs, which included the treatment of epicycles and techniques utilized to acquire adjustments.

III. ARYABHATA'S MATHEMATICAL CONTRIBUTIONS

The part on mathematics contained within the Aryabhatiya clearly shows the extent of Aryabhata's accomplishment. According to Britannica, he provided methods of calculating the square and cube roots using the decimal place-value system; he made calculations involving geometry, used $62,832/20,000$ (or 3.1416) for pi, a ratio accurate up to four decimals; he worked on similar right angles, intersecting circles, series, quadratic equations, and different kinds of linear equations. Of particular interest was his approach for linear indeterminate equations that came to be known as "kuttakara" or "pulverizer" by the Indian mathematician Bhaskara I. The method involved breaking down a problem into smaller and smaller sets of coefficients.

The contribution of Aryabhata in trigonometry deserves special attention. According to Britannica's account of the history of trigonometry, "the first table of sines is found in the Aryabhatiya." Moreover, "Aryabhata seems to have known the approximate values of the sine and cosine functions of certain angles." Aryabhata used the Sanskrit word *jya* or *jiva* for the function later translated into Arabic and then into Latin as the sine function. As reported by a recent scholarly article published on arXiv, "it was Aryabhata who first tabulated the sine function" and used "a sine difference formula of great ingenuity" to generate his sine table. Even if one ignores contemporary accolades, the historical significance of Aryabhata's contribution is obvious. He initiated the change from the use of chords (known from Greek astronomy) to sines.

IV. ARYABHATA'S ASTRONOMICAL CONTRIBUTIONS

Indeed, the astronomical contribution of Aryabhata was distinguished by the complexity of calculations as well as its conceptual revolutionary nature.

According to Britannica, Aryabhatiya describes predictions of solar and lunar eclipses and provides an explanation of the westward movement of stars due to the rotation of the Earth around its own axis. Besides, Britannica mentions that the contribution of Aryabhata includes his discovery that the luminosity of the Moon and planets is determined by the reflection of the sun. In turn, the Cambridge chronicle also highlights the rotating Earth theory, precise values used for astronomy, the introduction of the sine function, as well as his discoveries in measuring the Sun's greatest declination and the Moon's greatest latitude.

On the other hand, one must not anachronistically present Aryabhata as an early proponent of heliocentrism. According to the Cambridge source, the mean planetary system of Aryabhata was still geocentric; only epicycles or eccentrics were employed for actual planetary orbits. The innovations of Aryabhata lay in the synthesis of geocentric computational astronomy along with the rotation of the Earth on its axis, in the refinement of the numerical constants for computation, and in incorporating mathematics, such as sine tables, into astronomical practice. This approach is far more interesting from a historical perspective than the claim that he "anticipated" modern astronomy.

V. BHASKARA I: COMMENTATOR, EXPOSITOR, AND MATHEMATICIAN

Following the tradition established by Aryabhata came Bhaskara I, whose work is dated to around 629 CE. According to Britannica, he was both an astronomer and a mathematician who promoted the work of Aryabhata and wrote three significant commentaries, one of which is known as *Aryabhatiyabhashya*, which is a prose commentary on the Aryabhatiya. However, the role played by Bhaskara I went beyond simply copying what Aryabhata had achieved. Specifically, in his commentary, he described Aryabhata's approach for solving linear equations, provided concrete examples from astronomy, and emphasized that proof was necessary to prove any mathematical rule. In addition to that, Bhaskara I made contributions to both trigonometry and astronomy. According to Britannica, his writings in astronomy touched upon planetary longitudes, risings and settings of planets, conjunctions, eclipses, and moon-phases, and he made a surprisingly precise rational approximation of the sine function. The same is true about MacTutor's more general discussion on Aryabhata's commentators, where they highlight the role played

by Bhaskara I in algebra and his contributions towards expanding Aryabhata's work. Therefore, Bhaskara I represents an excellent example of a commentator who was also an innovator at the same time.

VI. BRAHMAGUPTA: CRITIC AND EXTENDER OF THE TRADITION

While Bhaskara I solidified the tradition set by Aryabhata, Brahmagupta rivaled and possibly exceeded Aryabhata in some aspects of his accomplishments. The Brahma-sphuta-siddhanta written in 628 C.E. came to be another text defining an important tradition of astronomy in India. According to Britannica, Brahmagupta is considered to have been one of the most distinguished astronomers in ancient India whose work left a deep impact on Islamic and Byzantine astronomy after it was translated into Arabic in Baghdad circa 771 C.E. Nevertheless, the relation of Brahmagupta to Aryabhata cannot be easily defined because he fiercely challenged the theory that Aryabhata proposed about Earth rotation, while simultaneously building upon his ideas.

The contributions made by Brahmagupta to mathematics are monumental. Britannica informs us that the mathematician "made fundamental contributions to the development of two branches of Indian mathematics, arithmetic (算法) and algebra (代数)." He was said to have introduced zero as the difference between any number and itself, invented arithmetical rules dealing with positive and negative numbers, provided partial solutions to the second-degree indeterminate equation, established an important theorem on the sum of the areas of four cyclic quadrilaterals, and devised an interpolation formula for computing sines. MacTutor mentions that Brahmagupta's Khandakhadyaka was also involved with planetary longitudes, rotation periods, and the study of eclipses. Once again, astronomy triggered some new developments in the field of mathematics.

VII. LALLA AND THE WORK OF REVISION

By the eighth century, both the Aryabhata and Brahmagupta schools had reached sufficient age to necessitate integration and corrections. Lalla, who lived around 720 to 790 AD, wrote extensively on the application of mathematics to astronomy and authored the Shishyadhividdhidatantra, a compendium that delves into the motions of the planets, the earth's daily motion, eclipses,

conjunctions, and sphere-related matters. According to MacTutor, Lalla worked within the school of Aryabhata but disagreed with certain aspects of Aryabhata's astronomy, particularly his rotating earth theory. However, Lalla still accepted Aryabhata's advanced value for pi and improved lunar tables. This period marks a mature phase in the development of the tradition when the authority was strong enough to warrant engagement but not so strong to forbid corrections.

The value of Lalla from a historical perspective is evident when one recognizes how ancient Indian mathematical astronomy evolved through a crucial process of continuity. He did not desert Aryabhata, instead he studied him, kept much of his methodology intact, and questioned some cosmological assertions while refining computations. From this point of view, the work of Lalla is more akin to a scientific practice than one that merely repeats commentary.

VIII. BHASKARA II AND THE LATER CULMINATION OF THE CLASSICAL LINE

Despite being separated by over six centuries, Bhaskara II stands as a notable climax in the tradition of Indian mathematics and astronomy. Britannica credits him as "the leading mathematician of the twelfth century, the direct successor of Brahmagupta [and] the writer of texts that made use of the decimal place-value system." In the area of algebra, he continued on from what his predecessor did, filling in blanks, solving first and second degree equations, giving approximations, and providing methods. He also dealt with the subject of astronomy.

Bhaskara II is relevant to the present paper on Aryabhata in the way that his work demonstrates the vitality of the Aryabhata synthesis throughout several generations. Indeed, according to the Cambridge survey, the principles established by Aryabhata were continued by future astronomers, who modified the manner of presentation, altered some constants on the basis of observation, and developed calculation techniques. One such future discovery concerning the moon is even mentioned in terms of its being post-Aryabhatic; it is attributed to Bhaskara II.

IX. TRANSMISSION BEYOND INDIA

Another crucial characteristic of this tradition is its dissemination outside of the subcontinent. As

Britannica mentions, the works of the Aryabhata and an early Brahma-sphuta-siddhanta were disseminated to the Islamic world at the end of the eighth century and made an indelible mark on Islamic mathematical astronomy. The Aryabhata was even translated into Arabic under the title *Zij al-Arjabhar*, while the work of Brahmagupta was translated in Baghdad around 771. Moreover, the history of trigonometry described in Britannica points out that the Indian term for *jya* or *jiva* gave rise to the current term “sine” via Arabic *jaib* and Latin *sinus*.

The importance of Aryabhata and his disciples to the world, therefore, is not just an array of discoveries made here and there. The work of these men contributed towards the development of long-term traditions in computation, trigonometry, and the construction of astronomical tables that transcended languages and civilizations. India in ancient times was no periphery to the transfer of scientific knowledge but one of the main centers for the synthesis of mathematics and astronomy.

X. CONCLUSION

Both Aryabhata and his successors have left their mark on ancient Indian mathematics and astronomy by creating an enduring culture of calculation where there was constant synergy between mathematical innovations and solutions to astronomical problems. Among Aryabhata's contributions were accurate calculation of pi, creation of the first known Indian sine table, solving techniques for indeterminate equations, eclipse prediction, and the fascinating theory that the rotation of the Earth causes the apparent diurnal movement of stars. Bhaskara, I furthered Aryabhata's legacy by explaining and innovating. Brahmagupta contributed to both mathematics and astronomy by introducing algebra, new rules for working with zero and negative numbers, and by compiling astronomical handbooks, although he was opposed to some aspects of Aryabhata's cosmology. Lalla represented the culmination of this tradition by synthesis, criticism, and improvement of existing knowledge, and the contributions of Bhaskara II proved the ongoing influence hundreds of years after its emergence.

A more general historical conclusion is that the contributions of ancient India to mathematics and astronomy were not mere moments of brilliance. The contributions emerged out of a culture of text that placed importance on the ability to memorize texts as well as the skill of offering interpretations

and commentary, from an astronomical culture that insisted upon accuracy in numbers, and from a culture of scholarship that allowed for debate while still being continuous. What was great about Aryabhata is not only what he had discovered by the year 499, but the way in which his discoveries served as a basis for future inquiry.

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