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Shri. Tameesham Pandya

Research Scholar

University of Mumbai

Email - Tameesham25@gmail.com

Language as Algorithm and Medium: A Study of Ancient Indian Epistemology

Shri. Tameesham Pandya

Abstract –

This research paper investigates the dual role of language in the ancient Indian intellectual tradition: as a subject of rigorous formalization and as the primary vehicle for scientific and philosophical discourse. By analyzing the algorithmic structure of Pāṇini's Aṣṭādhyāyī and the prosodic foundations of Piṅgala's Chandaḥśāstra, this study demonstrates how the education of language reached a level of computational precision that anticipated modern formal language theory. Simultaneously, it explores language in education by examining how Saṃskṛta served as the universal medium for advanced astronomy in the Āryabhaṭīya surgical procedures in the Suśruta Saṃhitā, and complex mathematical analysis in the Kerala School. The paper further discusses the pedagogical frameworks of Nālandā and Takṣaśilā, where mnemonic oral traditions and rigorous logic-based debates created a unique epistemic environment. The findings suggest that the integration of linguistic mastery with scientific inquiry formed a sacred-scientific synthesis that remains a foundational pillar of Indian Knowledge Systems (IKS).

Keywords: – *Aṣṭādhyāyī, Saṃskṛta, Nālandā, Takṣaśilā, Pāṇini, Piṅgala, Pedagogy, Indian Knowledge Systems.*

Introduction

Education in ancient India was regarded as a sacred duty and a comprehensive means to understand both the universe and the self, flourishing through a continuity of tradition that spanned from Vedic Gurukulas to world-renowned centers like Takṣaśilā and Nālandā. Takṣaśilā served as a cosmopolitan melting pot of cultures, where autonomous teachers managed independent schools offering over 60 disciplines, including the definitive Saṃskṛta grammar codified by Pāṇini. Nālandā, recognised as the world's first great residential university, refined this model into a transnational hub supporting 10,000 students and 2,000 teachers through a unique free education system sustained by the revenue of up to 200 villages. Entry into these institutions was strictly meritocratic; at Nālandā, scholar-gatekeepers known as Dvārāpāla conducted such rigorous oral examinations that 70–80% of applicants were rejected at the gates. Linguistic mastery was the mandatory foundation for this learning, providing a precise medium for an interdisciplinary curriculum that bridged medicine, mathematics, and philosophy. This immense intellectual output was preserved in monumental libraries like Nālandā's Dharmagaṇja (Treasury of Truth), which housed an estimated nine million hand-copied manuscripts across three buildings before its destruction, symbolizing a civilizational commitment to unbounded inquiry and the pursuit of wisdom.

The Linguistic Foundations of Computation

The language in India reached its zenith with Pāṇini (c. 4th century BCE), whose *Aṣṭādhyāyī* remains the most systematic description of language ever produced. Pāṇini's work consists of approximately 4,000 *sūtras* (rules) that function as a deterministic production system. Modern scholars identify Pāṇini's grammar as genuinely algorithmic, exhibiting properties such as recursion, where a finite set of rules can handle unlimited linguistic complexity. His use of meta-linguistic markers, known as *it-letters* (*it-samjñā*), functions similarly to processing instructions in modern programming languages or markup tags in HTML. Pāṇini's system was designed for systematic completeness, aiming to generate every valid form of the Saṃskṛta language while distinguishing them from invalid ones, a goal that aligns with modern formal language theory and the Backus-Naur Form used in computer science.

Parallel to Pāṇini, Piṅgala (c. 3rd-2nd century BCE) applied mathematical logic to the study of language through his treatise on prosody, the *Chandaḥśāstra*. Piṅgala's *Chandaḥśāstra* involved classifying syllables as either *Laghu* (short) or *Guru* (long), which he mapped into a binary numeral system. This is the first known instance of binary representation, predating European binary logic by nearly 2,000 years. Piṅgala developed four primary algorithms to manage these binary patterns:

1. **Prastāra:** A recursive procedure for the systematic enumeration of all possible metrical patterns of a given length.
2. **Saṅkhyā:** A method for determining the total number of combinations, reflecting an early understanding of exponential growth (2^n).
3. **Naṣṭa:** An algorithm to retrieve a specific linguistic structure from its numerical position, a precursor to modern data retrieval.

4. **Uddiṣṭa**: The reverse of Naṣṭa, finding the numerical rank of a given linguistic pattern. Piṅgala's work also contains the foundations of the **Fibonacci sequence**, referred to as *mātrāmēru*, and the binomial coefficients known as Pascal's Triangle (*Meru-prastāra*), demonstrating that in India, the most advanced mathematics emerged directly from the language.

Saṃskṛta as the High-Precision Medium of Science

Since the education was so precise, Saṃskṛta became the ideal language enabling scholars to encode scientific data with the accuracy of a mathematical formula. This is most evident in Astronomy. Āryabhaṭa I (b. 476 CE), in his work *Āryabhaṭīya*, used the precision of Saṃskṛta to propose that the Earth is a sphere that rotates on its own axis. He achieved remarkable accuracy, calculating the sidereal rotation of the Earth as 23 hours, 56 minutes, and 4.1 seconds—a value nearly identical to the modern measurement of 23:56:4.091.

Furthermore, Āryabhaṭa formulated the principle of relativity through a linguistic analogy: “just as a man in a boat sees stationary objects on the shore moving backward, people on the equator see stationary stars moving westward.” His mathematical framework allowed for the calculation of solar and lunar eclipses by correctly identifying them as shadows cast by the Earth and Moon, rather than mythological events. Modern computational analysis shows that the *Surya Siddhanta* achieved sub-degree mean positional accuracy for stars, while Āryabhaṭa *jyā-prakāra* (sine-difference function) reduced these errors by an additional 33%, marking a significant progression in the education through language.

Remarkably, the language also preserved a quantification of the speed of light. A shloka in the commentary on the *Rig Veda* by Sāyaṇa (14th century CE), drawing on a tradition from the 5th millennium BCE, states that light traverses 2,202 *yojanāḥ* in half a *nimiṣa*. When converted into modern units—where an *aṅgula* is 1.6764 cm and a *yojana* is 14.484 km—this yields a speed of approximately 299,792 km/sec, which is precisely equal to the modern measurement with zero error. This accuracy suggests that the language was capable of preserving complex empirical data that was later lost during the medieval period.

The Physical Sciences: Atomic Theory and Gravitation

The Vaiśeṣika school, founded by Ācārya Kaṇāda (c. 600 BCE), used the language to articulate a systematic atomic theory. Kaṇāda proposed that everything in the physical universe is composed of *paramāṇu* (atoms), which are indivisible, eternal, and indestructible. He described how atoms combine to form *dvyāṇuka* (diatomic) and *tryaṇuka* (triatomic) molecules, which are the smallest perceivable particles (*trasareṇu*).

Kaṇāda's Vaiśeṣika Sūtras also articulated the laws of motion 1,800 years before Isaac Newton. The three sūtras are:

1. **Vegaḥ nimitta-viśeṣāt karmaṇo jāyate**: Change of motion is due to impressed force.

2. **Vegaḥ nimitta-apekṣāt karmaṇo jāyate niyatadik kriyā-prabandha hetuḥ**: Change of motion is proportional to the impressed force and is in the direction of the force.
3. **Vegaḥ saṃyoga-viśeṣa-virodhī**: Action and reaction are equal and opposite.

Kaṇāda also correctly identified *gurutva* (gravity) as the cause for objects falling to Earth and for the movement of water. This was further refined by Bhāskarācārya (b. 1114 CE), who wrote in the *Siddhānta Śiromaṇi* that the Earth possesses a *dhāraṇātmikaṃ śakti* (universal force of attraction) that keeps the sun, moon, and constellations in their orbits.

The Kerala School: The Pre-European Origins of Calculus

The language reached its mathematical peak in the Kerala School of Astronomy and Mathematics, founded by Mādhava of Saṅgamagrāma (c. 1340-1425 CE). Mādhava is now recognized as the "founder of mathematical analysis". He developed power series expansions for trigonometric functions like sine, cosine, and arctangent—now known as the Mādhava-Gregory-Leibniz series—centuries before their formalization in Europe.

Mādhava's work involved a transition from finite algebraic processes to considerations of the infinite (*Kalanā Gaṇanā Śāstra*). He calculated the value of Pi (π) to 11 decimal places (3.14159265359) using rapidly converging series and understood the nature of error terms in infinite approximations. Circumstantial evidence suggests that this knowledge was transmitted to Europe via Jesuit missionaries in the 16th century who were seeking to solve navigational and calendrical problems, influencing the work of Fermat, Pascal, and Newton.

Medical and Surgical Excellence: The Schools of Suśruta and Caraka

In the field of medicine (*Āyurveda*), the language served as a repository for advanced biological knowledge. Suśruta (c. 800-600 BCE), known as the "Father of Surgery," described over 120 surgical instruments and 300 procedures in the *Suśruta Saṃhitā*. His most famous contribution was rhinoplasty (nasal reconstruction), where he used a leaf to measure the required skin and a cheek flap to rebuild the nose, a method still referred to as the "Indian method" in modern plastic surgery. Suśruta insisted that a surgeon must be a master of anatomy, which he studied by decomposing cadavers in rivers to observe tissues layer by layer without using a knife.

Simultaneously, Caraka advanced internal medicine in the *Caraka Saṃhitā*, detailing the three *doṣa-s* (Vāta, Pitta, Kapha) and the seven *dhātū-s* (tissues) that maintain health. The education and language in medicine included a code of ethics comparable to the Hippocratic Oath and rigorous training involving mock surgeries on gourds and cucumbers.

The Pedagogical Model: Nālandā and Takṣaśilā

The synthesis of language in education was institutionalized in great universities like Nālandā and Takṣaśilā. Nālandā, the world's first great residential university, was an idea far ahead of its time,

providing free education to 10,000 students supported by the revenue of 200 villages. Admission was based solely on intellect; the *Dvārāpālā* (scholar-gatekeepers) rigorously questioned applicants on logic and philosophy, turning away 70-80% of candidates.

The curriculum at Nālandā was interdisciplinary, embracing both the "art of war" and the "art of peace," with students studying medicine, mathematics, metallurgy, grammar and all sorts of subjects. Its legendary library, Dharmagañja, housed nine million hand-copied manuscripts across three nine-story buildings. The language of education here relied on the "oral tradition" and "versification", where regular, repetitive sonic structures acted as mnemonic devices for the long-term preservation of science. Modern neuroscience research into this "Saṃskṛta Effect" has confirmed that memorizing these ancient mantras physically increases the size of brain regions associated with cognitive function.

Conclusion

The research presented confirms that in ancient India, the language was the indispensable foundation for the education. By perfecting the structure of language like Saṃskṛta through Pāṇinian algorithms and Piṅgala's logic, ancient scholars created a medium of unparalleled precision that allowed for the unambiguous encoding of complex scientific findings. This linguistic architecture functioned as a "code" for reality, ensuring that scientific truth could be preserved and transmitted through a rigorous oral tradition without the corruption of data over millennia. The algorithmic perfection of Pāṇini's grammar (*Aṣṭādhyāyī*)—with its deterministic production rules, recursion, and meta-linguistic markers—shares structural properties with modern formal language theory and computer programming.

Similarly, Piṅgala's binary logic in the *Chandaḥśāstra* represents the first known instance of systematic binary representation, predating European binary mathematics by nearly two thousand years. This linguistic rigor enabled the quantified discovery of the speed of light in Vedic commentary, where light was calculated to traverse 2,202 *yojanas* in half a *nimisha*—a value that aligns precisely with modern measurements when converted. Furthermore, this tradition facilitated the development of calculus and infinite series in the Kerala School of Mādhava, the formulation of the laws of motion and atomic theory by Ācārya Kaṇāda, and the invention of advanced plastic surgery by Suśruta centuries before these concepts appeared in the Western canon.

The legacy of institutions like Nālandā and Takṣaśilā proves that true education in the Indian tradition was a holistic pursuit that bridged linguistics, science, and ethics. Takṣaśilā served as a cosmopolitan melting pot of cultures where linguistic mastery was a prerequisite for studying over sixty disciplines. Nālandā, the world's first great residential university, refined this into a meritocratic system where scholar-gatekeepers (*Dvārāpālā*) used logic-based examinations to ensure that only those with profound intellectual and linguistic foundations were admitted. This environment fostered an interdisciplinary synthesis where students did not study science in isolation but as part of a broader epistemic framework grounded in reason and moral discipline.

Recognizing these contributions is essential for decolonizing history and appreciating the deep, non-European roots of modern global knowledge. The evidence suggests that many "Western" breakthroughs,

including the Newton-Leibniz calculus, may have roots in the transmission of Indian mathematical texts to Europe via Jesuit scholars. Shifting the Eurocentric narrative helps reclaim the achievements of scholars like Mādhava, Pāṇini, and Piṅgala, ensuring that their names are remembered not just as historical artifacts but as the pioneers of the scientific and computational logic that powers the modern world. Ultimately, this research underscores that the Indian intellectual tradition did not separate mythology from mathematics but operated on a sacred-scientific synthesis where linguistic precision was the vital catalyst for empirical discovery.

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