

The Scientific Legacy and Knowledge System of Ancient Nalanda: A Review

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ABSTRACT: Ancient Nalanda is widely considered a golden phase of scientific development in the Indian subcontinent. Scientific knowledge here was not isolated theoretical speculation but deeply integrated with practical applications, documented research, and demonstrative teaching. Its great libraries once held thousands of manuscripts on science, medicine, astronomy and philosophy. Scholars carried these texts across Asia. Tibetan and Chinese monks translated Nalanda works into local languages. Though much of its physical legacy was lost, but Nalanda lives on in memory as a global beacon of learning.

KEYWORDS: Nalanda, Scientific Legacy, Knowledge System.

I. INTRODUCTION

Ruins of the ancient Nalanda complex in present-day Bihar, India mark a great symbol of knowledge and wisdom of ancient India. Founded around the 5th century AD under the Gupta emperors, Nalanda was a vast residential university near Rajagriha (modern Rajgir). Nalanda University is widely considered a golden phase of scientific development in the Indian subcontinent. Unlike many ancient educational institutions primarily structured around sacred or literary studies, Nalanda was distinguished by its systematic approach to science, empirical reasoning, inter-disciplinary curriculum, and structured research environment. Spread across a vast campus supporting thousands of students and teachers, Nalanda functioned as a global centre of scientific inquiry where scholars from different regions engaged in academic dialogue, experimentation and collaborative exploration.

Scientific knowledge at Nalanda was not isolated theoretical speculation but deeply integrated with practical applications, documented research, and demonstrative teaching. Evidence from archaeological remains, surviving manuscripts, and records from foreign scholars -particularly the Chinese pilgrims Xuanzang and Yijing - confirms that Nalanda offered advanced education in mathematics, astronomy, medicine, chemistry, metallurgy, logic, linguistics, and related sciences. The institution produced distinguished scientists including Aryabhata, whose astronomical calculations and mathematical revolution shaped global scientific progress.

The methods of instruction at Nalanda reinforced this scientific spirit. Its great libraries once held thousands of manuscripts on science, medicine, astronomy and philosophy. Scholars carried these texts across Asia. Tibetan and Chinese monks translated Nalanda works into local languages. Indeed, its scientific insights survived in Tibet, China and Southeast Asia for centuries after the site was destroyed. Much of its physical legacy was lost, but Nalanda lives on in memory as a global beacon of learning.

This article examines the scientific achievements of Nalanda, the structure of its curriculum, its methodological framework, contributions to distinct scientific branches, and its lasting global legacy.

II. HISTORICAL CONTEXT AND SCIENTIFIC ENVIRONMENT

When we consider of the Gupta dynasty we find that it is often recognized for intellectual flourishing, scientific research, and state support for scholars who dedicated their lives in the pursuit of knowledge in ancient India. Nalanda was a result of this environment of academic freedom and scientific curiosity. Students from diverse backgrounds - India, Tibet, China, Korea, Sri Lanka, Java and Sumatra - travelled to this epicentre of global knowledge to quench their intellectual and spiritual thirst. The campus reportedly contained extensive laboratories, observatories and one of the world's largest libraries, facilitating research in physical sciences, life sciences and mathematical sciences. Nalanda was noted for its specialization in the last stages of a University education. At that time Nalanda was particularly a

research institute for advanced students. The stamp of its approval was necessary for any opinion to gain currency in the country. The highest academic degree of distinction of the times was a fellowship of Nalanda (Bhattacharya and Guha, 2017).

Nalanda represented a structured scientific institution long before similar models evolved in medieval Europe. It displayed core characteristics of a research university:

- **A multi-disciplinary curriculum:** The multidisciplinary approach was the foundation of the curriculum at Nalanda. This approach ensured the holistic development of the best minds of the contemporary world.
- **Expert faculty (Acharyas) serving as principal investigators:** The faculty members or Acharyas were not only the teachers giving the lecture based on the scriptures but were actively engaged in the research as principal investigators.
- **Documentation of findings:** Working as investigator the Acharyas also meticulously documented their research finding in manuscripts.
- **Peer review through debate:** The academic discussion was an integral part of the knowledge system at Nalanda. Peer review through debate and analysis further consolidated the validation of the research finding. The approach is still pertinent in the modern centres of academic excellence.
- **Experimental and practical training:** Apart from the fundamental knowledge based on texts, the learning by doing was underlined by experimental and practical training in nature as well as laboratories.
- **International scholarly exchange:** The scholar from other parts of the contemporary world thronged to Nalanda which paved the way for international scholarly exchange.

The university thus functioned as a scientific community rather than a traditional centre of learning

III. SCIENTIFIC DISCIPLINES AT NALANDA

1. Mathematics

Mathematics served as a foundational scientific discipline. Researchers at Nalanda applied mathematics to architecture, calendrical science, astronomy, commerce and engineering. Aryabhata, one of history's great mathematicians, is believed to have studied and taught here. He was a prominent astrologer and mathematician of the Gupta period. When he was 23 year old he wrote 'Aryabhatiya Granth'. This Granth 'Aryabhatiya' was accepted from all around, due to which King Buddhagupta made Aryabhata the head of Nalanda University (Sahu, 2021). The pioneering work of Aryabhata in the field of mathematics earned him the title "father of Indian Mathematics" (Basar *et al.*, 2024). He did his fundamental work on Number System, Trigonometry and Theory of Equations etc. (Singh, 2017). His text Aryabhatiya introduced several core concepts including:

- **Approximation of π (pi) to 3.1416:** π represents the ratio of a circle's circumference to its diameter. Ancient mathematicians attempted to approximate this irrational number. Indian mathematician Aryabhata (499 CE) approximated π as 3.1416, remarkably accurate for the time.
- **Trigonometric functions (sine, cosine):** Trigonometric functions relate angles to ratios of sides in a triangle. Indian mathematicians like Aryabhata developed early sine tables. The modern trigonometric system evolved from these early contributions.
- **Place-value decimal positional numeral system:** This system uses **ten symbols (1-9 and 0)** and assigns value to a digit based on its **position** (units, tens, hundreds, etc.). It is the **foundation of all modern mathematics, science, engineering, and computing**. Nalanda taught this numeral system as part of **Ganita** (mathematics), **Jyotiṣa** (astronomy), **Commerce and surveying**.
- **Algebraic equations and quadratic solutions:** Aryabhata in his *Aryabhatiya*, introduced algebraic techniques for solving quadratic-type problems, especially in astronomy. Later Brahmagupta (628 CE) also developed rules for solving quadratics.
- **Spherical geometry:** Spherical geometry studies figures on the surface of a sphere rather than a plane. It is important in astronomy, geography, and navigation. Ancient Indians used spherical geometry for calculating planetary motions and eclipse predictions.

These elements became the basis of modern mathematical systems. The trigonometric principles later influenced Greek, Arab and Persian mathematicians, and were transmitted to Europe through Arabic translations.

2. Astronomy

Astronomy at Nalanda represented a highly advanced observational science supported by mathematical modelling. Studies here in the field included:

- **Planetary motion:** Indian astronomers recognized that planets have **complex motions**. Planets were explained to move in **epicycles** around their main orbits. These ideas are described in texts such as the *Surya Siddhanta* and works of Aryabhata. Planetary motion was essential for calendar-making and eclipse prediction.
- **Solar and lunar eclipse calculations:** Ancient India gave a **scientific (non-mythological)** explanation of eclipses. **Solar eclipse:** Moon comes between Earth and Sun. **Lunar eclipse:** Earth's shadow falls on the Moon.
- **Earth's rotation about its axis:** One of the most striking insights came from **Aryabhata** who proposed that earth **rotates on its axis** and apparent motion of stars is due to Earth's rotation, not the heavens moving.

Aryabhata correctly affirmed that Earth rotates about its axis. The movement of Earth causes the movement of the star, contrary to the then prevailing viewpoint, that it is the sky that got rotated. This work can be glanced in the first chapter of the *Aryabhatiya*, where he discusses the number of rotations of the Earth in a Yuga, and more explicitly in his *gola* section. Solar and lunar eclipses were scientifically explained by Aryabhata. He states that the Moon and the planets shine by reflected sunlight (Basar *et al.*, 2024). Astronomers constructed astronomical instruments, observatories and models to measure planetary coordinates with precision. Research integrated theoretical predictions and observational verification, demonstrating a scientific method ahead of its time.

3. Medical Science and Human Anatomy

Medical sciences taught at Nalanda were based on classical Ayurvedic texts such as Charaka Samhita, Sushruta Samhita and Astanga Hridaya. Students received training in human anatomy, physiology, pathology, diagnosis and surgical practice. Dissection of human and animal bodies was recorded as part of practical anatomical study. Chinese travellers Hiuen Tsang and I-Tsiang mention the study of medicine at Nalanda. Literarily, we can say that the medicine as a discipline was recognized at Nālandā and probably at other monasteries also (Kumar, 2016).

Subjects in this field included: Anatomy and physiology; Disease classification, Diagnostic indicators (pulse, urine, stool, eye examination); Surgical procedures such as suturing, extraction and cauterization; Emergency medicine; Herbal pharmacology and medicinal formulations. Chinese scholars documented that Nalanda had medical gardens, laboratories for drug preparation and surgical training with simulation models.

4. Chemistry and Metallurgy (Rasāyana and Rasaśāstra)

Chemistry, known as Rasāyana, developed as a scientific field focused on materials, transformation processes and medicinal chemistry. Research involved extraction, purification, crystallization, metallurgy and the formulation of chemical compounds.

Areas of study included: Preparation of metal-based medicines; Alloy formation and metallurgical treatment; Distillation; Fermentation; Mineral and salt processing; Manufacturing of pigments, perfumes and glass. These practices combined theoretical principles and laboratory experimentation, predating medieval European chemistry.

5. Logic and Scientific Method

Logic (Nyāya and Hetuvidyā) played a vital role in structuring scientific reasoning. The structured academic model parallels contemporary scientific methodology. Nalanda scholars emphasized on:

- **Rational argumentation:** At Nalanda, reasoning (*yukti*) was considered superior to blind authority. Teachers were required to **justify claims logically**. Texts were not accepted as infallible; they were **interpreted, tested, and critiqued**. Disciplines such as **Nyaya (logic)** and **Hetuvidya** trained students to detect fallacies.
- **Hypothesis-based reasoning:** Nalanda scholars often framed explanations as **provisional models**, not final truths. Astronomical models (planetary motion eclipses) were proposed as **hypotheses**. Competing explanations coexisted and were compared. A hypothesis was accepted only if it **explained observations more accurately**. This approach mirrors modern hypothesis testing.
- **Debate as peer review:** One of Nalanda's most distinctive features was its culture of **formal debate (vada)**. Scholars publicly defended their ideas before peers. Opponents were encouraged to challenge assumptions. A defeated scholar often **revised or abandoned** their position.

IV. SCIENTIFIC PEDAGOGY AND RESEARCH CULTURE

Nalanda's education system centered around:

- **Guru-Shishya mentorship:** Nalanda followed the traditional **Guru-Shishya model**, where education was built on a strong personal bond between teacher and learner. Teachers closely guided students in their intellectual, moral, and personal development. Instruction was adapted to individual abilities, ensuring deep understanding rather than memorization.
- **Research-based learning:** Nalanda promoted a culture of **critical inquiry and independent thinking**. Students were encouraged to question existing ideas and participate in scholarly debates. Learning progress was determined by reasoning and evidence, making Nalanda a centre for advanced research and intellectual exploration.
- **Experimental demonstration:** Education at Nalanda combined theory with practice. Disciplines such as astronomy and medicine relied on **observation, experimentation, and practical demonstrations**. This approach helped students verify knowledge through direct experience, reflecting an early scientific method.
- **Interdisciplinary collaboration:** Nalanda offered education in diverse fields, allowing interaction among different branches of knowledge. This exchange of ideas across subjects encouraged broader perspectives and innovation, leading to a more integrated understanding of learning.
- **Extensive manuscript-based study:** The institution maintained vast collections of manuscripts, which formed the foundation of teaching and study. Students actively engaged in reading, copying, interpreting, and preserving texts, supporting the transmission and advancement of knowledge.

V. GLOBAL SCIENTIFIC INFLUENCE

Nalanda attracted learners and scholars from many parts of Asia. This international presence promoted the exchange of ideas, languages, and intellectual traditions, establishing Nalanda as an early global centre of higher education. Nalanda's scientific achievements spread across Asia via translated manuscripts and travelling scholars. Xuanzang and Yijing carried scientific texts to China, contributing to medical, astronomical and mathematical advancements there. Tibetan monastic universities adopted Nalanda's scientific academic structure, preserving knowledge lost after Nalanda's destruction.

VI. DECLINE AND PRESERVATION

The university was destroyed in the 12th century CE. Its manuscripts are believed to be burned for months. The scientific community dispersed to Tibet, Nepal, Sri Lanka and Southeast Asia, ensuring continued transmission. Thousands of years passed over, dynasties passed, political ups and downs had been occurred - Nalanda and its pride may be de-memorised but its significance is still very much important and without it the history of Indian education system cannot be possible to analyse. Nalanda should not be considered as only an educational institution but it should be treated as the witness of the educational history of the human civilization (Bhattacharya and Guha, 2017).

VII. CONCLUSION

Nalanda University was a pioneering scientific institution embodying analytical reasoning, empirical research, experimentation and systematic documentation. Its achievements in mathematics, astronomy, medicine, chemistry, logic and linguistics influenced global scientific progress. Nalanda determined the foundation for scientific rationality in ancient India and shaped academic systems that continue to resonate.

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