

Math, Science, and Technology in India—From the Ancient to the Recent Past

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A Love of Numbers

Any account of the classical sciences of India must begin with mathematics, for, as the ancient Sanskrit text *Vedanga Jyotisa* (ca. fourth century B.C.E.) says,

Like the crest on the peacock's head,
Like the gem in the cobra's hood—
So stands mathematics
At the head of all the sciences.

The Sanskrit word used for mathematics in this verse is *ganita*, which literally means “reckoning.” What is unique about the classical Indian view of mathematics is that number was treated as the primary concept—and not geometry, as with the Greeks. A distinguished Swiss mathematician-physicist wrote in 1929 that “occidental mathematics has in past centuries broken away from the Greek view and followed a course which seems to have originated in India”¹ where “the concept of number appears as logically prior to the concepts of geometry.” The love affair of Indian culture with numbers has been long. Written at a time when most societies had difficulty handling numbers beyond 1000, the Buddhist text *Lalita-vistara* (before the fourth century C.E.) not only has no problem with huge numbers, but seems to revel in giving them names (10^{145} , the highest number quoted, being called *dhvaja-nis'a-mani*.)

The fact that the numeral system common today—the closest we have to a universal language—comes from India is well known. The idea of zero and its integration into the place-value system, which enabled one to write numbers no matter how large using only ten symbols, originated in India. At first encounter, it appeared marvelous to West Asians, and “satanic” to Christian clerics in the Europe of the Middle Ages. After quick adoption in ninth-century Baghdad, it came slowly to be transmitted to Christian Europe around the thirteenth century through Jewish scholars working in Islamic Spain. This long and tortuous path is illustrated by the works of such distinguished scholars as the Persian mathematician al-Khwarizmi (783-850), who worked in the House of Wisdom at Baghdad and from whose name the word *algorithm* is derived, and Fibonacci of Pisa (1170-1250), famous for the Fibonacci sequence still familiar today.

abacist

One who uses an abacus in casting accounts; a calculator.

algorist

One who computes with the Arabic system of numeration; the decimal system.

What is perhaps not so widely known is that the acceptance of the system in Europe followed centuries of bitter dispute between the **abacists** and the **algorists**. The abacists computed with beads mounted on strings or wires; the algorists computed with numbers and symbols on a sand-board (figures were written on a thin layer of sand or dust spread on a board, which was then

smoothed out once the calculations were completed so as to be ready for the next). The eventual victory of the algorists replaced physical manipulation of beads by operations with symbols, and led in due course to the nearly universal acceptance of the numerals in use today. These ‘international’ numerals are very close in shape to the ones in Sanskrit.

Apart from numbers, the idea of equations, in particular of algebraic equations, might also have come from India, with some very important contributions from West Asia. The *Bakhshali* manuscript, the earliest surviving written material on Indian mathematics now known (dating to the eighth century according to the Japanese scholar Hayashi, and discovered in 1881 near Peshawar in today’s Pakistan), already has the essence of what we think of as an algebraic equation, namely: (1) the use of symbols for unknown quantities and for arithmetical operations—addition, subtraction, multiplication, and division—and (2) a statement of equality between appropriate expressions involving those symbols for both operations and unknowns. One can see a correspondence between modern notation and the ancient one used in such texts as the *Bakhshali* manuscript. These ideas, juxtaposed with those from the Greeks and presented with important additions of their own by West Asians, are thought to have played a crucial role in the brilliant explosion of “mathematicized” science that occurred in Europe beginning with Galileo and Newton in the sixteenth and seventeenth centuries.

Aryabhata’s Influence

Aryabhata is the key historical figure in India who heralded these developments; his work the *Aryabhatiya*, which can be precisely dated to 499, must surely rank among the great astronomical-mathematical classics of the world. Like most Sanskrit works it is written in verse to make the text easier to memorize. (There was no paper in India at that time or for many centuries to come; knowledge was usually transmitted orally from the teacher, *guru*, to his disciple, *sisya*, who often made notes for himself by inscribing the verses on a material like palm leaf, which could survive for centuries.)

It is interesting to analyze Aryabhata’s approach to the subject and contrast it with the Greek methods that are far more familiar in the West. The most important difference is that Aryabhata’s approach, even on physical problems, is basically algorithmic. Indeed one is tempted to coin a term and say that he was doing *algorithmic astronomy*. While the Greek paradigm, as exemplified by Euclid, was to proceed from axiom to proof to theorem, the Indian paradigm seems to have been to proceed from observation to algorithm to verification/improvement/ conclusion. The concept of logical deduction from stated axioms does not appear to have been central to the Indian approach. This is most curious, because logic was another major science in the Indian knowledge system, valued highly even in metaphysical speculation, and several vigorous schools of logic have flourished in India for millennia. The reason for the Indian approach may have stemmed from general skepticism about the possibility of discovering “reliable” axioms (if indeed they exist at all), and disagreement on what truly constitutes “proof”: the approach was basically pragmatic and empirical. So when

Gregory Chaitin, the well-known mathematician at IBM, recently said that mathematics is “an experimental field where mathematicians stumble upon facts in the same way that zoologists might come across a new species of primate,” he was echoing the classical Indian view.

Aryabhata’s work, unlike that of many who followed him, had some sound physical reasoning as well. For example, he noted how motion was relative, suggested that the earth was round and rotated on its axis, and had the correct physical explanation for eclipses. He was undoubtedly influenced by Greek physical-mathematical models like Ptolemy’s astronomical epicycles. On the other hand, a model was only an inspiration for an algorithm—until everything was finally reduced to methods of calculation with numbers the work was incomplete. The influence of Aryabhata on Indian mathematics almost rivals that of Euclid in the West; Kodanda-rama wrote a commentary on the *Aryabhatiya* as late as 1850.

Particularly well known among the many astronomer-mathematicians who followed Aryabhata was Brahmagupta (b. 598), who in many ways had cleverer and more precise algorithms than Aryabhata but differed from him in interpretation. Indeed, Brahmagupta was very critical of what we would think of as the “rational” view that Aryabhata and his disciples adopted—for example, on the causes underlying eclipses, which went counter to traditional Indian mythological accounts. It is difficult to imagine that Brahmagupta truly believed his own objections, and there is a story that toward the end of his life he regretted having poured scorn on Aryabhata and his followers. However, there does remain in India to this day the two conflicting scientific philosophies of Aryabhata and Brahmagupta—one rational and the other conservative. It is possible that the cycles of acceptance and rejection of these philosophies reflect the social and political circumstances in which Indian civilization has found itself.

Among those who followed Aryabhata and Brahmagupta we can mention here only a few. The algebra referred to above was taken much further by many others, in particular Bhaskara II (b.1114). Among his well-known works is a charming book called the *Lilavati* (a title that may refer to his wife or daughter). Its most striking feature is that many of the problems it poses are couched in playful poetry. For example:

As the young lady tumbled with her lover in bed,
The necklace she wore—of the fairest pearls!—snapped.

A third of those pearls scattered on the floor; a fifth were seen
strewn on the bed. A sixth were lodged in her lovely hair, and a
tenth picked up by her lover.

But six still remained on the string. Tell me,
How many pearls were there originally on that necklace?

With problems like this, it is no surprise that the famous Indian dancer and choreographer Chandralekha has turned the *Lilavati* exercises into dance! Bhaskara II (and even earlier, Brahmagupta) also solved what later became known as Pell’s equation (after John Pell, 1611–1685). He also proposed *and*

solved another equation that Fermat proposed in 1657 and Euler solved in 1732. Indian mathematicians seem to have been particularly fascinated by indeterminate equations with multiple solutions.

The other direct intellectual descendants of Aryabhata were from the Kerala school, which blossomed in the early centuries of the second millennium C.E. and led to an extraordinary burst of creative mathematics and astronomy. This school challenged the prevailing geocentric view, proposing instead (ca. 1500) a partially heliocentric model in which the interior planets revolved around the sun, which still orbited the earth. Kerala mathematics led to the discovery of a variety of infinite series, including that which came to be named after Maclaurin in the early 18th century. Some of these series gave rapidly convergent expressions for pi; Bhaskara (1340–1425) offered the “approximate” value of 3.1415926536, an accuracy unmatched for centuries to come.

Indian contributions to mathematics were, however, not limited to numbers and algebra. Trigonometric functions were already defined by the sixth century, and algorithms for what we today would call sine of the half-angle were described in the *Aryabhatiya*. Similarly, germs of the ideas of calculus were present; for example, Munjala proposed (932 C.E.) a formula for interpolation that in present notation would be written as $\Delta \sin \theta = \Delta \theta \cdot \cos \theta$. It was also realized that the maximum of a function occurred where a “derivative” (such as the limit of the ratio $\Delta \sin \theta / \Delta \theta$ above) vanishes.

The earliest available account of the Indian approach to geometry is in the *S’ulva-Sutra* (loosely translated as *The Manual of the Cord*), from the seventh or eighth century B.C.E. It was intended to help lay out the fire altars that were characteristic features of Brahmanical sacrificial practices of the times. Layouts were made with the aid of string or cord, much as Indian masons do to this day; hence the title of the work. The altars took a variety of shapes, one of the most famous being that of the Vedic eagle.

The approach of these *sutras* is pragmatic and constructive rather than deductive. The work starts with a statement of the units used for measurement of length. It then states various geometrical results, including in proposition 12, the “theorem” that is now known after Pythagoras. (It is virtually certain that the *S’ulva-Sutra* predates him. Interestingly, Pythagoras’s belief in transmigration, his adherence to vegetarianism, and his respect for numbers have led to speculation that he may have visited India during his lifetime.) The result on the square of the hypotenuse—rather, the square of the diagonal of a rectangle as the *S’ulva-Sutra* has it—is stated in very general terms, as a truth; no proof is offered, and to one schooled in Western thinking, the question would arise whether it was seen as an empirical result or a logical deduction. Even the approach to geometry seems to have had an algorithmic flavor.

The Development of Medicine

The other major science that was highly developed in early India, and perhaps the first to do so along “rational” lines, was medicine. The *Caraka Samhita* (first

Sutra
A scriptural narrative, particularly a doctrinal text of Buddhism or Hinduism. A sutra is also known in other genres as a text that

Ayurveda
“Science of
Longevity.”
Known as the
medicine of the gods,
the original Hindu
medical system.

century C.E. or earlier) has remarkable statements about diagnosis, the primacy of cause and effect, and the importance of frank discussion. It advocated a system of medicine that depended on *yukti* (skill, human intervention) rather than *daiva* (the divine or superhuman). This ancient system of medicine, still widely popular in India as *Ayurveda*, depended heavily on the use of herbs; around 600 drugs, including those of mineral and animal origin, were noted and their use to treat specific diseases recommended. It is likely that the luxuriance of tropical vegetative growth led to a wide availability of naturally occurring substances whose use to combat specific diseases was studied extensively. That this vast storehouse of knowledge has not yet been completely tapped is clear from the advanced scientific work still being done on such traditional Indian herbal remedies as *neem* and *turmeric*, and from the vigorous and large-scale exploration of Indian bio-resources currently being carried out by multinational drug companies.

Indian advances in surgery were even more impressive. The treatise of *Sus'ruta* (written down fourth century C.E.; in existence in some form much earlier) had lasting influence, and as late as the eighteenth century, accounts of Indian surgical practices appeared in learned journals of the West. Vaccination, rhinoplasty, and eye surgery were practices well known in India long before they were introduced in the West. To this day, some of these ancient medical practices are in regular use in Indian villages.

Language and Technology

Linguistics has occupied a very high position as a branch of learning in India. The structures of language and of the sounds that constitute its spoken form have been an intellectual preoccupation in India for some 3,000 years, if not longer. The letters of the alphabets in all Indian languages are arranged in a systematic way, from vowels to consonants to sibilants and so on, classified according to the location of the source of the sound in the human vocal organs. To an Indian who is brought up on this system, the arrangement of letters in Semitic alphabets appears completely disordered. The treatise on Sanskrit grammar written by the renowned Panini (ca. third century B.C.E.) is considered a remarkable piece of constructive synthesis. It provides the rules (and the exceptions) that have defined linguistic usage of Sanskrit ever since. The treatise is so highly compressed that it can be recited all in a matter of some five hours or so. (Such compression was another Indian preoccupation: as an old Sanskrit verse has it, “If half a syllable can be saved/They feast as at the birth of a son!”) The magnitude of Panini’s early achievement is again being appreciated as we wrestle with the problems of constructing artificial languages for computers, and as scientific interest in communication between humans and animals grows.

Among the technologies, metallurgy in many ways holds pride of place. Excavations in the Indus Valley yielded the celebrated figure of a dancing girl cast in bronze some 4,000 years ago (striking a pose not unfamiliar today). India was a pioneer in the extraction of zinc—the process used in the Zuvar mines of Rajasthan in northwestern India since the fourth century B.C.E. was later patented in nineteenth-century Britain. The iron-and-steel industry throughout

India dates from around 1300 B.C.E. Legend has it that one of the gifts that Alexander took from India during his raid was a ball of steel weighing nearly 15 kilograms. Smiths during the Gupta Empire (fourth–fifth centuries C.E.) created the much-studied iron pillar that stands today near the Qutub Minar in Delhi; over seven meters tall and six tons in weight, it shows no sign of rust whatever. (It was manufactured by forge-welding a number of cylindrical stubs of the metal.) From around 1000 C.E., South Indian craftsmen began to cast superb bronze sculptures. The famous Damascus swords of West Asia were forged out of an Indian steel called *wootz* (derived from the South Indian word *wook* in a misprint that was never corrected). In the late eighteenth century, Tipu Sultan's rockets surprised British armies with a performance far exceeding anything then available in Europe, chiefly because of the excellence of the steel he used for the casings. Until late in the eighteenth century, India exported iron and steel to England, being the only source apart from Sweden of high quality iron then known to the British. The iron-and-steel industry in Europe was at that time expanding rapidly, and the technological advances made during the industrial revolution led to such significant improvements that the Indian industry, which had been in such a strong international position until the late eighteenth century, completely collapsed by 1850.

Perhaps the major industry associated with India for thousands of years has been textiles (see the **Clothing** essay). India was also at one time famous for boats and shipping. Although much Indian shipping stayed fairly close to the coast, Indian craftsmen displayed excellent skills in building ships. The best ships operated by the East India Company in the late eighteenth and early nineteenth centuries were usually made in the Bombay area. The first Indian to be elected to the Royal Society of London was the Parsi engineer Ardaseer Cursetji, whose docks in Bombay built ships better than the British could at the time. Cursetji managed to stay abreast of the industrial revolution in Britain and experimented with the use of steam engines for ships at about the same time as Europeans.

Contributions in the Nineteenth and Twentieth Centuries

As British power spread across India in the nineteenth century, in part through the use of superior technology, Indian intellectual leaders beginning with Raja Rammohan Roy realized that they needed to understand the revolution that had occurred in European knowledge systems. Eventually they created three major new institutions. The first was the Indian Association for the Cultivation of Science, which was established in Calcutta in 1876 by the medical practitioner Mahendra Lal Sircar. It was here that C. V. Raman later did the work in spectroscopy for which he won the 1929 Nobel Prize in physics. The second was the establishment of the Indian Institute of Science in Bangalore by Jamsetji N. Tata, an industrialist from Bombay who saw, long before others, that a Western sense of the pursuit of science as an intellectual discipline was essential for the well-being of India and its industry. Although initially resisted by British commercial interests in India, the Institute began work in 1909–1911. The third institution was the Indian Science Congress, which held in 1914 the first of a series of annual meetings of all Indian scientists. These enterprises were quickly followed by a variety of other initiatives, and Indian scientists began to make a

mark at the Presidency Colleges of Madras and Calcutta, and in universities elsewhere.

World attention was caught by the distinguished work of such scientists as J. C. Bose, who experimented with wireless transmission before Marconi; Meghnad Saha, whose law of ionization can be considered the first theoretical effort in astrophysics; Nobel Prize-winner C. V. Raman; and Satyendra Nath Bose, whose unusual statistics and work with Einstein led to a particle description of radiation.

Earlier, the mathematical genius Ramanujan (1887–1920) had represented a response to Western mathematics that was in the traditional Indian idiom. His education was not above the pre-university level, and in mathematics was entirely limited to familiarity with the basic compilations of mathematical formulas found in British manuals. In particular, Ramanujan was non-Euclidian in the sense that he did not proceed with proofs of the kind that underlie Western mathematics. However, whether or not he was able to prove them, his results were almost always correct and astonishingly original, which made an enormous impression on Cambridge mathematician G. H. Hardy and his colleagues. Ramanujan “saw” formulas in their entirety and often claimed that they were revealed to him by his family goddess in dreams. Littleton, one of his Cambridge collaborators, remarked, “If a significant piece of reasoning occurred somewhere, and the mixture of evidence and intuition gave him certainty, he [Ramanujan] looked no further.” Ramanujan’s brief career seemed to demonstrate to Indians that their innate scientific abilities could make a mark even in the otherwise unfamiliar territory of Western mathematics.

By the 1930s there were several Indians with an international reputation in science, but it was becoming increasingly clear that the opportunities available to them within the country were far too few. Bitter controversies erupted among scientific leaders who had to share very scarce resources. Probably the first great Indian scientist to flee the country in search of opportunity was the renowned astrophysicist Chandrasekhar (Nobel Prize 1983). He eventually settled down in Chicago after being at Cambridge in England. The trickle started in the 1930s grew by the 1970s into a westward flood of scientific talent that continues into the twenty-first century.

With the end of British rule, the new Indian Republic led by Jawaharlal Nehru and his successors took massive initiatives for the growth of science, leading to the establishment of new institutions or the vigorous expansion of older ones, including the Council of Scientific and Industrial Research, the Department of Atomic Energy, the Defense Research and Development Organization, the Indian Institutes of Technology, and the Indian Space Research Organization, among others. Nehru thought of these institutions, and the dams and factories that were built in the first decades of the new republic, as “modern temples.” He was convinced that it was impossible to solve India’s problems without the use of modern science and technology, and constantly spoke of promoting a “scientific temper” among the people. But to this day, as the continuing exodus of Indian scientists abroad shows, the limiting resource in India is opportunity, not talent.

One major feature of Indian science and technology in republican India has been the growth of the strategic sector. Considering India's history, and the widespread perception among her leaders that backwardness in science and technology invited the aggressive intrusion of Europe into their land, it is hardly surprising that the country began making relatively large investments in defense, atomic energy, space, and other related areas. Agriculture was another sector that received massive support, and the major initiative taken in agriculture in the 1960s turned the tide in a matter of five to ten years. The sudden and somewhat unexpected growth of the computer software industry in India plus the prominent role that nonresident Indians are playing in U.S. scientific and technological enterprises (particularly in Silicon Valley) have drawn attention to Indian talent in terms that the U.S. public can easily understand. Perhaps the much-discussed Indian prowess in software is really the most recent manifestation of the long Indian love affair with numbers.

The scene in India continues, as always, to be uneven. In spite of its size, India's presence in the world of science and technology is still small. The investment required to break into the world knowledge system is huge, and it appears both India and China will find it difficult to afford this for quite some time to come. In rough numbers, India accounts for about one-half percent of the total expenditure in the world on research and development, and about two percent of the resulting publications. Today the major problem in further development of India lies in learning to manage the extraordinary talent that the country possesses. India is often said to be home to one of the largest scientific communities in the world, but only a small percentage of those graduating in the sciences are doing research. Indian society has traditionally reserved its deepest respect only for persons of moral authority. The current challenge is to encourage respect for those distinguished in the sciences as well.

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¹ Hermann Weyl. *The Theory of Groups and Quantum Mechanics*. Trans. H.P. Robertson. New York: Dover Publications, 1950. vii.