सत्यमेव जयते

ज्ञान-विज्ञान विमुक्तये

Guidelines For Incorporating Indian Knowledge In Higher Education Curricula

विश्वविद्यालय अनुदान आयोग

UNIVERSITY GRANTS COMMISSION

GUIDELINES FOR INCORPORATING INDIAN KNOWLEDGE IN HIGHER EDUCATION CURRICULA

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GUIDELINES FOR INCORPORATING INDIAN KNOWLEDGE IN HIGHER EDUCATION CURRICULA

1. Preamble:

The *National Educational Policy 2020* (NEP 2020) recommends the incorporation of Indian Knowledge System (IKS) into the curriculum at all levels of education:

"The heritage of ancient and eternal IKS and thought has been a guiding light for this Policy. The pursuit of Knowledge (*Jñāna*), wisdom (*Prajñā*), and truth (*Satya*) was always considered in Indian thought and philosophy as the highest human goal. … The Indian education system produced great scholars such as Charaka, Susruta, Aryabhata, Varahamihira, Bhaskaracharya, Brahmagupta, Chanakya, Chakrapani Datta, Madhava, Panini, Patanjali, Nagarjuna, Gautama, Pingala, Sankardev, Maitreyi, Gargi and Thiruvalluvar, among numerous others, who made seminal contributions to world knowledge in diverse fields such as mathematics, astronomy, metallurgy, medical science and surgery, civil engineering, architecture, shipbuilding and navigation, yoga, fine arts, chess, and more. Indian culture and philosophy have had a strong influence on the world. These rich legacies to world heritage must be nurtured and preserved for posterity and researched, enhanced, and put to new uses through our education system." (NEP 2020, p.4. Emphasis added.)

To implement this vision, UGC constituted an expert committee to formulate guidelines for incorporating Indian Knowledge System into the higher education curricula of our country. The purpose of these guidelines for incorporating Indian Knowledge System into higher curricula is to provide a roadmap for systematic study and research of various disciplines of IKS and provide guidelines for incorporating IKS into undergraduate and postgraduate curricula.

2. Background:

Indian Knowledge System encompasses all of the systematized disciplines of Knowledge which were developed to a high degree of sophistication in India from ancient times and all of the traditions and practises that the various communities of India—including the tribal communities—have evolved, refined and preserved over generations.

The UGC-recognized academic institutions provide undergraduate and postgraduate education to the most number of students in India and form the bedrock of the higher education system in India. Therefore, it is imperative that the curriculums in these institutions incorporate IKS-related subjects in their curricula to implement the NEP 2020 in letter and spirit.

It is imperative that we expeditiously implement the following policy prescriptions, which are an important part of the NEP 2020:

a. Research on Indian Knowledge System should be among the mandated tasks to be undertaken by all our institutions of higher learning.

b. Indian Knowledge System should form an essential part of the curricula taught in our schools, colleges and other institutions of higher learning.

3. Scope:

The undergraduate curriculums are diverse and have varied subjects to be covered to meet the needs of the programs. It is not possible to have a single prescription for all the various UG and PG programs in the country. The primary purpose of the guidelines is to help the institutions come up with courses that will introduce the students to all aspects of IKS which are related to their fields of study and to promote interest in knowing and exploring more. A 10-year horizon is envisioned for the application of these guidelines, along with a revision and modification after five years to meet the evolving needs.

2.1 General Guidelines:

1. In view of the importance accorded in the NEP 2020 to rooting our curricula and pedagogy in the Indian context and in the corpus of Indian Knowledge System, every student enrolled in a UG or PG programme should be encouraged to take credit courses in IKS amounting in all to at least five per cent of the total mandated credits**.** It is envisioned that the interested students studying in UG and PG courses may be allowed to take a larger fraction of the total mandated credits in the fields of IKS.
2. At least 50% of the credits apportioned to the IKS should be related to the major discipline and should be accounted for the credits assigned to the major discipline.
3. Special care should be taken to ensure that the course materials for these IKS courses are based on authentic sources—such as source texts, historical accounts, inscriptions and other records, material and other evidence, and also rigorous sociological records of current practices of different communities.
4. The continuity of the Indian Knowledge Traditions from ancient times up to the relatively recent period of the eighteenth or nineteenth century must be emphasized in the design of the course content.
5. Efforts must be made to highlight the characteristic features such as the objectives, methodology and core concepts of the Indian Knowledge Traditions, which distinguish them from other Knowledge Traditions of the world.
6. Wherever possible, contemporary applications of the Indian Knowledge Traditions may be indicated.
7. The medium of instruction for the IKS courses could be any of the Indian languages which have been approved as a medium of instruction in higher education, apart from English and Sanskrit.
8. All the technical terms and citations from the Sanskrit sources should be given in the Devanagari script as well as in English transliteration for any course materials prepared in English.

2.2 Guidelines for IKS Courses in UG Programmes:

1. All the students who are enrolled in the four-year UG programmes should be encouraged to take an adequate number of courses in IKS so that the total credits

of the courses taken in IKS amount to at least five per cent of the total mandated credits. The students may be encouraged to take these courses, preferably during the first four semesters of the UG programme. At least half of these mandated credits should be in courses in disciplines which are part of IKS and are related to the major field of specialization that the student is pursuing in the UG programme. They will be included as a part of the total mandated credits that the student is expected to take in the major field of specialization. The rest of the mandated credits in IKS can be included as a part of the mandated Multidisciplinary courses that are to be taken by every student.

2. All the students should take a Foundational Course in Indian Knowledge System, which is designed to present an overall introduction to all the streams of IKS relevant to the UG programme. The foundational IKS course should be broad-based and cover introductory material on all aspects. It would enable students to explore the most fundamental ideas that have shaped Indian Knowledge Traditions over the centuries. Brief outlines of a few Model Curricula that may be followed in the Foundational Courses in IKS are presented in Appendix.
3. All UG-teaching Institutions should offer a large number of Elective Courses in IKS, from which the students may choose appropriately so as to complete a requisite number of courses and credits in IKS. These credits may be apportioned to the core disciplinary courses and the multidisciplinary courses. These courses could be in any of the disciplines/topics that are part of IKS, which are related to the field of specialization that the student is pursuing in the UG programme.
4. The students may be allowed to opt for internship/apprenticeship in any of the disciplines/topics that are part of IKS.
5. Wherever possible, the students may be encouraged to choose a suitable topic related to IKS for their project work in the 7/8th semesters of the UG programme.
6. Students who are enrolled in UG programmes in medicine may take a Credit Course in the first year on Indian Systems of Medicine, which will provide them with a "basic understanding of Ayurveda, Yoga and Naturopathy, Unani, Siddha, and Homeopathy" (NEP 20.2), which are continuing traditions of medicine that still attend to the health needs of large sections of the Indian population. During the second year, the students may take a two-semester credit course on the Theory and Practice of any one of the Indian Systems of Medicine, such as Ayurveda, Siddha, Yoga, etc.
7 These provisions may be incorporated into the curricular framework for the respective programmes with the approval of the competent authority/body of the Higher Educational Institutions/the concerned professional councils wherever applicable.

2.3 Guidelines for IKS Courses at the PG Level

1. All the students studying for PG programmes in Arts, Commerce and Sciences should take an adequate number of advanced credit courses in any of the disciplines/topics that are part of IKS and related to their subject of specialization

so that the total credits of the courses taken by the student in IKS amount to at least five percent of the total mandated credits.

2. The students may be allowed to opt for taking additional courses in disciplines/ topics that are part of IKS if such an option is available and is consistent with the requirements of the PG programme.

2.4 Guidelines for IKS Courses in Sanskrit and Indian Language Universities

1. There are a number of Universities in the country which are designated as Sanskrit or Indian Language Universities. These Universities should strive to broaden their scope and develop into Universities of Indian Knowledge System without giving up their focus on Sanskrit or the Indian Language of their region.
2. All students who are enrolled in UG programmes in the Sanskrit or Indian Language Universities should take the following credit courses in IKS:
   - A two-semester Foundational Course in IKS is designed to present an overall introduction to all the streams of IKS.
   - A two-semester Multidisciplinary Course on "IKS and Contemporary Knowledge in a Selected Discipline". The Universities should make due efforts to offer such courses in several disciplines that are part of IKS so that the students can choose their courses appropriately. For instance, the students studying Nyāya-Śāstra could opt to take a two-semester course on "Nyāya and the Greco-European Tradition of Logic."
   - A Course on "Manuscriptology and Critical Editing of Texts".

2.5 Guidelines for PG Programmes in Disciplines that are Part of IKS

1. Currently, there are some PG courses in disciplines that are part of IKS, such as Master of Arts in Indian Music, Master of Arts in Indian Philosophy, PG courses in different streams of Indian Systems of Medicine, etc. Many of the Sanskrit Universities also have an Acharya or Masters Degree programme in various Śāstras.
2. It is the view of this Committee that these courses need to be redesigned so as to ensure that they are anchored in the tradition of IKS. As of now, the PG courses in Indian Music, Indian Philosophy, or even Ayurveda or the studies of Śāstras in Sanskrit Universities are not particularly related to the perspective of IKS and tend to teach Western epistemologies and methodologies for studying and conducting research in these streams. While some of the latter may be required, the perspective and the main emphasis of these courses have to be rooted in the perspective of IKS.
3. After such PG programmes in disciplines that are part of IKS are approved and begin to be taught, the same curricula may be adopted for conducting NET examinations in these disciplines that are part of IKS. For instance, students who study a master's programme in Nyaya or Ganita will write a NET examination in Nyaya or Ganita, respectively.

2.6 Suggestions for effective implementation

1. All Universities should make due effort to promote and nurture UG/PG courses in all the disciplines that are part of IKS.
2. All students should be exposed to the common underlying philosophical foundation of the various disciplines that are part of IKS.
3. At least one to two lectures on the fundamental vocabulary of IKS should be conducted to familiarize faculty with the common terms used in IKS.
4. A strong emphasis should be placed on providing exposure to the primary texts of IKS, which is required for acquiring a deeper understanding.
5. Ready access to a wide range of primary and secondary resources should be provided to enable teachers to understand the continuous and vibrant tradition of IKS. These materials may be developed by a team of subject experts and made available to teachers. Extreme care must be taken to ensure the authenticity and scholarly nature of the content that may be developed for the orientation/induction and refresher courses.
6. A list of IKS content available in regional languages should be compiled and made available for the benefit of teachers.
7. Sharing the life and work of contemporary scholars and innovators who have made seminal contributions in their fields using IKS would motivate teachers to explore various dimensions of IKS.
8. To connect with the oral tradition of IKS, one practical session on the ancient technique of memorization, with a few examples from primary texts, would be helpful.
9. A few immersive sessions on Yoga, Meditation, Ayurveda, Classical Music, Indian Craft traditions, etc., should be arranged to give students some grounding in the experiential aspects of IKS.
10. The course curriculum development should be closely integrated with the teacher training in IKS.

APPENDIX

MODEL CURRICULA OF COURSES IN INDIAN KNOWLEDGE SYSTEM

Below are a few model curricula of courses in Indian Knowledge System (IKS) that may be useful for designing appropriate courses, including Foundation Courses in IKS and some possible Elective Courses on disciplines that are part of IKS, such as Indian Mathematics and Indian Astronomy. Apart from Elective Courses in these and other disciplines which are part of IKS such as Indian Logic, Indian Linguistics, Indian Metallurgy, Indian Architecture, etc., there can also be Elective Courses on Special Topics that are part of IKS, such as Indian Algebra, Indian Astronomical Instruments, Indian Iconography, Indian Musical Instruments, Water Management in Pre-British India, etc.

A. FOUNDATIONAL COURSES IN IKS

I. INTRODUCTION TO IKs

1. Bharatavarsha—A Land of Rare Natural Endowments:

Largest cultivable area in the world. Protected and nurtured by Himalayas. The Sindhu-Ganga plain and the great coastal plains. The great rivers of India.

Abundant rains, sunshine and warmth, vegetation, animals and mineral wealth. Most populous country in the world. India's prosperity held the world in thrall.

Splendid geographical isolation of India and the uniqueness of Indian culture.

2. Foundational Literature of Indian Civilisation:

The Vedic Corpus. The Itihasas— Ramayana and Mahabharata, and their important regional versions. The Puranas.

The role of Itihasas and Puranas in understanding the Vedas.

Foundational Texts of Indian Philosophies, including the Jaina and Bauddha. Foundational Texts of Indian Religious Sampradayas, from the Vedic period to the Bhakti traditions of different regions.

i. **The Vedangas and Other Streams of Indian Knowledge System**:

The six Vedangas — Siksha, Vyakarana, Chandas, Nirukta, Jyotisha and Kalpa. Other streams of Indian Knowledge System such as Ayurveda, Sthapatya, Natyasastra, Dharmasastra, Arthasastra, etc.

Continuity of the Corpus.The Indian way of continuing the evolution of knowledge through commentaries, interpretations and revisions of the foundational texts.

The large corpus of literature on IKS in Sanskrit and other Indian languages. Others sources for the study of Indian Knowledge System.

ii. **Indian Language Sciences**:

Language Sciences and the preservation of the Vedic corpus.

Varnamala of Indian languages based on classification of sounds on the basis of their origin and effort involved. The special feature of the scripts of most Indian languages, that each symbol is associated with a unique sound.

Word formation in Sanskrit and Indian languages. Basic purpose of the Science of Vyakarana as established by Panini.

Important texts of Indian Language Sciences —Siksha or phonetics, Nirukta or etymology, Vyakarana or Grammar, Chandas or Prosody.

How the Indian Language Sciences continued to flourish in the 18//19 the centuries. Navya-nyaya and Navya-vyakarana in Navadvipa, Varanasi and West and South India.

iii. Indian Mathematics:

Numbers, fractions and geometry in the Vedas. Decimal nomenclature of numbers in the Vedas. Zero and Infinity. Simple constructions from Sulba-sutras.

The development of the decimal place value system which resulted in a simplification of all arithmetical operations. Linguistic representation of numbers.

Important texts of Indian mathematics. Brief introduction to the development of algebra, trigonometry and calculus.

How Indian mathematics continued to flourish in the 18/19/20th centuries. Kerala School. Ramanujan.

6. Indian Astronomy:

Ancient records of the observation of the motion of celestial bodies in the Vedic corpus. Sun, Moon, Nakshatra & Graha.

Astronomy as the science of determination of time, place and direction by observing the motion of the celestial bodies. The motion of the Sun and Moon. Motion of equinoxes and solstices. Elements of Indian calendar systems as followed in different regions of India.

Important texts of Indian Astronomy. Basic ideas of the planetary model of Aryabhata and its revision by Nilakantha.

Large corpus of inscriptions recording observation of eclipses. Astronomical instruments.

How Indian astronomy continued to flourish in the 18/19th centuries. Astronomical endeavours of Jaisingh, Sankaravarman, Chandrasekhara Samanta.

7. Indian Health Sciences:

Vedic foundations of Ayurveda. Ayurveda is concerned both with maintenance of good health and treatment of diseases.

Basic concepts of Ayurveda. The three Gunas and Three Doshas, Pancha-mahabhuta and Sapta-dhatu. The importance of Agni (digestion). Six Rasas and their relation to Doshas. Ayurvedic view of the cause of diseases.

Dinacharya or daily regimen for the maintenance of good health. Ritucharya or seasonal regimen.

Important Texts of Ayurveda. Selected extracts from *Astāngahrdaya* (selections from *Sūtrasthāna*) and *Suśruta-Samhitā* (sections on plastic surgery, cataract surgery and anal fistula). The large pharmacopeia of Ayurveda.

Charaka and Sushruta on the qualities of a Vaidya. The whole world is a teacher of the good Vaidya. Charaka's description of a hospital. Hospitals in ancient and medieval India.

How Ayurveda continued to flourish till 18/19th centuries. Surgical practices, inoculation. Current revival of Ayurveda and Yoga.

8. Classical Literature in Sanskrit and Other Indian Languages:

The nature and purpose of Kavya. Drisya and Sravya Kavyas.

The ideas of Indian aestheticians on what constitutes the soul of Kavya.

Important examples of classical literature in Sanskrit and other Indian languages.

9. Indian Education:

Preservation of culture, tradition and Dharma through education. Svadhyaya, Pravachana. Also continuity of the family and the vamsha, who are the carriers of knowledge, tradition and Dharma.

The extent, inclusiveness and the sophistication of indigenous education in early19th century India.

10. The Purpose of Knowledge in India:

Para Vidya and Apara Vidya. The corpus connected with Para Vidya. Learning and formalization of concepts associated with Para Vidya also form part of Apara.

Apara Vidya. Nature and purpose of sciences, technologies, and all human knowledge concerning the world and the society.

The concept of Rita, Dharma. The cycle of mutual dependence of humans and all aspect of creation. Yajna and the inviolable discipline of sharing and caring.

11. Methodology of Indian Knowledge System:

Systematization of knowledge fields as Sastra. Each Sastra has a clearly defined purpose in Vyavahara.

The means of valid knowledge (Pramanas). Perception (Pratyaksha), Inference (Anumana) and Textual Tradition (Agama), as discussed in the canonical texts of all the disciplines.

The importance of Pratyaksha and Agama in relation to Anumana.

12. Indian Architecture and Town Planning:

The importance of Sthapatya-veda**.** The ancient cities of the Indus Saraswati region. Town planning and drainage systems.

Examples of the significance of architecture and materials in Ramayana and Mahabharata.

Public opulence and private austerity in Indian architecture. Why there are many more of Temples than Palaces.

Important texts of Architecture and Sculpture. The prevalence of high Indian architecture in almost all parts of India except the Ganga plains. Examples of high Indian architecture from ancient and medieval periods from different parts of India.

The building of Jaipur in the 18th century. How temple art and architecture continues to flourish in modern India.

13. Indian Fine Arts:

The importance of Gandharva-veda. Natyasastra on the nature and purpose of fine arts.

Basic concepts of Indian music and dance. Important texts of Indian music, dance and painting. Indian musical instruments.

Different schools of music, dance and painting in different regions of India. Important examples of Indian painting in various part of India.

Musicology as a science. Harmonising Lakshya and Lakshana (practise and theory).

Major developments in the science and practice of music the 17/18/19th centuries. The current revival of music and dance in India.

14. Indian Agriculture:

The significance of agriculture and irrigation as emphasised in the Ramayana, Mahabharata and other texts.

Mention of Indian agriculture by the Greek historians and later travellers. Significance of agriculture and irrigation for the kings of Indian tradition.

Major water-bodies of the ancient times. The Ery system of south India.

Excellence of Indian agricultural technologies as observed by more recent European observers.

Productivity of Indian agriculture in medieval Thanjavur and eighteenth century Allahabad, Chengalpattu, etc.

Indian attitude towards agriculture, based on Walker and later reports.

15. Indian Textiles:

India as the ancient home of cotton and silk fabrics. Weaving formed the most significant part of Indian economy after agriculture.

Varieties of textiles and dyes developed in different regions of India.

India as a leading exporter of textiles in the world in the 17/18/19th centuries.

16. Indian Metallurgy:

Vedic references to metals and metal working. Mining and manufacture in India of Zinc, Iron, Copper, Gold, etc., from ancient times.

Indian texts which refer to metallurgy. Important specimens of metal workmanship preserved/found in different parts of India.

The significance and wide prevalence of ironsmith and other metal workers in the pre-modern era.

European observers on the high quality and quantity of Indian iron and steel in the 18/19th centuries.

17. Indian Polity and Economy:

Indian conception of well-organised Polity and flourishing Economy as expounded in the foundational texts. The notion of Bharartavarsha as a Chakravarti-Kshetra and important attributes of Chakravartin.

King as the protector of Dharma. King as the strength and support of the weak. King as the protector of Varta. King as the protector of the times.

Meaning of Varta: Krishi, Gopalana and Vanijya forming the basis of Varta and the core of economic activity in society. The importance of sharing.

Grama as the centre of the polity.

18. The Outreach of Indian Knowledge System:

The outreach of Indian Knowledge System beyond Indian boundaries form the ancient times. Outreach to East, Southeast, Central and Southeast Asia of Indian phonetic script, decimal value place system based arithmetic, algebra, astronomy and calendar, medical pharmacopeia, architecture, methods of making iron and steel, cotton textiles, etc.

The transmission of Indian linguistics, knowledge of plants, iron and steel metallurgy, textiles and dyeing, shipbuilding etc., to Europe in 17/18/19th centuries.

Current global outreach of Ayurveda, Yoga and Indian Fine Arts.

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B. ELECTIVE COURSES ON SELECTED DISCIPLINES/ TOPICS THAT ARE PART OF IK

I. MATHEMATICS IN INDIA: FROM VEDIC PERIOD TO MODERN TIMES

1. Introductory Overview

Mahāvīrācārya on the all-pervasiveness of Ganita. The algorithmic approach of Indian Mathematics. Overview of development of Mathematics in India during the ancient and early classical Period (till 500 CE), later classical period (500-1250) medieval period (1250-1750) and the modern periods (1750- present). Proofs in Indian Mathematics. The genius of Srinivasa Ramanujan (1887-1920). Lessons from History.

2. Mathematics in the Vedas and Śulva Sūtras

Mathematical references in Vedas. The extant Śulbasūtra texts & their commentaries. The meaning of the word Śulbasūtra. Qualities of a Śulbakāra. Finding the cardinal directions. Methods for obtaining perpendicular bisector. Bodhāyana's method of constructing a square. The Bodhāyana Theorem (so called Pythagoras Theorem)

Applications of Bodhāyana Theorem. Constructing a square that is the difference of two squares. Transforming a rectangle into a square. To construct a square that is n times a given square. Transforming a square into a circle (approximately measure preserving). Rational approximation for $\sqrt{2}$. Construction of Citis. Details of fabrication of bricks, etc.

3. Pāṇini's *Aṣṭādhyāyī*

Development of Vyākaraṇa or Śabadaśāstra. Pāṇini and Euclid. Method of Pāṇini's *Aṣṭādhyāyī*. Śiva-sūtras and Pratyāhāras. Context-sensitive rules and other techniques of *Aṣṭādhyāyī*. Pāṇini and zero. Patañjali on the method of *Aṣṭādhyāyī*. *Vākyapadīya* on *Aṣṭādhyāyī* as an upāya.

4. Piṅgala's *Chandaḥśāstra*

Development of Prosody or Chandaḥśāstra. Long (guru) and short (laghu) syllables. Scanning of Varṇavṛtta and the eight Gaṇas. Pratyayas in Piṅgala's *Chandaḥśāstra*. Prastāra or enumeration in the form of an array. Saṅkhyā or the total number of metrical forms of n syllables. Naṣṭa and Uddiṣṭa (the association between a metrical form and the row-number in the prastāra through binary expansion). Lagakriyā or the number of metrical forms in the prastāra with a given number of Laghus. Varṇameru and the so called "Pascal Triangle".

5. Mathematics in the Jaina Texts

Place of Mathematics in Jaina literature. Important Jaina mathematical works. Jaina geometry. Circumference of a circle. Area of a circle. Relation between chord, śara (arrow) and diameter, etc. Approximation for the value of π. Notion of different types of infinity. The law of indices. Permutations and Combinations.

6. Development of Place Value System

Earliest evidence of the use of place value system. Numerals found in the inscriptions (Brāhmi & Kharosṭhi). Use of Zero as a symbol in Piṅgala's *Chandaḥśāstra*. References to use of decimal place value system in the commentary *Vyāsabhāṣya* on *Yogasūtra* and in Southeast Asian Inscriptions. Different systems of numeration employing place value system. Bhūtasaṅkhyā system. Āryabhaṭan system. Kaṭapayādi system. Algorithms for arithmetical operations based on decimal place value system.

7. *Āryabhaṭīya* of Āryabhaṭa

Āryabhaṭa, his period and his work *Āryabhaṭīya*. Names of the notational places. Square and Squaring. Algorithm for finding the square root. Cube and cubing. Algorithm for finding the cube root. Formula for the area of a triangle. Bhāskara I on altitude and area of a triangle. Numerical examples

Area of a circle, trapezium and other planar figures. Approximate value of π. Computation of tabular Rsines (geometric and difference equation methods). Approximate formula for Rsine (as given by Bhāskara I). Problems related to gnomonic shadow. Bhujā-koṭi-karṇa-nyāya, jyā-śara-nyāya and their applications. Arithmetic progressions. Finding sum of natural numbers, sum of sums, and so on.

Some algebraic identities. Rule of three. Problems on interest calculation. Ekavarṇa-samikaraṇa and anekavarṇa-samikaraṇa. The Kuṭṭaka problem (sāgra and niragra-kuṭṭaka). Illustrative examples.

8. *Brāhmasphuṭasiddhānta* of Brahmagupta

Introduction. Twenty logistics. Cube root. Rule of Three, Five Seven, etc. Mixtures. Interest calculations, etc. Progressions: Arithmetic and Geometric. Plane figures. Triangles, right triangles and quadrilaterals.

Diagonals of a cyclic quadrilateral. Rational triangles and quadrilaterals. Chords of a circle. Volumes with uniform and tapering cross-sections. Pyramids and frustum. Shadow problems.

Mathematical operations with plus, minus and zero. Rules in handling surds (karaṇī) Operations with unknowns (avyakta-ṣaḍvidha). Equations with single unknowns (ekavarṇa-samīkaraṇa). Equations with multiple unknowns (anekavarṇa-samīkaraṇa). Equations with products of unknowns (bhāvita). Brahmagupta on kuṭṭaka. The Second order indeterminate equation (Vargaprakṛti). Bhāvanā principle and its applications.

9. Bakṣālī Manuscript

The discovery of Bakṣālī Manuscript. Its antiquity and uniqueness. Use of symbols. Symbol for negative sign (kṣaya). Symbol for denoting unknown quantities (yāvatāvat). Solution of indeterminate equations. Formula for approximate value of surds. Some interesting problems involving simultaneous equations.

10. *Gaṇitasārasaṅgraha* of Mahāvīra

Introduction. Arithmetical operations, operations with zero. Squares, cubes, square roots, cube roots. Arithmetical and Geometric progressions, Citi (summation). Manipulations with fractions and solutions of equations. Mixed problems including interest calculations.

Vallīkāra-kuṭṭākara – linear indeterminate equations. Two and more simultaneous indeterminate equations. Other indeterminate equations. Vicitra-kuṭṭākara – Truthful and untruthful statements. Sums of progressions of various types. Variable velocity problem

Plane figures**:** Circle**,** Dīrghavṛtta, Annulus. Ratio of circumference and diameter. Segment of a circle. Janya operations: rational triangles, quadrilaterals. Excavations: Uniform and tapering cross-sections, volume of a sphere. Time to fill a cistern. Shadow problems.

11. Development of Combinatorics

Combinatorics in Āyurveda. Gandhayukti of Varāhamihira Mātrā-vṛttas or moric metres. Prastāra or enumeration of metres of *n*-mātrās in the form of an array. Saṅkhyā or the total number of metrical forms of given number of mātrās. The Virahāṅka sequence (so called Fibonacci sequence. Naṣṭa and Uddiṣṭa processes for finding the metrical form given the row-number and vice versa in a prastāra. Mātrā-meru to determine the number of metrical forms with a given number of gurus. Representation of any number as a sum of Virahāṅka numbers.

Saṅgīta-ratnākara of Śārṅgadeva (c.1225). Tāna-Prastāra or enumeration of permutations or tānas of svaras. Prastāra, the rule of enumeration of permutations in the form of an array. Khaṇḍameru and the processes of naṣṭa and uddiṣṭa. Factorial representation of Śārṅgadeva. Tāla-Prastāra: Enumeration of tāla forms. The tālāṅgas: Druta, Laghu, Guru and Pluta and their values. Prastāra: Rule of enumeration of all tāla-forms of a given value. Saṅkhyā and the Śārṅgadeva-sequence of numbers. The processes of naṣṭa and uddiṣṭa. Representation of natural numbers as sums of Śārṅgadeva-numbers. Laghu-Meru. The general relation between prastāra and representation of numbers.

12. *Līlāvatī* of Bhāskarācārya

Introduction. Importance of *Līlāvatī*. Arithmetical operations: Inversion method, rule of supposition. Solution of quadratic equations. Mixtures. Combinations, progressions.

Plane figures**:** Right triangles, applications. Sūcī problems. Construction of a quadrilateral: Discussion on earlier confusions. To find the second diagonal, given the four sides and a diagonal of a quadrilateral. Cyclic quadrilaterals. Value of π, area of a circle, surface area of a sphere, volume of a sphere.

Regular polygons inscribed in a circle. Expression for a chord in a circle. Excavations and contents of solids. Shadow problems (advanced problems). Importance of rule of proportions. Combinations (advanced problems).

13. *Bījagaṇita* of Bhāskarācārya

Development of Bījagaṇita or Avyaktagaṇita (Algebra) and Bhāskara's treatise on it. Understanding of negative quantities. Development of algebraic notation. The Vargaprakṛti equation $X^2 - D Y^2 = K$, and Brahmagupta's bhāvanā process. The Cakravāla method of solution of Jayadeva and Bhāskara.

Bhāskara's examples $X^2 – 61Y^2 = 1$, $X^2 – 67Y^2 = 1$. The equation $X^2 - D Y^2 = -1$. Solution of general quadratic indeterminate equations. Bhāskara's solution of a bi-quadratic equation.

Review of the Cakravāla method. Analysis of the Cakravāla method by Krishnaswami Ayyangar. History of the solution of the "Pell's Equation" $X^2 - D Y^2 = 1$. Solution of "Pell's equation" by expansion of √D into a simple continued fraction. Bhāskara semi-regular continued fraction expansion of √D. Optimality of the Cakravāla method.

14. *Gaṇitakaumudī* of Nārāyaṇa Paṇḍita

Importance of *Gaṇitakaumudī*. Solutions of quadratic equations. Double equations of second and higher degree – rational solutions. Determinations pertaining to the mixture of things. Interest calculations – payment in installments

Meeting of travelers. Progressions. Vārasaṅkalita: Sum of sums. The kth sum. The kth sum of a series in A.P. The Cow problem. Diagonals of a cyclic quadrilateral – Third diagonal, area of a cyclic quadrilateral. Construction of rational triangles with rational sides, perpendiculars, and segments whose sides differ by unity. Generalisation of binomial coefficients and generalized Fibonacci numbers.

Vargaprakṛti. Nārāyaṇa's variant of Cakravāla algorithm. Solutions of Vargaprakṛti and approximation of square roots. Bhāgadāna: Nārāyaṇa's method of factorisation of numbers. Aṅkapāśa (Combinatorics). Enumeration (prastāra) of generalised mātrā-vṛttas (moric metres with more syllabic units in addition to Laghu and Guru). Some sequences (paṅkti) and tabular figures (meru) used in combinatorics. Enumeration (prastāra) of permutations with repetitions. Enumeration (prastāra) of combinations.

15. Magic Squares

The earliest textual references and references in inscriptions. The sarvatobhadra square of Varāhamihira. Nārāyaṇa's classification of magic squares into samagarbha (doubly-even numbers of the form 4m), viṣamagarbha (singly-even or numbersof the form 4m + 2) and viṣama (odd). Use of Kuṭṭaka to find the arithmetic sequences to be used in magic squares. 4x4 Pandiagonal magic squares of Nārāyaṇa.

Ancient method for the construction of odd magic squares and doubly even squares. The folding method (samputīkaraṇa) of Nārāyaṇa for samagarbha squares. The folding method for Viṣama squares. Illustrative examples.

16. Kerala School of Astronomy and Development of Calculus

Background to the Development of Calculus (c.500-1350). The notions of zero and infinity. Irrationals and iterative approximations. Second order differences and interpolation in computation of Rsines. Summation of infinite geometric series. Instantaneous velocity (tātkālika-gati). Surface area and volume of a sphere. Summations and Repeated summations (saṅkalita and vārasaṅkalita). The Kerala School of Astronomy and the Development of Calculus. Mādhava (c. 1340-1420) and his successors to Acyuta Piśāraṭi (c. 1550-1621). Nīlakaṇṭha (c.1450-1550) on the irrationality of π. Nīlakaṇṭha and the notion of the sum of infinite geometric series. Binomial series expansion. Estimating the sum $1^k + 2^k + \dots n^k$ for large n.

Mādhava Series for π. End-correction terms and Mādhava continued fraction. Transformed series for π which are rapidly convergent. History of Approximations to π. Nīlakaṇṭha's derivation of the Āryabhaṭa relation for second-order Rsine differences. Mādhava series for Rsine and Rcosine. Nīlakaṇṭha and Acyuta formulae for instantaneous velocity.

Āryabhaṭa's sine table (makhi, bhaki, phaki…). Āryabhaṭa's recursion relation and the approximation involved in it. Attempts to improve the sine values by Lalla, Govindasvāmi, Vaṭeśvara, etc. Bhāskara's formula for sin $(A + B)$ and its application. The refined recursion relation in *Tantrasangraha* and its commentary. Mādhava's sine series and the use of mnemonics vidvān, tunnabala etc. Mādhava's sine table. Comparison of sine-tables of Āryabhaṭa, Govindasvāmi, Vaṭeśvara and Mādhava.

17. Trigonometry and Spherical Trigonometry

Crucial role of trigonometry in astronomy problems. Indian sines, cosines: Bhujājyā, Koṭijyā, sine tables. Interpolation formulae. Determination of the exact values of 24 sines. Bhāskara's Jyotpatti sin (18º), sin (36º).

Sine of difference of two angles. Sines at the interval of 3º, 1.5º. Jīve-paraspara-nyāya. Sines at the interval of 1º. Trigonometry in later texts such as *Siddhāntatattvaviveka* of Kamalākara

Spherical trigonometry in astronomy: Tripraśna problems. Applications to specific diurnal problems: Duration of day (carajyā), Time from shadow. Systematic treatment of spherical trigonometry problems in Nīlakaṇṭha's *Tantrasaṅgraha*. Proofs of *Tantrasaṅgraha* results in *Yuktibhāṣā.*

18. Proofs in Indian Mathematics

Upapattis or proofs in Indian mathematical tradition. Early European scholars of Indian Mathematics were aware of upapattis. Some important commentaries which present upapattis. Bhāskarācārya II on the nature and purpose of upapatti. Upapatti of bhujā-koṭi-karṇa-nyāya (Baudhayana-Pythagoras theorem). Upapatti of kuṭṭaka process. Restricted use of tarka (proof by contradiction) in Indian Mathematics. The Contents of *Gaṇita-yukti-bhāṣā*. *Yukti-bhāṣā* demonstration of bhujā-koṭi-karṇa-nyāya. Estimating the circumference by successive doubling of circumscribing polygon.

Expression for abādhās, area and circum-radius of a triangle. Theorem on the sum of the product of chords (jyāvargāntara-nyāya). Theorem on the difference of the squares of the chords (jyāvargāntara-nyāya). From jyāsaṃvarga-nyāya to jyotipatti (generation of tabular sines). The cyclic quadrilateral. Expression for the diagonals in terms of the sides. Expression for the area in terms of the diagonals. Expression for the area and circum-radius in terms of the sides.

Yuktibhāṣā estimate of the samaghāta saṅkalita $1^k + 2^k + ... n^k$ for large n. *Yuktibhāṣā* estimate of Vārasaṅkalita. *Yuktibhāṣā* derivation of Mādhava Series for π. *Yuktibhāṣā* derivation of end-correction terms. *Yuktibhāṣā* derivation of Mādhava Rsine and Rcosine Series. Upapatti and "Proof". Lessons from history.

19. Mathematics in Modern India

Continuing tradition of Indian Astronomy and Mathematics (1770-1870). Surveys of indigenous education in India (1825-1835). The Orientalist-Anglicist debate shaping the British policy on education (c.1835). Survival of indigenous education system till 1880. Modern Scholarship on Indian Mathematics and Astronomy (1700-1900). Rediscovering the Tradition (1850-1900). Development of Higher Education and Modern Mathematics in India (1850-1910). Srinivasa Ramanujan (1887-1920). Brief outline of the life and mathematical career of Ramanujan. Hardy's assessment of Ramanujan and his Mathematics (1922, 1940). Some highlights of the published work of Ramanujan and its impact. Selberg's assessment of Ramanujan's work (1988). The saga of Ramanujan's Notebooks. Ongoing work on Ramanujan's Notebooks. The enigma of Ramanujan's Mathematics. Ramanujan not a Newton but a Mādhava.

Rediscovering the tradition (1900-1950). Rediscovering the tradition (1950-2010). Modern scholarship on Indian Mathematics (1900-2010). Development of modern mathematics in India (1910-1950). Development of modern mathematics in India (1950-2010). Development of higher education and scientific research in India (1900-1950). Development of higher education and scientific research in India (1950-2010). Comparison with global developments.

Suggested References

1. B. Datta and A. N. Singh, *History of Hindu Mathematics*, 2 Parts, Lahore, 1935, 1938; Reprint, Asia Publishing House, Bombay 1962; Reprint, Bharatiya Kala Prakashan, Delhi 2004.
2. C. N. Srinivasiengar, *History of Indian Mathematics*, The World Press, Calcutta, 1967.
3. T. A. Saraswati Amma, *Geometry in Ancient and Medieval India*, Motilal Banarsidass, Varanasi, 1979.
4. S. Balachandra Rao, *Indian Mathematics and Astronomy: Some Landmarks*, 3rd Ed. Bhavan's Gandhi Centre, Bangalore, 2004.
5. G. G. Emch, M. D. Srinivas and R. Sridharan, Eds., *Contributions to the History of Mathematics in India*, Hindustan Book Agency, Delhi, 2005.
6. C. S. Seshadri, Ed., *Studies in History of Indian Mathematics*, Hindustan Book Agency, Delhi, 2010.
7. G. G. Joseph, *Indian Mathematics Engaging the World from Ancient to Modern Times*, World Scientific, London, 2016.
8. P. P. Divakaran, *The Mathematics of India Concepts Methods Connections*, Hindustan Book Agency 2018. Rep Springer New York, 2018.
9. *Gaṇitayuktibhāṣā* (c.1530) of Jyeṣṭhadeva (in Malayalam), Ed. with Tr. by K. V. Sarma with Explanatory Notes by K. Ramasubramanian, M. D. Srinivas and M. S. Sriram, 2 Volumes, Hindustan Book Agency, Delhi, 2008.

1. BASICS OF INDIAN ASTRONOMY

1. Introduction

The science of Astronomy. Astronomy as one of earliest sciences; observational astronomy in the Vedic corpus. Emergence of Jyotiḥśāstra encompassing the three skandhas of Gaṇita (Astronomy), Horā (Horoscopic Astrology and Saṃhitā (Omens and Natural Phenomena). The purpose of Astronomy—as stated in the texts. Contents of a typical Indian astronomical *Siddhānta* text. Broad classification of the texts in Indian astronomy. Names of some of the prominent astronomers and their important contributions. Highlight the continuity of the Indian astronomical tradition (1400 BCE – 19th cent CE).

2. The different units of time discussed in the texts

Brief introduction to the concept of time (approach of physics and philosophy). Quote from Bhāskara I's commentary at the beginning of Kālakriyā; also quote the verse in the famous text *Sūryasiddhānta*. Recount the currently used units of time—duration of year, month, week, etc. in the Gregorian calendrical system—subtly point out that they do not have any astronomical basis whatsoever. Introduce the different shorter units of time discussed in Indian astronomical texts year, month, fortnight, *tithi*, etc. Introduce larger units or time like *yuga, mahāyuga, manvantara* and *kalpa*.

3. Systems employed for representing numbers

Highlight the need for having different systems for representing numbers in those days. Explain the three systems adopted - *Bhūtasaṅkhyā, Kaṭapayādi and Āryabhaṭīyapaddhati*. With illustrative examples, bring out their beauty and ingenuity. Briefly discuss the advantages in each of these systems.

4. Spherical trigonometry

Introduce the notion of shortest path on a non-Euclidean surface. Definition of great circle, small circle, spherical triangle, etc. Their illustration using the Earth as an example, which the students will be familiar with. Compare and contrast the properties of a spherical triangle with a planar triangle. Derive the cosine and sine formula from 'first' principles. Introduce the four-part formula. Work out a few illustrative problems (such as distance travelled by a flight along the great circle arc, small circle arc, etc) that would help visualise the circles on a sphere, as well as assimilate the application of the formulae. Demonstrate how to derive the sine formula simply using the planar triangles, and their projections inside the sphere.

5. Celestial Sphere

The notion of celestial sphere and the need for its conception. The different coordinate systems (horizontal, equatorial and ecliptic) employed. The range of the coordinates in each of these systems. The advantages and disadvantages of one system over the other. Some illustrative examples for converting one set of coordinates into another. Indian names for the fundamental circles and the coordinates used in these systems.

6. What is *Pañcāṅga*?

Division of the celestial sphere/ecliptic into 12 and 27 equal parts — *rāśi* and *nakṣatra* division. Explain their significance by pointing out their basis; that is, they are connected with the duration of 12 lunar months and the period of moon's revolution around the earth, and not introduced arbitrarily. Explain the five elements that constitute *Pañcāṅga* – and also bring out their astronomical significance. Also point out that they are essentially different units of time. Illustrate with numerical examples the computation of these elements in a *Pañcāṅga*. Explain how to compute the average period of a lunar month; Bring out the need for the introduction of an *adhikamāsa* in the calendrical system. Outline the broad categories into which different calendars that are followed can be put into— namely solar, lunar and luni-solar.

7. Key concepts pertaining to planetary computations

The revolution numbers of various planets, nodes, apogees, etc.; The count of the number of civil days, *adhikamāsas*, etc. in a *mahāyuga*. Introduce the concept of Ahargaṇa, and its significance; The basis for choice of epoch. Calculation of *Ahargaṇa*; Illustration with a few numerical examples choosing contemporary dates – using *siddhāntic* text (to begin with). Explain the computation of mean motion of planets, and how its computation along with the *Ahargaṇa* can help in finding the mean position of planets.

8. Computation of the true longitudes of planets

Provide an overview of the steps involved in the computation of the true longitudes. Explain *manda-saṃskāra* in detail using epicyclic model and eccentric model. Outline the nature of the resultant orbit, etc, and explain how this correction takes into account the eccentric nature of the planetary orbit. Emphasise and make the students appreciate the simplification achieved in computation by the 'constraint' $r/R = r_0/R$. Explain *śīghra-saṃskāra* in detail; Point out how this correction boils down to the transformation of the heliocentric coordinates to geocentric. Also indicate how this simple model takes care of the retrograde motion of the planets. Bring out the distinction between the inner and outer planets.

9. Precession of equinoxes – *sāyana* and *nirayaṇa* longitude

Introduce the concept of precession of equinoxes. Explain solsticial and equinoctial points, and connect them to the concept of *uttarāyaṇa* and *dakṣiṇāyana* in the Indian calendrical system. Derive the formula for finding the declination of the sun on any day at any time, and also illustrate it with examples. Also highlight how crucial its accurate computation is for the computation of various other quantities precisely — including the problem of finding the direction and the latitude of the place — even if we choose to do them by experimental methods.

10. Finding the cardinal directions and the latitude of a place

Introduce *śaṅku* (the gnomon), and explain how it has to be prepared as described in the texts. Describe the experimental set up that has to be made meticulously for conducting experiments with *śaṅku* and doing shadow measurements. Explain how with a very simple experiment the directions at a given place can be easily and precisely determined. Also point out that this experimental method is very old—described even in the *Śulbasūtras*. Also outline the theoretical basis for the formula that has been given for correcting the points marked in connection with determination of the direction using *śaṅku*. Bring out the versatility of this simple device *śaṅku* in determining a variety of physical quantities of interest including the latitude of the place. Explain the concept of parallax in general, and how it introduces an error – that is unavoidable in conducting this experiment for determining the latitude of the place. Outline the corrections that have been prescribed in the text that would take into account the above error, as well as the fact that sun is not a point source of light.

11. Determination of the variation of the duration of the day at a given location

Introduce the 6'o clock circle and its significance. Derive the formula for the hour angle at sunset, and explain how the latitude and the declination of the sun play a role in it. Explain the concept of *cara* as outlined in the Indian astronomical texts that captures the variation in the duration of the day at a given location. Present the formula for determining the local time using shadow measurements. Also outline how *cara* plays a role in determining this local time. Bring out the distinction between this local time and the standard time that we are generally familiar with and generally keep track of.

12. *Lagna* and its computation

Introduce the concept of *lagna*, and how non-trivial a problem it is to determine it precisely. Also point out how this is deeply connected with fixing times for various social and religious functions such as marriage, etc. Bring out the connection between its computation and the computation of declination, *cara* etc. that would have been discussed before. Explain how this can be determined 'reasonably' accurately using interpolation. Also outline more precise formulations that have been given by later astronomers by introducing the notion of *kālalagna*.

13. Eclipses and their computation

Briefly explain the phenomenon of lunar and solar eclipses, and the crucial role played by the position of the lunar nodes in their computation. Also bring out how difficult it is to precisely determine the position of the nodes—as they are not physical objects available for observation. Explain how the latitude of the moon is computed, and then outline the procedure for the determination of the semi-diameters of the eclipsing and the eclipsed bodies. Derive the simple formula for determining the duration of eclipses as well as the obscuration. Also mention that iterative procedures are followed to improve accuracy. Point out the role of parallax in the determination of solar eclipses.

Suggested References:

1. S. N. Sen and K. S. Shukla, *History of Astronomy in India*, 2nd Ed., INSA, Delhi, 2001.
2. S. Balachandra Rao, *Indian Astronomy An Introduction*, Universities Press, Hyderabad, 2000
3. *History of Astronomy: A Handbook*, Edited by K. Ramasubramanian, Aniket Sule and Mayank Vahia, SandHI, IIT Bombay, and T.I.F.R. Mumbai, 2016.
4. B.V. Subbarayappa and K.V. Sarma, *Indian Astronomy: A Source Book*, Nehru Centre, Bombay, 1985.
5. *Tantrasaṅgraha of Nīlakaṇṭha Somayājī*, Translation and Notes, K. Ramasubramanian and M. S. Sriram, Hindustan Book Agency, New Delhi, 2011.

I. INTRODUCTION TO INDIAN ASTRONOMY

1. Preliminaries

Sky viewed as the inside of a hemisphere. Cardinal directions, zenith, horizon, pole star at any location. Daily motion of celestial objects (Sun, Moon, planets, stars) and diurnal circles. Motion in the stellar background. Ecliptic. Basic time units: Day, Month and Year. Celestial coordinates and elementary spherical trigonometry. Cosine and Sine formulae. Horizontal (z,A), Equatorial (δ, α and H), and Ecliptic (λ, β) systems. $\cos z = \sin \varphi \sin \delta + \cos \varphi \cos\delta \cos H$, and other relations. Planetary positions.

2. Developments from the Vedic period up to the *Siddhāntic* period

Vedic Astronomy: Astronomical concepts in Vedic literature regarding Sun, Moon, Stars, Earth. Months, seasons, year. 27 *nakṣatras*. Ecliptic and *ayana*. Planets, Comets etc. Pole star in an earlier era. *Nakṣatra* division of the ecliptic and motion of the Sun along it in *Vedāṅga Jyotiṣa* (VJ) and other texts. VJ calendar. VJ computations. Duration of a day. Better value for an year in Vedic literature.

Siddhāntic astronomy: Earlier *Siddhāntas* and *Pañcasiddhāntikā*. Introduction of trigonometry, Indian *jyā*–astronomy. *Āryabhaṭīya* . *Mahāyuga*. (*Kalpa* etc., and also smaller units of time can be introduced at this stage). Revolution numbers of planets. *Ahargaṇa* and Mean longitudes, Examples. Obtaining the true longitudes by applying corrections to mean longitudes.

Epicycle models: *Manda* correction (Equation of centre) in detail. Its significance. Latitude of Moon.

Śīghra correction to planets and its significance: Essential features only with the aid of diagrams and final formulae. Latitudes of planets.

Precession of equinoxes— *Nirayana* and *Sāyana* longitudes.

Nature and organisation of texts. *Sūtra* (algorithmic) format. *Siddhānta*, *Tantra*, *Karaṇa* and *Vākya* texts. *Sāraṇis* or Tables.

3. Indian Calendar

Pañcāṅga. *Adhikamāsas*. Solar and Luni-Solar systems.

4. Solar and Lunar Eclipses

Angular diameters of the Sun, Moon and Earth's shadow. Possibility of eclipses. Finding the middle of an eclipse by iteration. Amount of obscuration at any time.

5. Tripraśna Topics (Diurnal problems)

Description of the celestial spheres and various circles. Similarity to modern description. Determination of the East-West directions. Derivation of the expression for the declination in terms of the longitude. Shadow of a gnomon. Equinoctial day when the locus of the tip of the shadow is a straight line. Finding the latitude. Mid-day shadow. Finding the declination. Relation between the time and the shadow at an arbitrary instant (no derivation).

6. Planetary longitudes and latitudes and Nīlakaṇṭha Somayājī's revised planetary model

True longitudes of planets: *Manda* and *Śīghra* corrections in detail. Geometrical description. Comparison with Kepler's model. Latitudes of planets.

Nīlakaṇṭha Somayājī's revision of the planetary model: Nīlakaṇṭha's analysis of the motion of the interior planets (Mercury and Venus). His geometrical model which is geometrically similar to the Tycho Brahe model (planets moving around the Sun which itself orbits the Earth), but computationally approximates the Kepler model.

7. Rates of motion of planets

Idea of derivative in finding the *Mandagatiphala* (*manda*-correction to the mean rate of motion). The correct formula due to Nīlakaṇṭha. True rates of motion of planets: Correct expression due to Bhāskara. Application to calculate retrograde motion of planets.

8. *Tripraśna* topics

Latitudinal triangles (of Bhāskara) and applications. *Agrajyā* or the distance between rising-setting line and the east-west line. Correction to the east-west line due to change in Sun's declination. Zenith distance in terms of the declination, hour angle and latitude ($\cos z = \sin \varphi \sin \delta + \cos \varphi \cos \delta \cos H$). Derivation of this formula as in S*iddhāntaśiromaṇi*. Relation among *Śaṅkutala* (*Śaṅkvagra*), *Bhujā*, *Agrajyā* and its applications.

9. Rising times of *Rāśis* and finding *Lagna*

Relation between the right ascension and longitude and rising times of *rāśis* at the equator. Rising times at an arbitrary latitude. Finding the *Lagna* at any instant after Sunrise (approximate).

10. Eclipse calculations

Details of calculations of the middle of a lunar eclipse and half-durations iteratively, using the correct expression for the rate of motion of the Moon. Parallax and the calculation of the middle of a solar eclipse.

11. The *Vākya* system

Longitude of the Sun from the 'subtractive minutes' at any time ('*Bhūpajña* etc. *vākyas*). *Vākyas* for zodiacal transit times ('*Śrīrguṇamitra*' etc.). Longitude of the Moon using the *Candravākyas* ('*gīrnaśreyaḥ*' etc). More accurate values due to Mādhava.

12. Astronomical Instruments

Gnomon. *Cakra* and *Dhanur* yantras for measuring the zenith distance of the Sun. Approximate and exact times from a '*yaṣṭi*'. *Phalakayantra* to measure the hour angle. Equatorial sundial to measure time. Clepsydra for measuring time. Celestial globe and Armillary sphere for explaining celestial coordinates and various circles.

13. Indian Astronomy in the 18th and 19th centiries

Astronomical endeavours of Savai Jayasiṃha. *Samrat-yantra* and other instruments in the observatories of Jayasiṃha. European observers on the simplicity and accuracy of Indian eclipse computations. The work of Śa□karavarman and Candraśekhara Sāmanta. Efforts to update the Indian calendar.

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1. M. S. Sriram, *Man and the Universe- An elementary account of Indian Astronomy*, (Unpublished 1993).
2. M. S. Sriram, *Elements of Indian astronomy- 5 Lectures*, Instructional Course on Indian Sciences, Prof. K.V. Sarma Research Foundation, 2019.
3. (Videos available at https://www.youtube.com/watch?v=Qzam3vEnD-8&list=PLF72fmBZVDxlkv0Ih_aSHnax5S5-wug8v)
4. S. N. Sen and K. S. Shukla, Eds., *History of Astronomy in India*, 2nd Ed., INSA, New Delhi, 2001.
5. S. Balachandra Rao, *Indian Astronomy-Concepts and Procedures*, M.P. Birla Institute of Management, Bengaluru, 2014.
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10. *Karaṇapaddhati of Putumana Somayājī*, Translation and Notes, R. Venkateswara Pai, K. Ramasubramanian, M.S. Sriram and M. D. Srinivas, Hindustan Book Agency, New Delhi, 2018 (Rep. Springer, New York 2018).

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