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Space Science, Technology, and Innovation through Indigenous Knowledge Systems

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ABSTRACT

This paper discusses the importance of Indigenous Knowledge Systems (IKS) in the development of space science, technology and innovation with specific reference to India's rich scientific traditions and space-development priorities. Ancient Indian knowledge traditions show notable achievements in astronomy, mathematics, astronomical systems, observational practices and systematic investigation of celestial phenomena. The research investigates how such data can provide complementary perspectives for modern space science and cutting-edge technologies when interrogated using rigorous scientific techniques. Special emphasis is placed on the potential use of indigenous knowledge and Earth-observation knowledge for such areas as climate surveillance, ecological resource management, disaster planning, and sustainable development. The need for multidisciplinary research that integrates mathematics, astronomy, environmental sciences, social sciences, and traditional knowledge. It considers the importance of educational institutions and public policies in preserving, documenting, validating and effectively incorporating Indigenous Knowledge Systems into modern scientific research. It presents a qualitative, descriptive and interdisciplinary research methodology, based on academic literature, historical and policy documents, and modern studies of space research and Indigenous knowledge. It argues that the responsible use of verified indigenous knowledge alongside advanced research and technological innovations can foster regionally relevant innovations, strengthen scientific learning, and promote sustainable space applications. India's extensive knowledge heritage can supplement contemporary space science, while also promoting innovation, ecological sustainability, and social development at large.

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INTRODUCTION

Indigenous Knowledge Systems (IKS) in space research, technology and innovation is a significant step that integrates ancient knowledge with modern scientific methods. This means an advantage not only for technology but also for the preservation and protection of cultural heritage. Acknowledging the significance of Indigenous perspectives, particularly regarding space technologies, offers an opportunity to develop a sustainable and inclusive approach to innovation. The effect of IKS on space science and technology, its development implications and its potential to promote innovation will be discussed in subsequent sections.

Indigenous Knowledge Systems (IKS) provide important perspectives that enhance space research through the integration of cultural knowledge, environmental stewardship, and holistic approaches to understanding the natural world. Space-based technology used for climate observation, environmental surveillance, and sustainable resource use can complement traditional knowledge of environments, periodic cycles and resource management. Indigenous Knowledge Systems holistic perspective that highlights the interconnectivity of humankind, the natural environment, and the universe promotes the development of standard space technology that recognize societal and ecological effects (Salunke, 2023). The rich traditions of Indigenous astronomical understanding, celestial observation, navigation and chronology also provide historic foundations that continue to fuel interdisciplinary research, sustainable development, and contemporary space science, and invite culturally inclusive approaches to scientific progress (Janani & Harshini, 2025).

The inclusion of Indigenous Knowledge Systems (IKS) in the development of space science and technology promotes user-driven innovation, ensuring that space-based solutions are responsive to local needs as well as cultural values and customs. Engaging Indigenous communities in the co-design and co-implementation of technology reinforces their sovereignty, supports their self-determination and strengthens their capability to manage natural assets and territories sustainably (Marino et al., 2024). In addition, the inclusion of IKS in space programs can help minimise the gaps in access to technical benefits, particularly in poor regions like Africa, by promoting broad innovation, equitable allocation of resources, capacity building and sustainable socio-economic development (Oguamanam, 2022).

The combination of Indigenous Knowledge Systems (IKS) with modern science encourages interdisciplinary collaboration and generates new ideas that are sustainable for the environment, culturally relevant, and scientifically valid (Rajabova, 2022). In the context of the Fourth Industrial Revolution, the convergence of traditional knowledge with emerging technologies can contribute to the reinforcement of the bioeconomy, inclusive innovation, research capacity and the participation of countries in global information manufacturing and sustainable technological advancement, particularly in Africa (Oguamanam, 2022).

Ancient Indian Space Science Foundations

The mathematical astronomy of Ancient India introduces two astronomers, namely Aryabhata and Brahmagupta. One of the greatest names in the background of astronomical mathematics in India is Aryabhata. He lived in the 5th century and wrote a short work called Aryabhatiya in which he treated both astronomy and mathematics. Aryabhata suggested that the Earth rotates around its axis which was a rather strange idea for that period. He also gave ways to know how eclipses could have been calculated. They looked at what the people saw, understood the natural alignment between the sun, Earth and moon, and not just dealt with mythological explanations (Vasoya & Trivedi, 2026).

Indian mathematical astronomy was advanced by Brahmagupta, the successor of Aryabhata. His major work Brahmasphutasiddhanta defines zero as a number and defines its features in adding and subtracting zero. It sounds such as mathematics, but it did impact astronomy. Better ways of handling numbers led to better calculations and therefore to better predictions of where the planets would be. Since his writings provide a clear picture of the encyclopedic direction of Indian astronomical scholarship, Varahamihira may be listed here. Five distinct astronomical systems from his era are summarized in the Panchasiddhantika. For historians, this might have been older historians of information about the worth of information. Varahamihira assessed a few systems, highlighted their pros and cons, and endeavored to clarify an area in which there existed several contemporaneous (and conflicting)

models. A scientific mentality is clearly reflected in this comparison format. Older ideas were not simply taken as gospel by ancient Indian astronomers.

In certain instances, educational curricula establish a clear connection between historical achievements, such as Aryabhata's precise calculation of the solar year, and contemporary space missions, enabling students to recognize that India's present space research endeavors are not entirely novel or externally derived but are deeply anchored in a longstanding tradition of astronomical inquiry. The arcana of meticulous sky observation and exact mathematical prediction, which served as the foundation for ancient and medieval Indian eclipse prediction, offers Indian space mathematicians and scientists historical inspiration as well as a significant sense of scientific consistency that connects the mathematicians who predicted eclipses in ancient and medieval India to the researchers and engineers of India's upcoming lunar and solar space missions. This is true even as India is busy developing its space science and astronomy prowess and capabilities (Vasoya & Trivedi, 2026).

India's scientific and astronomical heritage is reflected in classic astronomical texts such as the Surya Siddhanta, which discusses advanced methods for observing celestial bodies, finding planets, and predicting solar eclipses (Swathi et al., 2024).

Indigenous Knowledge and Space Technology

There are important connections between traditional knowledge and space technology, especially when it comes to environmental surveillance, cultural sustainability, and democratisation of space. Indigenous perspectives can be included in geospatial technology to improve environmental stewardship and promote cooperation between scientists and Indigenous populations.

Indigenous Knowledge Systems (IKS) must be meaningfully integrated with contemporary space science and GIS technology to close knowledge gaps. Indigenous knowledge highlights the importance of local environmental settings, cultural linkages, and place perspectives that are frequently neglected in traditional digital mapping systems. Encouraging Indigenous data sovereignty guarantees that communities maintain ownership, authority, and control over their knowledge and its uses (Briggs et al., 2020). Mutual respect, fair collaborations, and the active involvement of Indigenous perspectives in research, technological advancement, decision-making, and space-based program execution are essential for successful collaboration (Sinclair, 2025). Indigenous approaches, especially the idea of kinship, offer useful foundations for advancing sustainability in environmental management and space exploration (Neilson, 2024). These methods promote moral judgment and long-term stewardship by highlighting connections, accountability, and the interdependence of humans, the natural world, and the universe. Future space flights and communities can be more socially and environmentally sustainable if traditions and a sense of connection are acknowledged (Milligan, 2022).

Ensuring consistency with Indigenous rights, interests, and cultural values is a difficulty when incorporating space technologies into programs for development. In addition, it provides possibilities for co-designing technologies that uphold Indigenous worldviews, encourage inclusive innovation, increase community involvement, and produce long-term development solutions that are both technically and socially sustainable (Marino et al., 2024).

Sustainable Space Innovation using Indigenous Knowledge

Indigenous knowledge, which offers distinctive viewpoints that contradict traditional methods, is vital in forming sustainable methods in space innovation. Space initiatives can encourage long-term sustainability and a closer relationship with the environment by incorporating Indigenous practices. The corpus of information known as Indigenous Knowledge Systems (IKS) is the result of generations of intimate interactions between people and their natural surroundings.

This long-standing knowledge offers essential guidelines for resilience, environmental stewardship, and sustainable resource management that can guide future space travel and habitation. Through transdisciplinary collaboration, IKS may be integrated with contemporary scientific knowledge to address complex socio-ecological concerns in a more comprehensive manner. Such integration encourages creative, environmentally responsible and culturally inclusive approaches that contribute to the sustainability of space missions and interplanetary settlements (Laxmi, 2025).

Indigenous kinship ideas stress the interdependence between humans, the environment, and the universe and encourage stewardship over appropriation of space settings. These viewpoints emphasise sustainable resource usage, group accountability, and ethical decision-making (Neilson, 2024). Through history, norms, and a sense of belonging, cultural stability can help future space initiatives to be kept socially important, culturally respectful, and environmentally friendly for future generations (Milligan, 2022). Indigenous knowledge may provide useful starting points for a sustainable future in space, but economic interests may override such perspectives, which results in the same exploitative practices seen on Earth. A future in space in which these interests are balanced is totally viable.

Indigenous Earth Observation and Environmental Knowledge

Traditional knowledge about the planet and its environment is essential to managing natural resources and combating climate change. When paired with contemporary Earth observation tools, indigenous tribes' distinct environmental insights can improve environmental surveillance and adaptation tactics. The combination of Indigenous knowledge using Earth observation data, the advantages of such partnerships, and the difficulties encountered in this integration are all highlighted in this synthesis.

In fusing conventional ecological knowledge with satellite-based data, the combination of Indigenous Knowledge Systems (IKS) with Earth-observing technology improves understanding of environmental change. Indigenous groups have in-depth knowledge of ecosystems, seasonal trends, and hydrological cycles, which helps them understand the effects of climate change, biodiversity, and water quality (López-Maldonado et al., 2024). Communities can monitor forest loss, sea ice fluctuations, degradation of land, and other environmental alterations with the help of satellite photography and remote sensing, which supports resource management and climate adaptation (Hub, 2024). Collaborative projects, such as hackathons and participatory research, have shown how to effectively engage Indigenous people, promote culturally inclusive, scientifically sound, and sustainable Earth observation techniques, and exchange knowledge (López-Maldonado et al., 2024).

The integration of Indigenous Knowledge Systems (IKS) and Earth observation technologies enhances environmental monitoring by combining satellite-based data with conventional ecological knowledge. By enhancing water quality evaluation, mapping watercourses, and ecosystem monitoring, this integration promotes sustainable resource administration and climate change monitoring and information insights (López-Maldonado et al., 2024). These collaborations also improve cultural heritage preservation, safeguard land and resource rights, and advance inclusive, community-driven environmental governance by giving Indigenous communities access to cutting-edge geospatial tools while honoring indigenous knowledge systems (Rattling Leaf, 2022).

Indigenous knowledge remains marginalized in many international Earth observation frameworks, despite its enormous significance, which limits prospects for more efficient environmental management (López-Maldonado et al., 2024). Improved infrastructure, technical capability, education, and fair access to Earth observation technology are necessary to close this disparity. Indigenous communities will be able to use geospatial data efficiently while preserving traditional knowledge systems if community involvement and capacity-building programs are strengthened (Hub, 2024).

Although there are many prospects for environmental management when Indigenous knowledge is integrated with Earth observation, it is crucial to address the structural obstacles that prevent these partnerships. The success of these projects will depend on creating genuine collaborations and guaranteeing fair access to technology.

Innovation through Multidisciplinary Research in Space Science

Multidisciplinary research, which encourages cooperation across many domains, greatly boosts innovation in space science. In addition to combining several approaches, this strategy promotes analytical thinking and alternative ideas, which results in groundbreaking developments. For example, combining biological, engineering, and technological knowledge might result in creative solutions that are inspired by nature, as Mathis pointed out. Addressing the intricate scientific, technical, and operational difficulties of space exploration requires

interdisciplinary cooperation. Combining specialists from a variety of disciplines, such as biological engineering, computer science, ecology, and social sciences, encourages creative and comprehensive solutions for new space applications (Hoornaert et al., 2019). In order to support innovative studies, technological advancement, and capacity building while bolstering national security and promoting sustainable space science and technology, funding mechanisms such as the Small Business Innovation Research (SBIR) as well as the Multidisciplinary University Research Initiative (MURI) programs promote collaborations among academic institutions, business, and governmental organizations (Ewart et al., 2012).

In space science and technology, educational programs such as the Undergraduate Student Instrumentation Project (USIP) give students the chance to engage in practical problem-solving, interdisciplinary cooperation, and hands-on research. These courses develop critical thinking, teamwork, creativity, and leadership while strengthening technical skills. Additionally, they foster professional connections, research ethics, and a feeling of accountability, preparing students for careers in science, engineering, and the rapidly developing space industry (Bering et al., 2023).

By combining ideas, techniques, and information from several scientific fields to tackle challenging problems in space science, interdisciplinary research propels technological growth. This cooperative method speeds up scientific discovery while promoting flexible and effective solutions (Jyothsna et al., 2024). It is needed to integrate astronomy with data analysis, biology, and different disciplines to increase understanding and facilitate future space travel, as demonstrated by emerging topics like astroinformatics and astrobiology (Mickaelian, 2021).

Perspectives on Education and Policy for Space Science

Space science learning and policy perspectives underline the need to integrate space science into educational systems to inspire future workers and meet demand for employment. This combination opens the door to scientific understanding and prepares students for technological challenges. Space science education is important for motivating children to pursue careers in science, technology, engineering, and mathematics (STEM) by fostering curiosity, analytical thinking, and scientific inquiry. Given its broad scope and practical importance, research shows that students and educators strongly favour the inclusion of space science in educational curricula (Afful, 2022). Programs such as NASA's Space Science Enterprise demonstrate how important it is to collaborate with educational facilities to improve scientific literacy, develop technical skills, strengthen K-12 science education, and create a highly qualified workforce that can support future developments in space technology and science (Pertzborn, 2005).

In order to promote its incorporation into formal education systems, effective space science learning should be in line with national curricular requirements (Urquhart et al., 2009). International tests like PISA and TIMSS can assess learning outcomes and improve scientific literacy by including space science. However, long-term research is required to evaluate its efficacy and long-term educational benefit (Rosu & Ceobanu, 2024). Even while interest in space science education is growing, creating interest, inquiry-based learning opportunities that adhere to the requirements of standardized curricula and high-stakes testing continues to be extremely difficult (Urquhart et al., 2009). To further prepare students for upcoming scientific and technological developments, future policies on education should support interdisciplinary teaching methods that incorporate space exploration with STEM fields, enhance analytical thinking, problem-solving, cognitive abilities, and scientific literacy (Rosu & Ceobanu, 2024).

RESEARCH METHODOLOGY

The study's research methodology is qualitative, descriptive and interdisciplinary to understand the connection between Indigenous Knowledge Systems (IKS) and current space science, technology and innovation in India. The research is mainly based on secondary sources such as articles, books, historical documents, institutional reports, policy documents, and documents related to Indian astronomy, space sciences, and technological development. A review of the historical and scientific works is undertaken to identify the contributions of the ancient Indian knowledge traditions pertaining to mathematics, astronomy, observation and calendrical practices.

A thematic examination is employed to detect links between historical understanding and advanced scientific approaches. Multidisciplinary coordination, education, policies, knowledge preservation and scientific validation are given special emphasis. The methodology attempts to evaluate how equitably documented and verified IKS can enhance modern space science and encourage sustainable technological development.

Current Significance of Space Science

Space research is extremely important nowadays since it advances scientific understanding, spurs technological advancement, and aids in national development. It advances our knowledge of the cosmos and helps with normal communication, navigation, meteorology, disaster relief, environmental surveillance, and economic progress. Because of these achievements, space research is now a crucial component of security, sustainable development, and international scientific advancement. Significant technical developments in a variety of sectors, such as information technology, robotics, materials science, telecommunications, and remote sensing, have been fueled by space research (Velinov, 2021; Sun & Wu, 2015). Modern society has been improved by innovations such as satellite communications, global navigation systems and earth monitoring technologies that enhance connectivity, transportation, crisis management, environmental surveillance and economic production. These developments are continuing to stimulate creativity and to push sustainable development globally.

Space science plays a very important role in industry, technology and economic development. Investment in space exploration helps to create growth in technologically advanced companies, skilled jobs, and opportunities for business in a range of sectors from manufacturing to telecommunications to satellite services (Sun & Wu, 2015). Investing in space science enables countries to improve their future national development and strategic resilience, while enhancing their technological capabilities, boosting their ability to compete in the global market, and fostering innovation-driven economic growth (Wang, 2022).

Space science is still one of the primary objectives of space exploration, which continues to expand our knowledge of the cosmos and improve understanding of questions about the origins of life, planetary development, and cosmic processes. Space missions have generated important knowledge through the discovery of moons, planets and asteroids, and far-off galaxies (Frolov, 2007; Kennedy & Hanson, 2004). The search for extraterrestrial life, which may alter the human perspective of the universe, continues in the fields of astrobiology, astronomy and exoplanet exploration (Wang, 2022). Meanwhile, there remains a debate about the right mix of robotic and human spaceflight. Human exploration provides capabilities that are unique and fosters technological advancement, but robotic missions often represent a less expensive, less risky way to make important scientific discoveries. Therefore, for plans of space exploration, the two methods should be complementary (Kennedy & Hanson, 2004).

CONCLUSION

Indigenous Knowledge Systems have become increasingly integrated into space research innovations to promote a comprehensive and sustainable method for understanding and probing the cosmos. Ancient India introduced two astronomers, namely Aryabhata and Brahmagupta. The Vedas, the Surya Siddhanta, and a number of other scientific research customs of ancient India reveal an active background to celestial observations, mathematical invention, and philosophical experimentation that continues to influence modern scientific thinking. The integration of Indigenous knowledge and cutting-edge technology for space enables culturally appropriate and inclusive creativity and improves accountability for the environment, Earth surveillance, climate adaptability, and accountable resource administration. This information can be used to solve difficult problems in space exploration by applying science, technology, social science, and native cultures in a multidisciplinary research context. Equally important are actions related to education and policy to promote multifaceted learning, scientific literacy, and inclusive participation in the expanding space economy. These procedures guarantee responsible technological advancement and the promotion of innovation without jeopardizing the cultural heritage. Besides scientific advances, space science is now highly significant for the advancement of nations, economic development, ecological sustainability, and international cooperation. The upcoming space odyssey could be more ethical, equitable and eco-friendly by

considering the intersection between Indigenous Knowledge Systems and modern scientific methods. It promotes science and technology and establishes the shared responsibility of mankind to explore and use outer space with due regard to the interests of all mankind, in the interest of all present and future generations.

Declarations

Conflict of interest: The authors declare that there is no conflict of interest.

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