International Cooperation in Science and Technology: A Suggestive Indian Model*

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Introduction

Global trade is becoming technology-savvy through disruptive scientific innovations, making it more technology-focused. These evolving technological demands are slowly recognising the role of small stakeholders and transforming the world into a global laboratory for developing world-class products. This transformation is also redefining advancing science and technology between nations.

In this regard, scientific cooperation is crucial in fulfilling national needs, ensuring technological freedom, industrial reliance, and boosting the economy. Such collaborations involve the sharing and exchanging of ideas, human resources, infrastructure, and regulatory aspects that impact the futuristic export and import policies. As the challenges facing humanity become more complex and transboundary, it is empirical to shift from individually-driven initiatives to team-based efforts with the rational involvement of commercial entities.

Science is facing multifaceted challenges worldwide, such as rising research costs, shortage of skilled researchers, limited infrastructure, restricted access to finance, diminishing venture capital and increasing regulatory expenditures. These challenges are further compounded by geopolitical tensions, creating uncertainty in research collaborations and disturbing the world's peace. Divergent intellectual property rights (IPR) regimes and conflicting data-sharing policies hinder trust and transparency in international partnerships.

Amidst these constraints, the mega-science projects, as well as concepts like science without boundaries, are showing increased traction and fostering a new ecosystem involving multiple global players to understand the scientific mysteries at a deeper level and developing complex science-powered precise products. Initiatives like the Large Hadron Collider, the COVID-19 vaccine development and the successful polio eradication highlight the transformative impact of deeper international engagements. The complexity of international cooperation is further escalated with the advent of advanced technologies

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such as artificial intelligence, which possesses tremendous power and speed for converting an invention into a market-ready product. But it also raises ethical concerns. The unethical practice of AI and deepfake technologies might lead to the erosion of trust by increasing safety and security concerns and hinder equitable development through unequal access to AI benefits, creating a digital divide and potential for exploitation. The lack of global standards and regulatory frameworks might lead to political disagreements and complicate international cooperation. The unethical issues in AI can be resolved by sharing and following the best practices, adopting ethical guidelines and developing common standards such as those proposed in UNESCO's Recommendation on the Ethics of Artificial Intelligence (2022). In conclusion, the traditional model of scientific cooperation must transform and align with the dynamic scientific requirements.

Cooperation Modes

India runs its international scientific cooperation in three modes: (a) Technology synergy with developed countries, (b) Diplomacy with developing and least developed countries (LDCs), and (c) Targeted industrial research leading to techno-entrepreneurship. These cooperation modes are not mutually exclusive but complementary, collectively contributing to India's strategic positioning in the global science and innovation landscape.

A. Technology Synergy

This mode operates through bilateral or multilateral platforms, emphasising equitable resource-sharing and joint outcomes. All stakeholders contribute financially, intellectually and share the outcomes as joint publications, patents or demonstrator technologies. Since most of the activities under this approach are driven by individual research groups, they lack focus on process and product development. To maximise the impact of such partnerships, the cooperation has to be more visionary and aligned with long-term national priorities and global technological trends. An ideal model must assess the potential risks and ethical dimensions of technology development and overall outcome, nurture the innovation ecosystems, strengthen institutional facilities, build quality and future-ready human resources, achieve diplomatic goals and extend the scope of cooperation in mutual interest. Such a cooperation model would help position India as a key player in global technology governance.

B. Technology Diplomacy

Through the diplomacy route, India fosters partnerships with developing and least developing countries (LDCs), positioning itself as a trusted partner in South-South cooperation. It involves developing human resources in these countries (through specialised courses/ training program and entrepreneurship activities) and creating scientific infrastructure, like African Centres of Excellence (ACEs). A case in point is India's support for leather technology entrepreneurship in Rwanda, which has the potential to be replicated across other sectors and regions.

India contributes to sustainable technological development in other developing countries through initiatives in areas like renewable energy (International Solar Alliance), digital innovations (Aadhar, **U**nified **P**ayments **I**nterface (UPI) and DigiLocker), and agricultural advancements. Such initiatives can be role models of sustainable development for replication in other developing countries.

India also supports the development of scientific infrastructure and human resources through remote teaching, curricular co-development, faculty and student exchanges, laboratory training, practice entrepreneurship and regulatory capacity-building. These efforts help generate goodwill and provide access to Indian technology products in their markets. Programmes like India-Africa S&T Initiatives, ASEAN-India S&T cooperation, DST-TWAS Fellowships and the Scheme for Young Scientists

and Technologists (SYST) underscore India's long-standing commitment to technology diplomacy. India's supply of COVID-19 vaccines to many developing countries is a vivid example of how science and diplomacy can work in tandem to strengthen global partnerships and promote equitable access.

C. Industrial Research and Development

Industrial R&D is a targeted approach centred on developing new hi-tech products, tools, applications and scalable, innovative solutions for global progress. Unlike in the developed world, where the industry sector contributes a substantial percentage of R&D expenditure of a nation's GDP, developing and LDCs continue to rely heavily on government resources, with limited industry participation in the research ecosystem. It suggests that while developed nations' major focus is on translational research driven by industrial needs, developing countries still operate within academic silos. Strengthening industrial R&D through international cooperation can help bridge this gap. Industrial R&D can be nurtured through networking, academic-industry matchmaking, connecting startups to global talent pools, improving access to incubators and facilitating engagement with international investors. Equally important are regulatory harmonisation, collaborative frameworks for intellectual property management and access to global testing & certification facilities. In addition, the specific entrepreneurship fellowships and end-to-end training programmes ranging from ideation to market entry can further empower the next generation of entrepreneurs. Such interventions are critical to ensure that the outcomes of R&D are scientifically sound, commercially viable and socially impactful.

Suggestions

The central point of international cooperation is its global multidimensionality. Such initiatives integrate elements of science diplomacy, national interests, and engagement with the scientific community for the betterment of society and economic prosperity. To ensure the financial sustainability of such programs, the outcomes of joint scientific collaborations must help industries develop new technology products and generate revenue, which could be further reinvested for new scientific collaborations.

Countries like India, with relatively lower investment in R&D (as a percentage of GDP), need to prioritise their scientific investments and increase industry participation in R&D. Aligning scientific priorities with market demands should be a key strategic objective. International scientific cooperation must also be informed by the export/import patterns of the partner countries to identify areas that have optimum relevance for the cooperation.

To perfectly align national goals among the parties and maximise mutual benefits, Indian S&T departments may consider developing flexible, country-specific strategic plan documents annually. Dedicated country- or region-specific committees may be established for their effective implementation. These should include representatives from S&T departments, trade and commerce ministries, regulatory authorities, and the Ministry of External Affairs, alongside academic and industrial experts. Such committees should periodically assess the short- and long-term goals, evaluate expected outcomes and returns on investment and consider the impact of international cooperation. They should also ensure the strategic vision remains aligned with respective global partners. The committee may be assisted by subcommittees involving scientific experts from both academic and industrial domains, startup representatives, entrepreneurs, and investment specialists. These subcommittees would be tasked with monitoring project execution closely, identifying roadblocks early, and recommending course corrections or project termination, if warranted, in consultation with partners. This strategy is not uncommon and practised in countries such as the United States (National Cislunar Science and Technology Strategy, 2022) and the United Kingdom (International Technology Strategy, 2023), where coordinated and outcome-driven frameworks guide global scientific partnerships. Consolidating India's international scientific engagements under

a single-window mechanism could reduce duplication, improve efficiency, and facilitate smoother engagement for international collaborators.

Historically, India's international S&T cooperation focussed on academic R&D activities, scientific exchange, and human resource development. But now, industrial engagements are beginning to creep in through scientific agencies supporting R&D projects under Indo-German, Indo-UK, Indo-Singapore, Indo-Israel, Indo-Spain, etc, bilateral programs. Academic projects, especially those in fundamental research or early-stage innovation, should ideally be funded for two years to establish proof of concept. Based on expert evaluation, only the most promising projects should be extended further. The current model of supporting a project for three years under international cooperation is more appropriate for industrial sectors, particularly those targeting co-development, market validation, or technology deployment. Further, pressing challenges like climate change demand deeper engagement with industrial sectors in international S&T cooperation. Therefore, major funding under international cooperation may be reserved for research challenges likely to lead to technology/product development or nurturing startups.

International cooperation has immensely contributed to human capital development. Regular exchange and training opportunities help forge long-term scientific relationships. With its vast pool of youngsters, India looks forward to more opportunities and channels for transformation. The focus on human resource development should be on emerging and futuristic areas with an emphasis on training at pre-Ph.D. levels. Initiatives aimed at post-school and early university students in frontier areas of science would yield better long-term dividends, given their openness to learning, enthusiasm, and potential to drive innovation. The trained workforce may be encouraged to pursue entrepreneurial paths. Further, engagement with diverse stakeholders such as academia, industry, NGOs, philanthropists, Micro, Small and Medium Enterprises (MSMEs) and entrepreneurs can ensure that cooperation spans a broad spectrum of science and technology areas relevant to societal needs.

Aligning IP outcomes, however, is a herculean challenge as partner countries often operate under different rules and regulations. Therefore, both sides' concerned ministries must ensure in bilateral and multilateral agreements that IP clauses are harmonised with international legal norms rather than solely reflecting national legislation. One solution could involve including contractual clauses mandating equitable benefit-sharing from future commercialisation, even if IP ownership resides with a single party.

While such provisions may increase the risk of legal disputes, a structured approach can mitigate these concerns. All grant recipients should be legally required to compile and transfer a detailed technology licensing dossier to the partnering industry, including information on domestic and international funding contributions. Transparent tracking of contributions and enforceable benefit-sharing mechanisms can build trust, encourage greater openness in sharing scientific resources, and act as an informal source of venture capital. This, in turn, can stimulate startup formation and innovation diffusion across borders.

Conclusion

International scientific cooperation is a powerful instrument for excellent fundamental research, but it also has immense potential to enrich industrial and economic aspects. To capitalise on its strengths, such as a vast and affordable talent pool, a thriving startup ecosystem, and supportive government policies like Make in India, Startup India and Invest India Programmes, it must reimagine its cooperation frameworks to be more agile, outcome-oriented, and innovation-driven.

By enhancing the capabilities of the established scientists, empowering young researchers through capacity-building initiatives and encouraging them to spin off their own startups, India can not only accelerate the achievement of its national goals but also emerge as a key partner in addressing global scientific challenges. Aligning international cooperation with co-development and co-production models will indirectly infuse greater foreign investment and create a better sustainability and social welfare ecosystem.