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RESEARCH ARTICLE

Strengthening Research Infrastructure and Advances in Indian Chemical Sciences Education: A Perspective on DST – Government of India's FIST Scheme

Chanchal Gupta *
Technology Bhawan, Department of Science & Technology, R&D Infrastructure Division

Shivaprasad Amaravayal
Technology Bhawan, Department of Science & Technology, R&D Infrastructure Division

Pratishtha Pandey *
Technology Bhawan, Department of Science & Technology, R&D Infrastructure Division

Abstract
India has recently increased its engagement with globally esteemed scientific publications, positioning itself as a growing economic powerhouse. Despite various challenges, India's contributions to scientific research publications have consistently risen, surpassing similar economies. The enhanced availability of research funds has further strengthened India's global standing. Chemistry education and research, in particular, have become central, significantly contributing to India's research output. According to the Nature Index, chemistry comprises half of India's overall research activities. This underscores India's robust inclination towards advancing chemistry research which is heavily influenced by state-of-the-art infrastructure facilities. This article examines the role of state-of-the-art infrastructure in advancing chemical sciences research, focusing on the Fund for Improvement of S&T Infrastructure in Universities and Higher Educational Institutions (FIST) by the Department of Science and Technology (DST). This study offers a comprehensive analysis of the pivotal role that FIST plays in fostering the emerging research areas in chemistry across diverse scientific institutions in India.

Keywords
Chemical Education and Research, Education/Research, General Public, India, Research Infrastructure, DST, FIST

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State of the literature
- Overview of India's global contribution to chemistry research, emphasizing the importance of research grants in nurturing emerging research fields
- Transformative role played by DST-FIST in elevating the status of high-end research areas within the realm of chemical sciences in India.
- Demonstration of strengthening of teaching and research infrastructure in various academic and research institutions done by FIST program.

Contribution of this paper to the literature
- This article can be benefitted to many of the developing nation to show that despite of poor contribution of GDP in Research and Development (R&D), the innovative and distinctive programs can boost-up the research output in terms publications in high impact journals and patents.
- Further, these efforts can be placed to provide the possible solutions in healthcare and material development for the society.
- These programs have potential to build up the scientific capacity to tackle pressing issues in energy, water, food and pollution.

Introduction
R&D activities are the building-blocks of socio-economic progress of any nation. These activities lead to the efficient utilisation of resources for better communal and individual outcomes. They have garnered much more importance towards our transition from conventional resource-based to knowledge-based economies. The scientific research is the most powerful tool for increasing the knowledge and thereby facilitates to achieve excellence in almost every aspect of life (Som, 2012; Thalassinos et al., 2019; Noja et al., 2019). Therefore, constructing and implementing unique systems for enhancing R&D activities will greatly contribute in achieving national priorities, inculcate an innovation-led approach and contribute towards the well-being of society. In India, the R&D activities reinforce the nation domestic improvements in health, agriculture, urban and rural development, water and environmental resources along with other areas of strategic importance. Thus, R&D activities are elemental key factor in India's development program. In recent years, India is experiencing a variation from developing country to an emerging economic superpower due to upsurge in the world's high class scientific publications (Schot et al., 2018). The evaluation of performance in scientific research at individual and institutional levels readily depends on the quantity and quality of research publications (Murali, 2019). India has been placed at a reputable thirteenth position throughout the world by the Nature Index report 2015. This report observes research articles published in more than 60 internationally recognized journals. Since 2015, India is continuously improving its position and presently finds itself ahead of countries like Netherlands, Taiwan, Russia and Brazil (Kogleck et al., 2015). Despite stagnation of funding and research infrastructure, the government has taken several positive steps which helped to boost up the R&D activities.

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* Corresponding author

The Gross Domestic Expenditure on R&D (GDERD) in India has been consistently increasing over the years and has more than doubled from ~ ₹60 thousand crores in 2010-11 to ~ ₹127 thousand crore in 2020-21 (Research and Development Statistics, 2023). The National Expenditure on R&D in India and R&D as % of GDP from 1995 to 2021 shows that in the year 2020-21, India spent only 0.64% of its GDP which is less as compared to the other developing countries like Brazil (1.3%), Russian Federation (1.1%), China (2.4%) etc. (**Figure 1**). Whereas, most of the developed countries spent more than 2% of their GDP on R&D. Despite of poor GERD, India's scientific publication output has shown a rising trend during the last decades (S&T Indicators Tables, 2023).

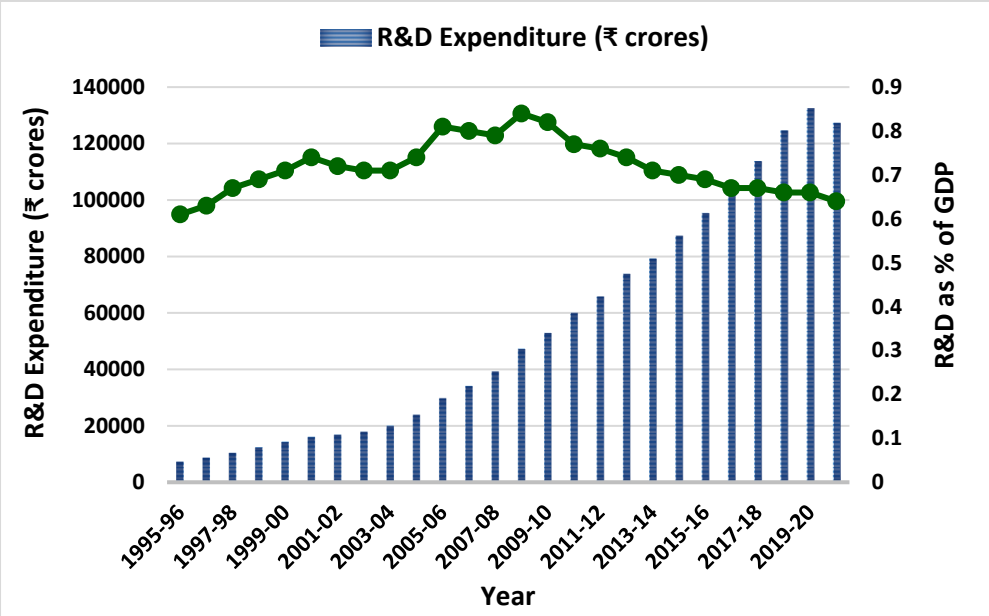

Figure 1. National Expenditure on R&D in ₹crores and R&D as % of GDP from 1995-2021 (Murali, 2019).

Research output of India in terms of publication has been increased by 2.5 times from 60,555 in 2010 to 1,49,213 in 2020 as per NSF-USA database (Science and Engineering Indicators, 2021). The number of publications from the top 15 countries of the world in 2020 clearly indicates the increment in the publication number from 2010 to 2020 (**Figure 2**). Moreover, India ranked 3rd in scientific publication output with around 2,78,000 publications as per the NSF 2022 database. Also, India has high growth rate of scientific publication i.e. 9.4% as compared to the world average of 4.3% during 2010–20 as per the NSF database. According to Global Innovation Index (GII) 2022, India is among the top 26 developing countries that are outperforming on innovation relative to their level of economic development. As per NSF-USA database 2022, India occupies the third rank in terms of the number of Ph.D awarded in S&T after USA and China (Science and Engineering Indicators, 2021).

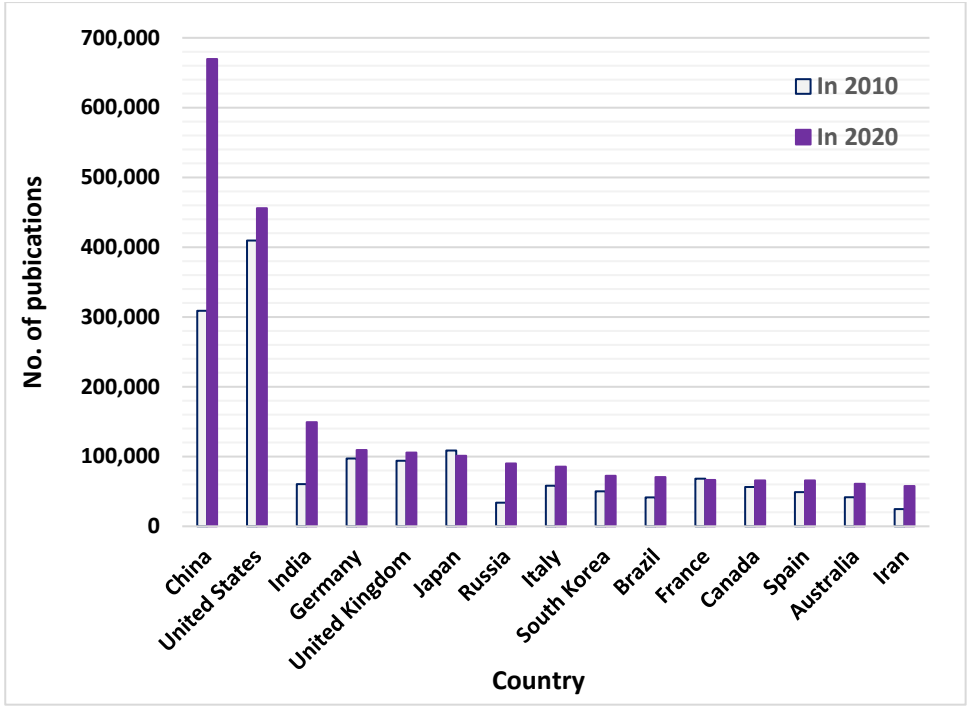

Figure 2. Enhancement in the number of publications of top 15 countries of the world from 2010 to 2020 (as per NSF-USA database) (Science and Engineering Indicators, 2021).

According to the Nature Index report 2015, academic institutions in India have good collaborative ties with international corporations. In 2014, India collaborates with 85 countries where the maximum association is with USA and Germany. The weighted collaboration score of India with USA and Germany is 180 and 80 respectively (Kogleck et al., 2015). Although there are more international collaborations as compared to domestic collaborations, the industry-academia link appeared to be very weak. Only very few institutes are engaged with industrial research. To boost-up the R&D activities and industry-academia collaborations the National Research Foundation (NRF) bill has been approved in June 2023 by Union Cabinet of India (Aithal et al., 2020). This bill aims to promote, support and monitor the scientific and

technological research interfaces. NRF will provide high-level strategic direction of scientific research in the country as per recommendations of the National Education Policy (NEP). This bill will further pave the way to seed, nurture and encourage R&D activities in the country. This will foster a culture of research and innovation throughout Indian universities, colleges, research institutions and R&D laboratories (National Research Foundation bill, 2023). To provide high-level strategic direction of scientific research in the country ₹50,000 crores have been approved for the next five years (2023-2028) to build up collaborations between industry, academia, government departments and research institutions. NRF will create an interface mechanism for participation and contribution of industries and State governments in addition to the scientific and line ministries. The DST will be the administrative Department of NRF which will be directed by a Governing Board consisting of eminent researchers and professionals across disciplines (Parliament passes the Anusandhan NRF bill 2023).

Indeed, research in the field of chemistry plays a crucial role in strengthening the economy and well-being of humankind. From the ancient times chemistry was one of the popular field in India. The foundation of the several divisions of chemistry developed from the technologies used in ancient civilizations in India (Ray, 1948). According to the Nature Index report 2015, among all of S&T disciplines, Chemistry accounts for half of the India's overall scientific output, which clearly reflects the country's resilient inclination towards chemistry (Arunan et al., 2013). Also, India occupies 8th position in the weighted fractional count (WFC) in the global ranking for chemistry (National Research Foundation bill, 2023). Moreover, some of the Indian Institutions producing more output than world's top institutions in Asia. According to the performance of India, Nature Index has selected chemistry in India as a rising star. NEP 2020 catalyses the drive towards the elevation of Indian chemistry education and research (Senapati et al., 2022). There are several core and the interdisciplinary areas involved in chemistry research (**Figure 3**). Since from the development of first synthetic fertilizers in the mid eighteenth century, chemistry researchers have immensely contributed in improving agricultural productivity. Advancement in the chemistry research contributed in the development of several useful materials including life-saving pharmaceuticals, energy efficient technologies, waste management, pollution prevention measures, food production and sustainable development. Therefore, chemistry has significantly improved the lives of people and thereby critically contributed in the nation's economic development.

The nature and type of research funding plays a critical role in the building of strong and viable scientific research and innovation ecosystem for the country (Jacob et al., 2011; Gök et al., 2016; Ebadi et al., 2013). In government systems, creating schemes for enhancing R&D activities, greatly contribute towards the achievement of national priorities, contribute towards the welfare of all sovereign citizen of India. The R&D in India can be grouped under a variety of funding sources and performers. The funding sources could be categorised broadly to include the Central

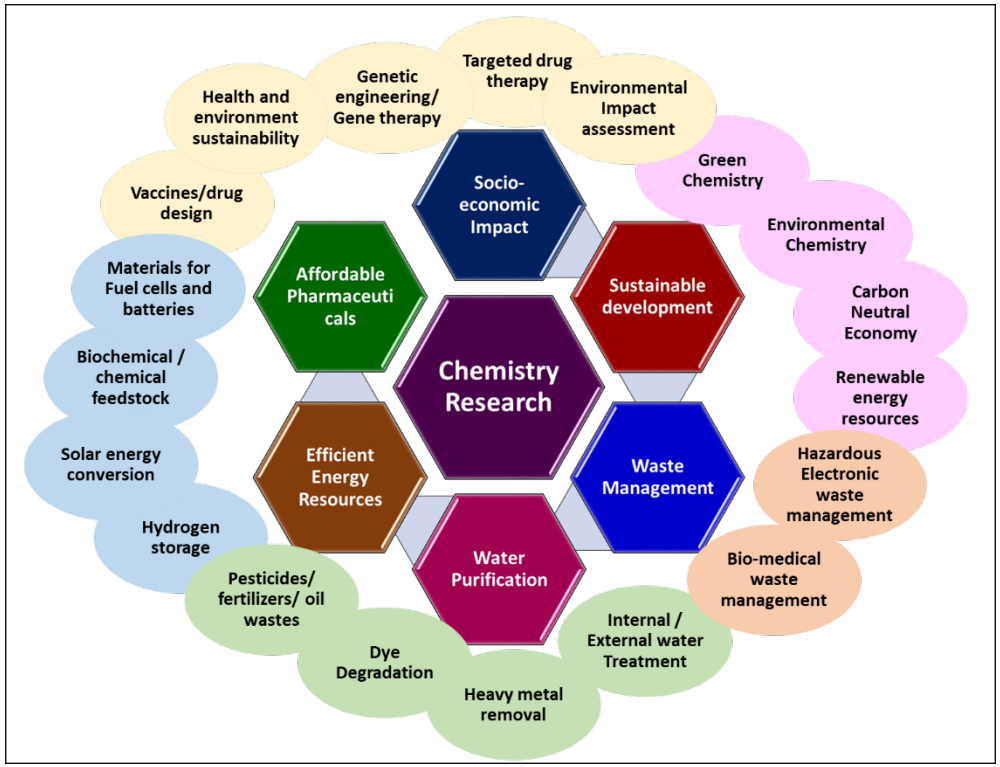

Figure 3. Various core and the interdisciplinary research fields involved in Chemistry Research.

Government, State Governments and the industry (private sector). The performers could be grouped to include the national laboratories, universities, in-house R&D laboratories and non-profit organisations. There could be multiple combinations of funding sources and performers through which R&D is actually carried out. The major R&D funding group under the central government includes DST, DBT, MEITY, DRDO, ICMR, ISRO, UGC, DoC, DoE, MoES etc. Extramural R&D support by Central Government Agencies increased to ₹2529.42 crore in 2019-20 from ₹2454.02 crore in 2016-17 (India on the cups of transformation, 2023). Its share in the national GERD was 1.9% during 2019-20. According to the funding agency-wise support to extramural R&D projects in India during the year 2019-2020 as per NSTMIS, Government of India, (India on the cups of transformation, 2023) the Department of Science and Technology (DST) and Department of Biotechnology (DBT) were the two major leading players, contributing 55% and 13% respectively of the total extramural R&D support in the country (**Figure 4**).

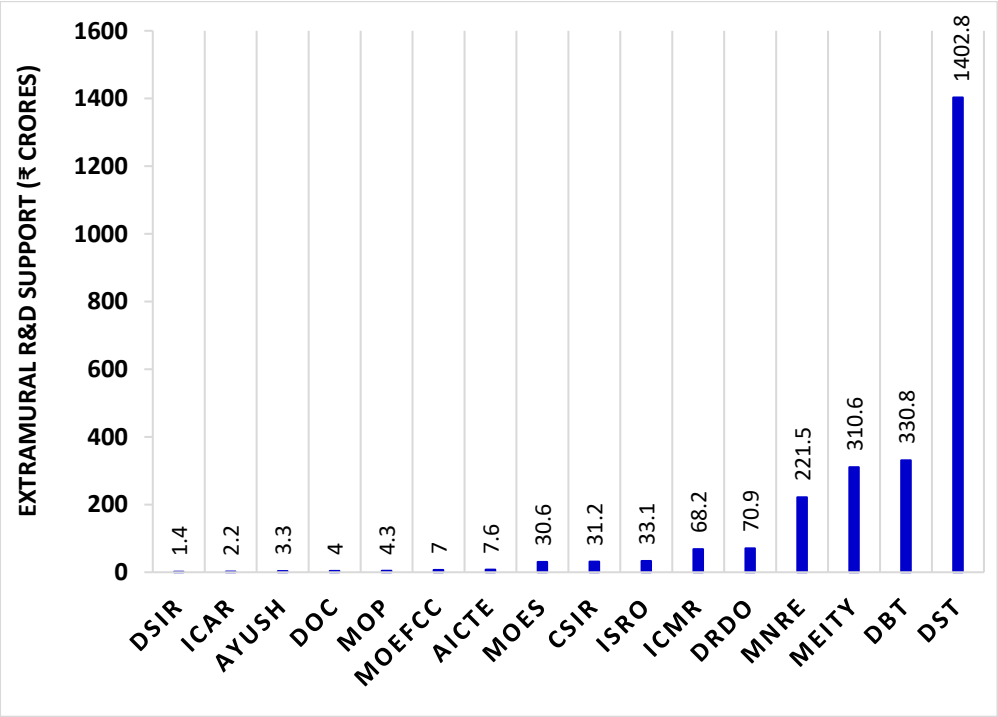

Figure 4. Extramural R&D projects in India with their respective funding agency (during 2019-2020) as per NSTMIS, GoI (India on the cups of transformation, 2023).

DST is the major contributor towards the R&D support through the extramural projects and contributes ₹1402.8 crore in the year 2019-20. From NSTMIS data, DST GoI, provides the largest extramural R&D support throughout the country to reinforce Science and Technology capacity and capability via wide range of funding schemes to address the varied needs of the research community in the country. Furthermore, DST is a policy making body for S&T sector in India. SERB (Science and Engineering Research Board), a statutory body of the DST established in 2011, serves as a major national funding agency for planning, promoting and funding internationally competitive research in emerging areas of Science and Engineering. Through its programs, like CRG, SUPRA, FIRE, IRHPA, SRG, POWER, SURE etc., SERB strides the advance scientific research in the country (Science and Engineering Research Board, 2023). The R&D Infrastructure division of DST initiated various funding schemes like FIST, PURSE, SAIF, STUTI and SATHI for strengthening and revolutionizing the R&D facilities in India from many years. Among these schemes, particularly FIST, Funds for Improvement of Science & Technology Infrastructure, plays an essential role in reinforcement of research infrastructure in various scientific research institutions. FIST is the major program towards the modernization and establishment of infrastructure in science departments of Indian Universities, which rejuvenates the research and thereby enhances the research outputs in terms of publications, collaborations, fellowships, awards and recognitions for the faculties and students (Krishnan et al., 2016).

Background: Brief History of the FIST Program

FIST has been launched in 2000 and it became one of the most important S&T infrastructure development programme supporting excellence as well as handholding aspiring institutions, departments and faculties across the country. From the beginning, the scheme has been spread across the country over different S&T disciplines and institutes. In these institutes, national issues regarding the outcome and efficient management of the program were considered. Over the years, the FIST Program has performed a vital role in strengthening the both teaching and research infrastructure in various academic and research institutions. However, with the shift in priorities and the S&T needs of the country, the program restructured in the context of the current National interests, National Missions, Sustainable Development Goals and its scope to strengthen the vibrant economy towards building up of a self-reliant India (Gupta et al., 2018). This scheme is targeted to foster the well-equipped and cutting edge R&D facilities in labs, centres or research institutions ranging from PG colleges to state/central universities and institutions of national importance like IISc, IITs, IISERs, AIIMS, NITs etc. The FIST scheme supports seven broad subject areas including Physical Sciences, Chemical Sciences, Engineering Sciences, Earth & Atmospheric Sciences, Mathematical Sciences, Life Sciences and PG colleges (only S&T departments) (FIST Program, 2023).

The FIST scheme is majorly focused on strengthening the state-of-the-art scientific research infrastructure. This scheme works for paving a way by which individuals, institutes and societies develop abilities to perform research effectively and efficiently in a sustainable manner. Over a span of twenty-one rounds, from 2000 to 2021, the FIST Advisory Board (FISTAB) has played a crucial role in fostering academic and research growth by recommending financial support to a vast network of 3072 scientific departments and PG colleges. The allocated funds were distributed strategically to numerous institutions mainly for Equipment, Networking & Computational Facilities, Infrastructure and Maintenance of the facilities along with the other benefit to facilitate the cutting-edge research in the country. Till 2022 nearly 381 projects have been granted under chemical sciences for various research as per the data of total number of projects with their respective funds release in different subject areas (**Figure 5**). The amount of support in chemical sciences along with its percentage share from 2000 to 2022 has been shown in **Figure 6**.

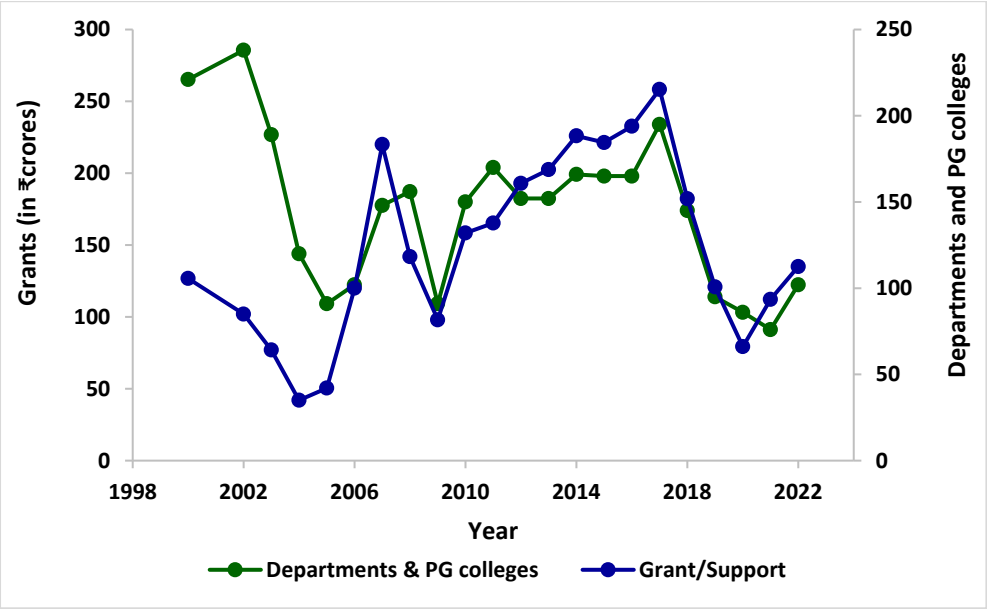

Figure 5. Amount of Research Grants (in ₹crores) and Number of Departments/PG colleges supported by the FIST program from 2000 to 2022.

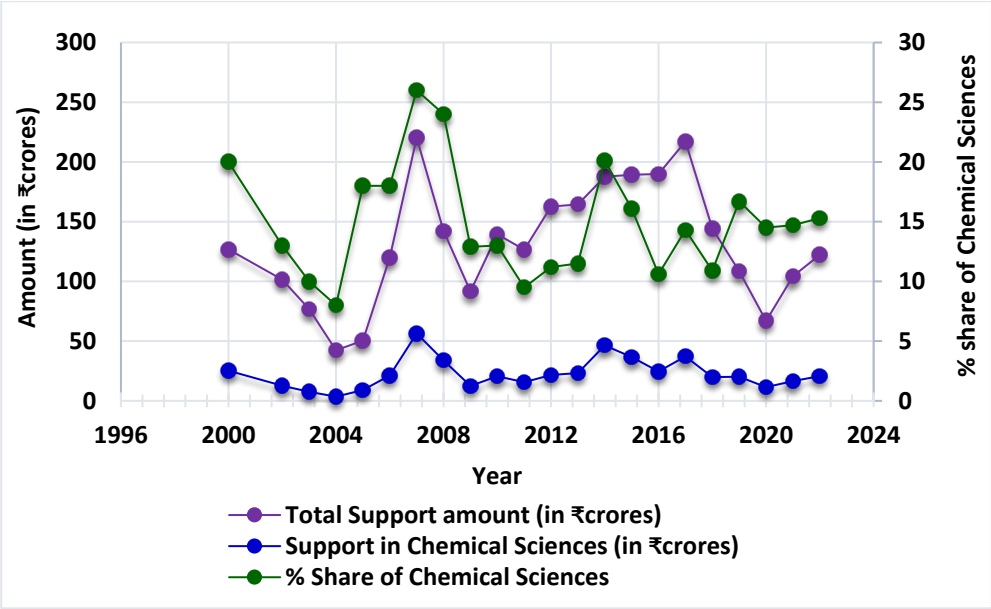

Figure 6. Amount of support in Chemical Sciences along with its percentage share from 2000 to 2022.

Each round of FIST witnessing an increase in the number of departments and colleges benefitting from the program. This consistent support has significantly contributed to the advancement of scientific and technological endeavours across various universities and colleges, fuelling innovation and progress in India's research landscape. The activities concerning to Scientific Social Responsibility (SSR) have also been taken-up under the restructured FIST to make the program connect with more inclusive approach towards the different sections of the society. The SSR policy is intended to constructing an effective ecosystem for optimal utilization of existing resources in order to empower the less endowed, marginalised and exploited sections of society by enhancing their capability, capacity and latent potential (SSR guidelines, 2022). The present article highlights the statistical analysis of discipline wise funds distribution under FIST scheme along with the number of projects. Here, we also summarise the role of DST-FIST scheme in significant promotion of research in chemical sciences and quality of chemistry education in India.

Methodology Adopted for the Selection of Department/Group

The selection of departments under FIST has been done by major focus on the research capabilities of various chemistry department in the organization. The consideration and recommendation of support is being carried out through two-tier mechanism, comprising, Subject Expert Committees (SECs) and FIST Advisory Board (FISTAB). Initially, the proposals submitted by the departments under the scheme will be evaluated by SECs. The screen-in projects are called for presentation. The selected projects are placed before FISTAB for the final selection. The synergy and focus of research may preferably be aligned to National Missions, Priorities and Sustainable Development Goals. The different funding levels (level A, B, C and D) has been categorized according to the amount of funding, academic profile of the departments and type of the institution. The details of the selection criteria with respective funding levels have been provided in the supplementary information. Upon project completion, a Project Completion Report (PCR) along with a FIST impact summary is submitted by the targeted groups. This report provides insights into the impact of FIST support, including improvements in areas such as publication records, PhD output, sponsored research grants, and achievements of faculty and students etc. The reports are then evaluated by the SEC and FISTAB. The data presented in this paper is derived from these reports.

Advancement in Thematic Research Areas in Chemical Sciences Departments supported by FIST

The Chemistry Department from various institutes and universities has made significant contributions towards research in variety of areas. As, the scientific research in any field is directly related to the availability of S&T facilities. Therefore, the facilities provided by FIST empowers the young, talented and motivated researchers to contribute towards path breaking discoveries in frontier areas of scientific research and cutting-edge technologies. The R&D infrastructure facilities established by FIST, paved the way towards the advanced research activities in the country. These facilities play a crucial role in scientific and technological expansion of variety of research areas. The outcome of the FIST scheme significantly boost-up the research activities in various department of the revolutionary research institutes including IISc, IITs, AIIMs, central/state funded universities and PG colleges.

The FIST support has demonstrated an immensely progressive impact on the working environment of academic and research output of recipient departments and institutions across the country. Due to this program, the sophisticated R&D facilities have also been developed in research laboratories in remote regions less endowed regions. There is overwhelming evidence and responses representing highly significant positive changes after FIST grant. Many of the institutes report a significant improvement in motivation for innovation, number and quality of research publication and research collaborations. The improvement in number of research publications has been seen in many of the FIST supported institutes (**Figure 7**). There are considerable positive changes in research publication with higher citations and higher impact factor journals. Along with the increase in quality of research, there has also been an increase in number of fellowships, national and international collaborations, awards and recognitions for the faculties.

There are variety of chemistry related fields encouraged by the research facilities provided by FIST, including electrochemistry, material chemistry, polymer chemistry, computational chemistry, solid state chemistry, medicinal chemistry, environmental chemistry and nano-chemistry. These fields contribute towards the pioneering discoveries in cutting edge areas of research. Many of the research groups are engaged in the investigations of the contemporary areas of chemistry includes development of novel materials for energy storage and conversion application, water purification, environmental pollution remediation, renewable energy resources, chemical sensors for variety of applications and many more.

Enhancement in the Research Facilities provided by the FIST

The funding provided by the FIST enhances the facile availability of many of the basic instruments in numbers of institutes. Some of the state-of-the-art research facilities includes TEM, FE-SEM, single crystal XRD, XPS supported from the FIST (**Figure 8**). Gradually, with the availability of research funds, the upgradation and advancement in the scientific instruments and research facilities has been done. The TEM has sufficient resolving power to conduct structural analysis even on the finest particles. TEM with the combination of microanalysis the quantification of particle size distribution, volume fraction and number density as well as particle structure, defects and chemistry, can also be determined. TEM instrumentation has made significant progress over the last decades. From simple instrumentation to integration of TEM with femtosecond lasers that make capable of studying ultrafast processes at the nanoscale (Schröder, 2015). SEM has emerged as a breakthrough in resolution and image quality. The SEMs could now resolve features as small as 1 Å, enabling detailed studies of nanostructures and materials. With time, the advancement in SEM has been done with high resolution (in HR-SEM) and field emission (in FE-SEM) enabling more complex and detailed studies (Ul-Hamid, 2018). EPR or ESR, is a technique for studying materials with unpaired electrons. It is an effective instrument for examining the electrical dynamics and structure of many different kinds of materials, such as semiconductors, transition metal complexes, and organic and inorganic radicals. In the past 20 years, there have been major breakthroughs in EPR spectroscopy, especially in the areas of spectrum complexity, resolution and sensitivity (Bakker et al., 2020).

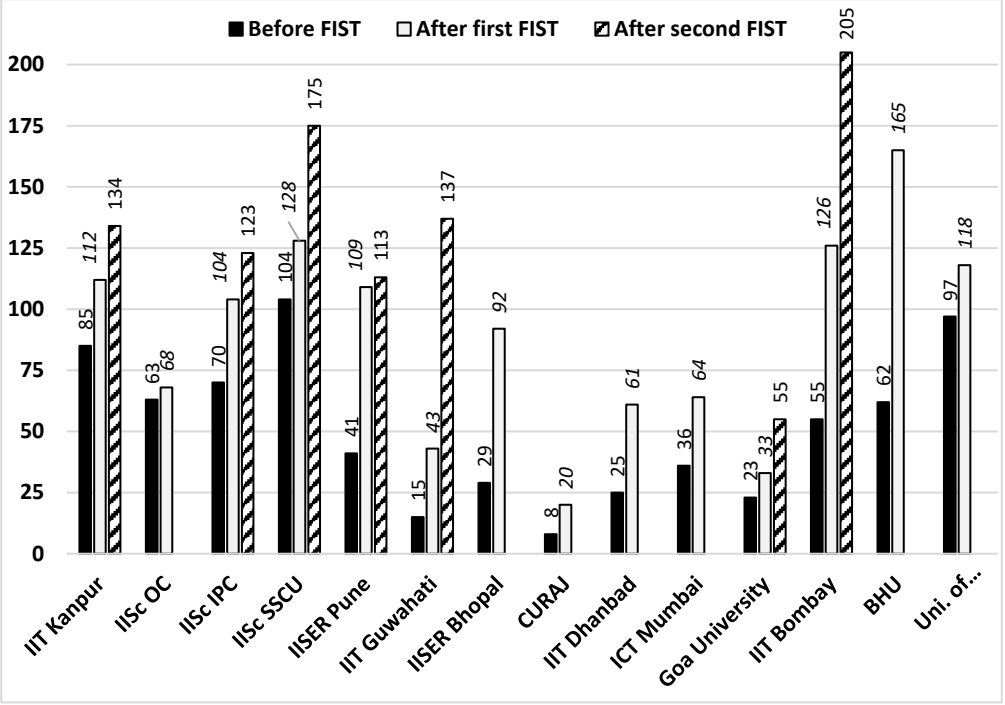

Figure 7. Improvement in number of research publications in some of the FIST supported institutes.

Figure 8. Collage of some of the research facilities provided by FIST in various institutes: (i) 500 MHz HR FT-NMR spectrometer at IIT Guwahati (IIT Guwahati webpage); (ii) Single crystal XRD at Goa University (Goa University, webpage); (iii) K-alpha XPS at IISc IPC; (iv) UV-Vis spectrophotometer at University of Hyderabad; (v) CHNS Elemental analyser at Central University of Rajasthan; (vi) HPLC at ICT Mumbai; (vii) Scanning Probe Microscopy at IISc SSCU; (viii) HR-MS setup at IIT Delhi; (ix) 200 KV HR-TEM at IISER Bhopal (TEM Facility at IISER Bhopal).

Developments in hardware, software, and pulse techniques have propelled these advances. Raman Spectroscopy is a non-destructive chemical analysis technique which provides detailed information about chemical structure, phase and polymorphic, crystallinity and molecular interactions. It is based upon the interaction of light with the chemical bonds within a material (Hess, 2021). With the advancement in optics, electronics, and specific needs, the derivative methods possessing better sensitivity, resolution, and stability than normal Raman spectroscopy have been developed over time. Mass spectrometry (MS) is a powerful analytical technique used to identify and quantify chemical compounds based on their mass-to-charge ratio. Over the past 20 years, advancements in mass spectrometry have transformed the field, enabling researchers to push the boundaries of analytical capabilities (Dilmetz et al., 2021).

Role of R&D Activities Developed from FIST Grant in Promoting the Research Endeavours

The Department of Chemistry from IIT Delhi has been supported by many of the R&D facilities like single crystal XRD, Fast Atom Bombardment Mass Spectrometry (MS-FAB), High-Resolution Mass Spectrometry, femtosecond ultrafast spectrometer etc. by FIST. These research facilities are used in the synthesis and characterisation of natural products, organic, inorganic, biomaterials, nanomaterials for variety of applications, macromolecules, catalytic materials and functional materials. The HR-MS is the first step towards characterisation of novel task-specific ionic liquids and organic molecules from Transition-metal catalysed reactions, for identification of the molecular composition, characterisation p-Lactam conjugates and tricyclic p-lactams for antibacterial applications and compound characterisation. These research facilities enhance the quality of research also an increase the impact of research. There is drastic change in the number of research publications per year that have been increased from 70 (before FIST) to 110-120 (after FIST). There is also increase in the average citation of the publications after the FIST support. By utilizing the various research facilities provided by FIST, the researchers from IIT Delhi, developed a Cobalt based complex for catalysing 4-electron reduction of oxygen. In this Co(III) complex of a bis-pyridine-bis-oxime ligand the oxime site can participate in reversible proton exchange reactions to facilitate the 4-electron ORR. Electrocatalytic ORR of the complex was examined in aqueous buffer solutions and acetonitrile consisting of trifluoro acetic acid as the proton source. The studies have been published recently in 2023 in *ACS Catalysis* (Das et al., 2023). With the facilities the department actively involved in the development of catalyst for asymmetric vinylogous reaction, a key reaction for industrial-scale production of chiral APIs.

The Department of Chemistry from IIT Kanpur is one of the most recognised chemistry department in the country. The department is engaged in high-end research with numerous faculty members and students. The research facilities provided by FIST are used in the advanced research in functional thin films, micro-batteries, super capacitors, porous materials or membranes, nano materials, green chemistry, medicinal chemistry, biomaterials and many more for variety of applications. The number of publications has been increased from 83 (in 2001 before FIST) to 140 (in 2007 after first FIST support) and 171 (in 2014 after 2nd FIST support). Increment in the quality of the research publications have also been observed. The average impact factor has been increased from 2 (before FIST support) to 4 (after FIST support). Average

citations of the articles have been increased to ~18.98 citations per article. Apart from this new science and technological deliverables also done from the research facilities developed from FIST. Some of these includes development of olefin oxygenation by water on an Iridium center, electrochemistry and electro generated chemiluminescence of twisted Anthracene-functionalised bi-mesitylenes and many more. In one of the research article the theoretical calculations were employed using the computer cluster facility installed at the Department of Chemistry, IIT Kanpur, through DST-FIST program. Using the HPC facilities provided in the department, an extensive hybrid quantum mechanical/molecular mechanical (QM/MM) Car–Parrinello molecular dynamics simulation of the reaction with the aid of the meta dynamics technique has been used. Based on this the mechanism for the formation of the acyl–enzyme complex from Henry-Michaelis complex has been done. The studies had been reported in *JACS* in 2013 (Tripathi et al., 2013).

The Division of Chemical Sciences of Indian Institute of Science (IISc) is among the top 50 chemistry departments in world rankings over the past decade. There are four departments under this division, these are Inorganic and Physical Chemistry (IPC) Department, Materials Research Centre (MRC), Organic Chemistry (OC) Department and Solid State and Structural Chemistry Unit (SSCU) (Web page of IISc Bangalore). After the FIST support research in the many of the cutting-edge topics like medicinal chemistry, supramolecular materials, ultrafast optics and spectroscopy, applications of spectroscopy in atmospheric and environmental chemistry, chemical routes to functionalise the nanomaterials and polymers, synthesis of materials for energy have been emerged in the chemistry division. There is drastic improvement in the number and impact factor of the publications. The average number of publications has been reported as 601 (during the 2009-2014) also the average impact factor of the publications was 4.5. The average citations of the articles per year has been increased to 1058. These can be the major contributors for the improvement in the *World ranking of the Chemistry Division* of IISc.

The Solid State & Structural Chemistry Unit (SSCU) of IISc, is known as a leading research centre in areas of Solid State, Materials, Physical, Inorganic and Theoretical Chemistry. Experimental and theoretical research pursued in the Unit aims at understanding diverse phenomena associated with solids and condensed phases at a fundamental level. The enhancement in number of publications has been reported from the research facilities envisaged from research facilities supported by FIST. The average number of publications has been increased from 104 (from 1997-2002 before FIST support) to 128 (from 2002-2007 after 1st FIST support) and 175 (from 2008-2013). The number of patents filed has also been increased from 1 (during 1997-2002) to 15 patents (during 2008-2013). After the FIST support many of the technological innovations has been done by the department like development of novel materials for applications in catalysis, lighting, energy harvest and energy storage. Lead-carbon ultra-capacitor for rural lighting and grid deprived areas is one of the technological interventions to the society done by the department after the FIST support. By using synchrotron X-ray reflectivity, the researchers from IISc SSCU, evaluated the hemoglobin adsorption characteristics on silicon substrates with varying chemical functionalities. These studies deliver a set of significant recommendations that an electrode surface functionalisation can able to control molecular conformation/orientation, especially protein adsorption on the substrate (Samajdar et al., 2019). This study in turn is likely to have a major influence on the protein electrochemical function and response of biomolecular devices. The results have been published in *The Journal of Physical Chemistry B* in 2019. During the previous FIST program, SSCU strengthened its research in solid-state materials for energy storage and materials for quantum technologies. Researcher from the department contributed towards the novel innovations in the areas of solar cells, batteries, quantum dots and nanocrystals for optoelectronics.

The facilities provided in Inorganic and Physical Chemistry (IPC) Department of IISc were utilised in effective synthesis of Aryl boronates via Cobalt-catalyzed Borylation of Aryl Chlorides and Bromides. In this an efficient catalytic system based on a Co(II)-NHC (N-Heterocyclic Carbene) precursor has been developed for the cross coupling of bis(pinacolato) diboron with aryl halides including aryl chlorides, affording the aryl boronates in good to excellent yields. The results reported in *ACS Catalysis* in 2018 (Verma et al., 2018). The stoichiometric reaction was performed and monitored by NMR spectroscopy. In order to gain further details on the radical species synthesised in the Co-catalyzed borylation reaction, the EPR studies has been performed. GRID neutral solar battery storage with 24 hours back up, 15 kW, an Indo-UK project funded by DST, with indigenous components has been developed by utilizing the FIST facilities.

IISER Bhopal has been supported in the year 2015 by ₹5.5 crores, 200 kV HR-TEM facility has been provided in the Chemistry Department. Redox-active, pyrene-based pristine porous organic polymers for efficient energy storage with exceptional cyclic stability have been developed by the researchers in IISER Bhopal. The studies published in ChemComm in 2018 (Bandyopadhyay et al., 2018). Due to the long-term cyclic stability and the high energy density of PYBDA explore the way for application of pristine conjugated porous organic polymers as energy storage materials. By the achievements startup company, Plabel tech Private Limited, is established at the Incubation Center, IISER Bhopal, for translation of protein engineering technologies. An efficient Ag(I) catalyzed tandem intramolecular transannulation of ((2-alkynyl) aryl) cyclopropyl ketones leading to the 2,3-dihydronaphtho[1,2-b] furans have been developed in IISER Bhopal (Dawande et al., 2016). The reaction features a regioselective alkyne hydration, cyclopropylketone-2,3-dyhydrofuran rearrangement, and benzannulation. The reaction is proposed to involve a Ag(I)-catalyzed tandem regioselective hydration of the alkyne moiety, a region selective ring expansion of donor–acceptor cyclopropyl ketone to 2,3-dihydrofuran, and benzannulation. Further studies on the application of this new methodology to the synthesis furan based natural products are underway. The studies had been published in *ChemComm* in 2016

(Dawande et al., 2016). The progress of the reaction was monitored by thin layer chromatography and the structural confirmation has been done by NMR, MS and IR spectroscopy.

The Department of Chemistry from Banaras Hindu University (BHU) shows the drastic increment in the number of publications after second FIST support. The average number of publications per year has been increased from 62 (during 2002-2007 after 1st support) to 165 (during 2007-2012 after 2nd FIST support). Apart from the advancement in the quality of research some technological innovation has been done after the FIST support. The development of novel and practical protocols for privileged structures has been done. Also, the development of intercalated materials with reversible photochromic property has been done by the department. One of the publication reported Saponification-triggered gelation of ester-based Zn(II) complex through conformational transformation. This has been published in *ChemComm* in 2014 where the NMR facility used to do the studies demonstrates the conversion of esters into carboxylate moiety (Kumar et al., 2014). Another study includes the Click chemistry inspired synthesis of Glycoporphyrin dendrimers published in The Journal of Organic Chemistry in 2013. These porphyrins have interesting application in photodynamic therapy that can be employed to destroy the tumor cells when exposed to light of particular wavelength. The research facilities like NMR, IR and TOF-MS were used for the structure determination of the synthesised molecules (Kushwaha et al., 2013). **Figures 9a & 9b** show the average number of publication along with the average impact factor, number of patents filed, Ph.D produced and research project granted after 5 years of FIST support in some of the institutes.

The Department of Chemistry in Central University of Rajasthan, has been supported by CHNS Analyzer, UV-Visible spectrophotometer and computational facilities in 2015. In one of the studies, a novel N', N' di-substituted benzo hydrazides were synthesised by the reaction of Morita−Baylis−Hillman (MBH) ketones with aryl/alkyl hydrazines in the presence of triethyl amine. The reaction displays a region selective insertion of the hydrazine into the benzoyl acrylate skeleton. A brief mechanistic study has been done which indicate the involvement of a cyclic hemiaminal intermediate that preferentially breaks down to the acyclic amide by a general base mediated proton transfer. The studies have been published in Tetrahedron Letters in 2021 (Jha et al., 2021). In IISER Thiruvananthapuram, the Chemistry Department has been supported in 2017 by ₹3.5 crores with a 500 MHz solid state NMR. In one of study, a new viologen-based ionic porous organic polymer (IPOP) has been developed in the department.

The confirmation of successful formation of IPOP has been established by solid-state ^{1}H and ^{13}C NMR spectroscopic studies. In this study, a novel efficient and eco-friendly approach has been developed for the synthesis of β-aryl thioketones and biscoumarins; the IPOP can be employed as a heterogeneous catalyst for at least 10 catalytic cycles without any loss of catalytic activity. The studies have been published in Journal of Catalysis in 2022 (Yadav et al., 2022). The collage of several results obtained from the research facilities provided in chemistry departments of some institutes has been shown in **Figure 10**.

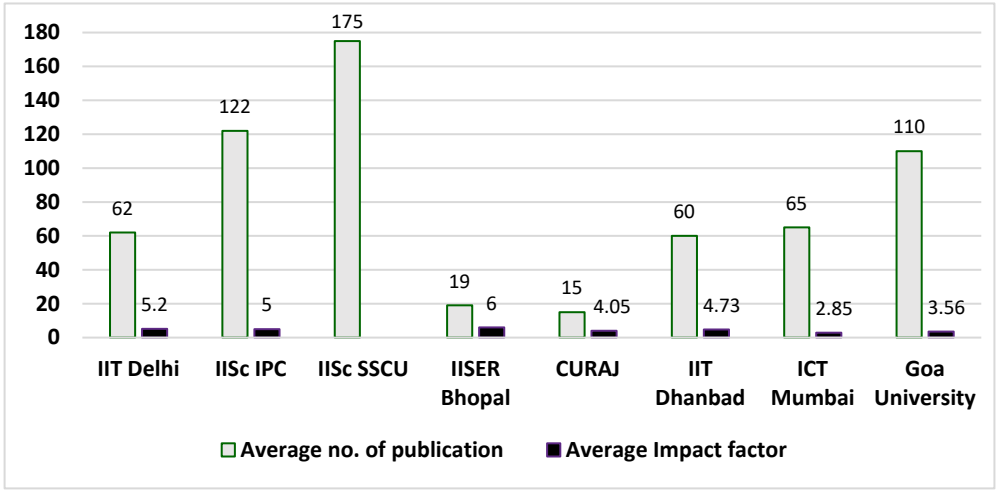

Figure 9a. Average number of publications along with the average impact factor

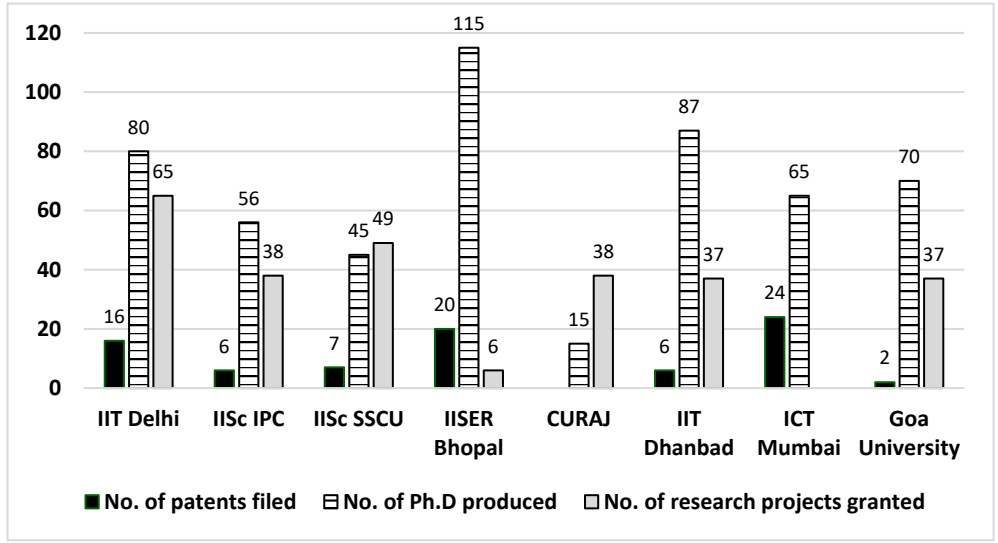

Figure 9b. Number of patents filed, Ph.D.s produced and research project granted after 5 years of FIST support in some of the institutes.

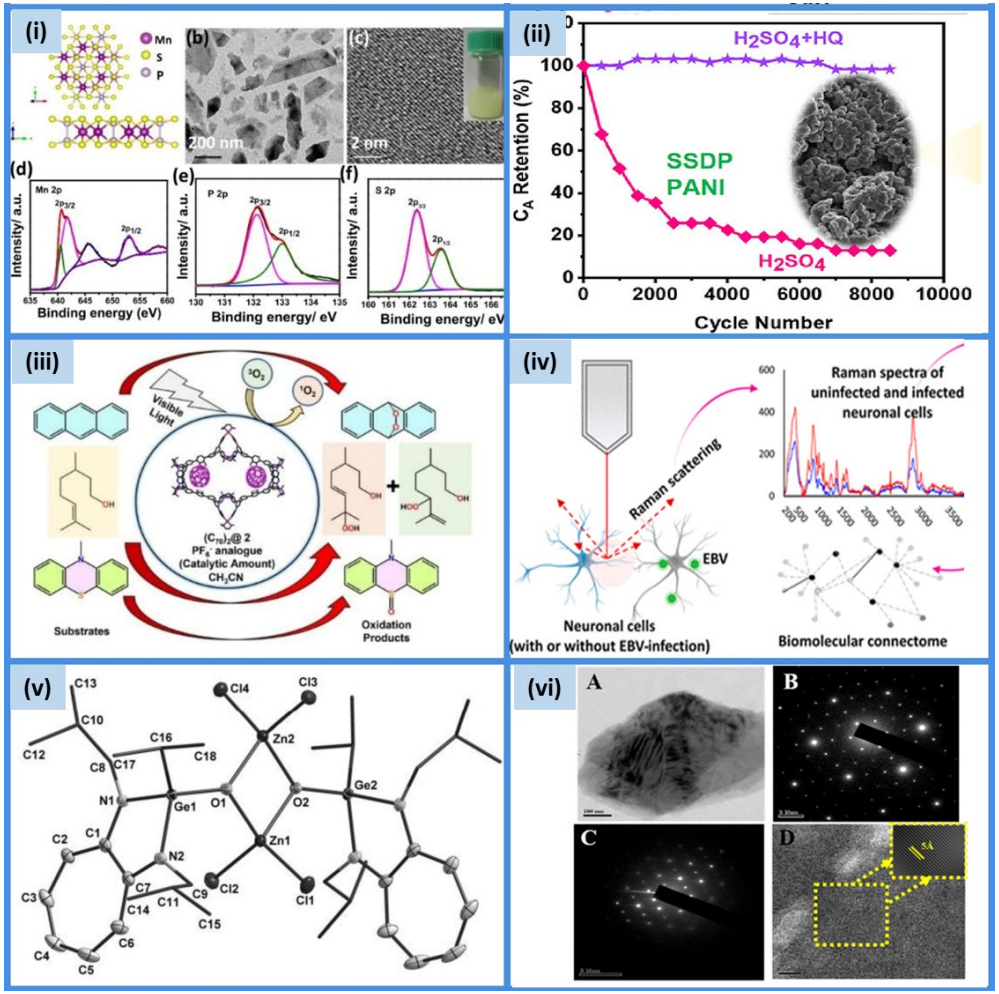

Figure 10. (i) (a) Schematic, (b) TEM image, (c) HRTEM image, (d–f) represent the HR XPS of exfoliated $MnPS_3$ (Kumar et al., 2020); (ii) Capacitance retention of SSDP PANI based electrodes in sulphuric acid and sulphuric acid with hydroquinone electrolyte (Anandhu et al., 2022); (iii) Schematic representation of reactions catalyzed by the PF6 analogue (Banerjee et al., 2023); (iv) Raman spectra of infected and uninfected neuronal cells (Indari et al., 2022); (v) Molecular structure of compound (Germanone-stabilised zinc chloride complex) with thermal ellipsoids set at 30% probability (Sinhababu et al., 2016); (vi) (A) TEM image and (B) Corresponding SAED pattern of the crystalline precipitate obtained following addition of Zn^{2+} salt to Au14 nanoclusters in the liquid medium. (C) SAED pattern of the crystalline precipitate along different zone axis highlighting the inter-planar distance in the crystal. (D) HR TEM and corresponding inverse fast Fourier transform (IFFT, in the inset) images of the crystal (Basu et al., 2016).

Conclusion and The Way Forward

Despite of funding, resources and infrastructure complexities, India's biggest strengths are the quality of its most elite scientific institutions committed by researchers to address India's social and economic challenges. Indeed, the country is sitting at the correlation of some grand challenges in building scientific capacity to tackle pressing issues in energy, water, food and pollution. The scientific research is the most powerful means for achieving excellence in almost every aspect of life. Also, the quality of scientific output of any discipline is critically dependent on the extent of research funding and eminence of the scientific education. Among various funding programs launched by several funding agencies, the DST- FIST scheme strengthens the S&T infrastructure with adequate funding and associated flexibility. The restructuring in the program has been done with the variation in the S&T needs of the country. This scheme works for paving a way by which individuals, institutes and societies develop abilities to perform research effectively and efficiently in a sustainable manner. In the present study the measure of India's contribution towards chemistry research in a global perspective has been shown. The detailed analysis of importance of the research grants in the development of emerging research fields of chemistry in various scientific institutions supported from FIST grant is discussed.

In future, the R &D facilities developed in various departments can be shared among researchers working at nearby institutions along with industries. A sustainable plan will be developed wherein short-term National and International courses and workshops on various aspects of procured equipment shall be conducted for the skill enhancement of the individuals. These facilities and activities will certainly boost up the collaborative research work to be taken up that will result in publications in high impact journals and patents. Finally, in the way forward ongoing policy measures pertaining to augmenting R&D in India can be done. The Science, Technology & Innovation Policy along with Scientific Social Responsibility Policy can be done to leverage the contribution of the private sector and encourage the states to invest in R&D. This can lead to promote a more decentralised approach to R&D and innovation in the country. The India Innovation Index developed by NITI Aayog can be used to promote states' expenditure in R&D through competitive federalism. Similarly, the provisions of Corporate Social Responsibility could be leveraged to augment the contribution of the private sector towards R&D. With the finalisation of these documents and capitalizing on existing frame works and provisions, India will have a robust R&D ecosystem that would also ascertain the incorporation of R&D systematically into the formulation of different development schemes and programs. The inclusion of the R&D institutions into the policy and programme implementation is instrumental to India's endeavour under the "Atma Nirbhar Bharat" to transform itself into a self-dependent and self-sufficient welfare state.

Associated Content

Supporting Information

The methodology adopted for the selection of department/group, details of some of the chemistry departments along with the major research facilities provided from FIST, technology developed from FIST and their technological intervention done to the society (as Table S1). The details of the achievements and R&D activities from chemistry department of some of the institutes including, IIT Bombay, Organic Chemistry Department of IISc Bangalore, IIT Dhanbad, University of Hyderabad, IISER Pune, IIT Guwahati and Goa University. List of expansions for the acronyms used in the manuscript has been attached as Table S2.

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Disclosure of Interest

The authors have no competing interests to declare.

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