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Scientific activities, and extent of collaborative efforts in the top academic institutions of India : A scientometric study using Web of Science data

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Using more than one lakh publication records from the Web of Science database, we tried to identify the scientific activity (publications, collaborations and citations), sectors of collaboration (University-Industry-Government), & subjects of collaboration in the top 10 NIRF ranked engineering institutes and universities in India. The study indicated that collaboration in different types of academic institutions has steadily increased from 2011 to 2020. Greater growth has been observed in domestic collaboration than foreign collaboration. The international collaboration network tends to be very dense with more advantageous countries. Although, international collaboration resulting in more citations, the fractional impact strength of domestic publications is better than foreign. The impact factor of the journal was observed to be a better predictor than the number of authors per article. University-University sector - mainly different departments of the same institute emerge as the predominant form of domestic collaborative research. While assessing the disciplinary output of the top 10 institutions by establishing a subject framework based on the Frascati Manual and Essential Science Indicator of Clarivate, it was observed that Civil, Mechanical & Electrical Engineering; Chemical, Material & Environmental Engineering; Chemical Sciences, and Theoretical aspects of Physics were the major fields amongst science disciplines with overall 52% of domestic and 48% of foreign collaboration.

Keywords: *Collaborative Research-India, University-Industry Collaboration-India, UIC-India, Triple-helix mode-India, Research Collaboration-Indian Universities, Engineering Institutions-India.*

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Background

Advancement in Research and Development (R&D) activities of any country is a key indicator for measuring national development. Because of the increasing specialization in sciences, the complexity of the problems investigated, and funding needed to conduct multi-faced experiments, research in academia has become collaborative. Benefits of increased collaboration include easier access to public funding, hope of better prominence and visibility as a result of working with recognized research groups, and the potential to increase productivity (Lee & Bozeman 2005). One of the two techniques used to investigate phenomena connected to scientific collaboration is the qualitative approach, which aims at determining the factors that encourage collaboration as well as the dynamics that drive it. Quantitative methods, are used to map and measure collaborative activities, such as bibliometric analyses of co-authorship in scientific publications published in international journals and indexed in specialized databases (Abramo et al. 2009).

To rank academic institutions across the country, MHRD introduced the National Institutional Ranking Framework (NIRF) in 2016. Based on five broad parameters- Teaching, Learning & Resources, Graduation Outcomes, Research and Professional Practices, Outreach & Inclusivity, and Perception - every year it declares discipline-specific (like Engineering, Law, Architecture, Medical etc.), discipline non-specific university, as well as overall rank of Indian institutions.

The importance of interaction between University-Industry-Government to foster the social and economic development of a nation has been prominently discussed by Henry Etzkowitz and Loet Leydesdorff in their triple helix model in 1990s (Etzkowitz & Leydesdorff, 1995). Although the initial role of universities is to promote education and basic research, industries to manufacture commercial goods and services, and government to regulate resources (land, tax, finance etc.), the interaction and transfer of people between these sectors can enhance the transfer of knowledge. To replicate the innovative ideas generated by academia, the involvement of industry for its production on a large scale with support from the government is essential for a country like India. In recent years, communication between universities and industries has been gaining attention and is regarded as an important means of technology transfer from university to industry. The present world university ranking system also depends on the aggregate effect of university research output on knowledge creation, particularly the patent performance, as the number of patents filed by any institute is regarded as a valid yardstick of R&D activity. Development of university-industry collaboration (UIC) projects shows that several initiatives have been carried out throughout the globe, mainly in the countries like China, Japan, and the USA (Rahm et al., 2013), however, India has showcased very little research attention in this domain so far. This investigation explores the existing channels of interaction, and university-industry-government collaboration mechanisms in top NIRF ranked institutes in India that are listed in engineering and universities categories.

Review of Literature

Scientific collaboration has received increasing attention during years. The significant and positive relationship between collaboration and citation count (Moldwin and Liemohn, 2018; Sooryamoorthy, 2017) has been discussed widely. However, some studies also failed to show significant correlation (Bornmann et al, 2012) and others have reported negative effect (Fu and Ho, 2018). From country level perspective, Hayati and Didegah (2010) found positive strong correlation (r=0.685) for Iranian publications but Ronda-Pupo et al. (2015) observed weak relationship (r=0.133) for Latin-American management articles. Therefore, it is necessary to explore this relationship in the context of different countries. Some recent studies examined the relationship between scientific collaboration and citation count using meta-analytic method (Shen et al., 2021) and found a positive but weak correlation (r=0.146). This study found that discipline, countries, document type and citation sources act as moderators that influence the correlation significantly.

Some recent studies have explored the university-industry collaboration (UIC) drivers from the industry perspective and analyse how, and to what extent, policy interventions could increase the engagement of industrial actors in UICs (Giones 2019). Cheng (2020) showed that the UIC policy had a significant positive effect on both industry–university collaboration input and government–university collaboration input. Nsanzumuhire (2020) made a systematic review of the literature that covers the gap by integrating the literature on university-industry collaboration implementation processes from developed and developing countries' contexts. In another study, Abbas et al. (2019) explored the internal and external R&D activities of university and industry collaboration for educational innovation and industrial product development. Fan et al. (2015) assessed the impact of university-industry collaboration on the academic output in Chinese research-oriented universities. The bibliometric indicators like co-authorship, international cooperation, citation, and journal impact factors have been used to measure the level of diversified influence and academic influence. The study finds that University-industry collaboration in China has high diversified influence with low academic influence, as universities in China are academic-oriented and enterprises are profit-oriented. In another study Zhou, Tijssen and Leydesdorff (2016) compared the UIC in China and USA in terms of co-authorship publications and found Chinese universities are much less active in collaboration with industry in terms of collaborative productivity and collaboration intensity. Kleiner-Schaefer & Schaefer (2022) identified a lack of awareness about opportunities that UIC provides in enhancing the National Innovation System and lack of monetary support as the potential barriers that prevent firms from using UI collaboration for innovation in emerging markets of Turkey.

In the Indian context, Karki and Garg (1995) made a bibliometric study of industrial research and related activity in India and argued that industrial research in India is mostly dependent on foreign and non-patent literature. Bhattacharya and Arora (2007) made a study to investigate various types of interactions between industries and science departments of seven selected universities in India. They concluded that collaborative research needs to be emphasized for a better outcome for both industry and university.

Rupika (2015) measured and personated the network of University-Industry-government collaboration present in Indian research activities. They identified and analysed top partnering institutes in each sector along with the strength of each linkage. To stimulate UI collaboration in Indian settings, a working group on enhancing and enabling University-Industry Linkage constituted by UGC made recommendations for the establishment of dedicated Technology, Innovation, and Entrepreneurship (TIE) cells in universities (2019).

In terms of discipline, it was seen that scientific collaboration had positive relation with citation in all disciplines. However, the significance was observed to be highest in life science and biomedicine followed by social science but weak in physical science, technology and arts & humanities. The higher value for social science, as explained by them, might be because of social science research was often multi-paradigmatic and produced arguments and interpretation (Puuska, 2014). On the other hand, life science and biomedicine required more instruments, ideas, analyses and interpretation calling for more quality-based research (Shehatta & Mahmood, 2016). The weaker relation in arts and humanities was because of the fact that they had the lowest extent of scientific collaboration among the domains (Franceschet & Costantini, 2010) also in physical science & technology because of the fact that team size in these fields are quite large and the profits of collaboration could be limited by excessive coordination cost (Wuchty et al., 2007).

Research Questions

At this point, it has become clear that the effect of collaboration in gaining citation has been widely discussed. However, no consensus has been reached as there is still lack of widely-agreed quantitative evidence at country level. The importance of university-industry-government collaborations for sustainably developed nation-building is mentioned in various studies without any quantitative data, especially for a country like India. Whether authors of all domains of knowledge are willing to collaborate frequently in a country like India has not been proved yet. Through this present study, the following research questions have been addressed;

- Is there any uniform structure and dynamics of collaboration existing in terms of quantity and impact among the top ranked academic institutions of India?
- How much domestic collaboration has been made through university, government, and industry sectors by these top institutes?
- What are the prominent domains where authors of these institutes are collaborating frequently, nationally, and internationally and what are the major fronts in academic collaboration?

Methodology

The database of ISI web of Knowledge (WOS) provides access to multidisciplinary databases of bibliographic information (SCI-EXPANDED, SSCI, A&HCI) which are used as a data source for the analysis. For this study, the search was conducted during the December of 2021. The data for this study was taken from Indian Ranking 2021 released by NIRF. Naturally, international ranking fails to represent national institutions appropriately on various parameters, therefore National Institutional Ranking Framework which provides a proper assessment of the HEIs in India was considered for the study. As it was not possible, due to computational and time limitations to take all the institutions, we took top 10 from the list. Our sample consist of top 5 engineering institutions and top 5 central and state funded universities (other than engineering, discipline non-specific) as per NIRF ranking 2021. Engineering institutions like Indian Institute of Technology- Madras (IITM); Indian Institute of Technology, Bombay (IITB); Indian Institute of Technology, Kanpur (IITK); Indian Institute of Technology, Kharagpur (IITKH); Indian Institute of Technology, Delhi (IITD); and discipline non-specific traditional universities (Category: University in NIRF) like Indian Institute of Science-Bangalore (IISc), Jawaharlal Nehru University, New Delhi (JNU); Banaras Hindu University, Varanasi (BHU); University of Calcutta, Kolkata (CU) and Amrita Vishwa Vidyapeetham, Tamil Nadu (AVV) have been considered under study. The publication data was collected through an institution-based search (affiliation) and by individually selecting the institutions indexed in the affiliation list of the WOS database with a refined timespan =2011-2020. As the search was based on institutions, all documents with at least one author from the selected institutions were retrieved. The data collected was of different record types namely Articles, Reviews, news items, editorial material, retraction, bibliographical items, etc. For the purpose of this study, however, we restricted with document type “Article” (i.e. original research paper that attract citations, not those that have dissimilar citation patterns) only. Initially, we obtained a total of 117879 records (with at least one institutional affiliation selected under the study in every record), from which 116466 unique values (articles) were selected after removing duplicates. Of these articles, there were 112355 (96.5%) articles had joint authorship and the remaining 4111 (3.52%) had solo authorship. Since, the volume of publication under single authorship was of waning and our intention of this study was to analyze the collaborative research trend in top ranked academia, we restricted our further analysis only to articles published in collaboration. To know the faculty-wise publication in selected institutes we excavated the NIRF-2021 datasheet. Data analysis was done using MS Excel by downloading bibliographic details of the articles.

One of the questions of this study was to measure the effect of collaboration on citation. For that, number of citation-received by each article was analyzed with various parameters like extent (domestic vs international) of collaboration, number of authors per article, Impact factor of the publishing journal, etc. A new measure, namely the fractional impact strength (FIS) of each type of collaboration for each individual institution was analyzed. For that matter, publications were adjusted with the Impact Factor (IF) of the journal in which they were published. The FIS equals the weighted sum of publications realized by the scientist. The weight is the fractional output (FO) multiplied by the impact factor of the publishing journal.

To understand the type of collaboration from these known variables (fields), new variables were generated such as domestic collaboration (sets without an author address from any other country except India), international collaboration (the affiliation of at least one author belongs to the institution outside India), and partnering countries for collaboration. Domestic and international collaboration are the commonly used types of collaboration in literature (Sooryamoorthy 2009). To identify the partnering countries, we used country-level fractional counting using the VOSviewer open ware tool. Each country was given credit only once despite multiple occurrences in a document.

Next, the nature of domestic collaboration has been identified in terms of University-University linkage, University-Government linkage, University-Industry Linkage, and multiple sector linkage. The affiliation field of WoS (C1) contains the names and affiliations of contributing authors. The sector of the first 10 contributing authors (median of authors being 9.07) from their affiliation addresses were separated and coded for analysis. When the C1 field contained the name of different or same academic institutes along with the name of the institute we considered in this study, we categorized it as University-University linkage. The same process was carried out for detecting other types of linkage. If any author of the collaborative article belongs to the institute that is directly funded and managed by the Government, like CSIR, DST, DBT, etc., or managed by a public sector undertaking (PSU, eg. Maharatnas and Navratnas companies), we categorized it in the Government sector, and when an institute was funded and managed by private bodies, like Sun Pharma, TVS motors, IBM Corporation, etc, we kept it under industry sector. And in case the affiliation contained authors from two different sectors, we kept it under multiple collaborations.

The most challenging part of this study was the grouping of diversified fields of subjects as available in WoS data under WC (Web of Science Category) and SC (Research Area) into a considerable limit so that subject trend of collaboration can be visualized. Our whole dataset contained 1370 research sub-fields. Because of several sub-fields, we felt the necessity to develop a framework for grouping all identified sub-fields into a cluster of broad fields. For developing the framework, we consulted the Essential Science Indicator (ESI) maintained by Clarivate Analytics and the revised fields of science & technology (FOS) classification in the Frascati Manual of OECD (2007). On consulting both the schemas and keeping two principles in mind i.e., specific topic preceded by the general topic and publication having both practical and theoretical aspects, to be kept under practical sub-field; we developed a new schema consisting of 26 research sub-fields and 10 broad fields. In case any publication contained more than one sub-field (not from the related fields) from our schema, we considered it as multidisciplinary.

Results

The collaborative research trend in terms of domestic and foreign collaboration and their citation impact in the top-ranked engineering institutes and universities in India for the period 2011-2020 is shown in Table 1. While adjusting publications with number of faculty (based on NIRF 2021 data) presently institutions have, it was observed that all the engineering institutes have almost equal trend with 20 to 24 articles per faculty. But for universities, the trend is quite low (2 to 8 article per faculty) except IISc, Bangalore (39 articles per faculty). It is also visible that almost 72% of the total collaborative research was generated in collaboration with the institutes of India and the remaining 28% were from institutes of foreign origin. This may indicate that academic authors of top ranked institutes still prefer to collaborate locally than globally. However, while considering volume of citations between articles written in collaboration with domestic and foreign authors, the $P(T <= t)$ two tail (0.003) gives the absolute value of the t-Statistic (3.993) as higher than the Critical t value (2.262). Since the p-value is less than our alpha, 0.05, we reject the null hypothesis that there is no significant difference in the means of each sample. Overall, it was seen that articles published in collaboration with international authors (though lesser in number) received more citations per article (Mean=21.19, SD=89.95) as compared to the articles published with domestic authors (Mean=12.12, SD=22.89). However, the higher standard deviation for international collaboration indicates skewed distribution of citation among articles. On the other hand, the fractional impact strength (measured by multiplying fractional publication with the 5-year impact factor of the journal where the article was published) of all engineering institutions (SD=1.1437) and universities (SD= 1.1104) is observed to be higher when collaborated with domestic authors.

In the next steps, attempts have been made to know whether the number of authors in an article is responsible for receiving more citation. We observed a strong correlation between citations and the number of authors, with a Pearson's correlation coefficient of 0.085 for universities and a weak correlation of 0.037 for engineering institutes. It is important to note here, we observed almost 943 or 1.4% publication of engineering institutes and 514 or 1.1% publications of universities have mega-authored articles that have more than 500 authors per article and under foreign collaboration with 20 or more collaborating countries. These outliers were discarded from this analysis.

Our dataset shows that overall foreign collaboration have a positive effect on citation but fractional impact strength of domestic collaboration gain more positive impact. Furthermore, size of authorship also exhibits positive correlation. As a robustness check, we next sought to understand which factor has more influence on getting citations? Is it the authorship (excluding mega authored articles) or the corresponding impact factor of the journal? For that we performed a regression analysis using dummy variables, 1 for foreign collaboration and 0 for domestic collaboration in SPSS, the result of which is displayed in Table 1a.

Table 1

Collaboration trends and citation impact

Institutions	TP	TC	CPP	Collaboration & Citation impact										
				Overall			Domestic				International			
				Art	APF	CPP	Art (% Art)	TC (CPP)	SD	FIS	Art (% Art)	TC (CPP)	SD	FIS
Engineering Institutes				(n=66219)			(n=47728)				(n=18491)			
IIT Madras	14343	178123	12.41	14040	22.29	15.15	9694 (69.04)	134907 (13.91)	21.405	1.39	4346 (30.96)	71257 (16.39)	72.822	0.80
IIT Delhi	13390	176473	13.17	12970	19.86	14.48	9788 (75.47)	120936 (12.36)	24.381	1.16	3182 (24.53)	52871 (16.61)	43.416	0.95
IIT Bombay	14242	200307	14.06	13828	23.66	15.80	9257 (66.94)	106414 (11.49)	25.213	1.12	4571 (33.06)	91984 (20.12)	81.738	0.82
IIT Kanpur	10210	128935	12.62	9819	20.87	13.91	7036 (71.65)	81906 (11.64)	17.5477	1.12	2783 (28.34)	45078 (16.19)	59.335	0.89
IIT Kharagpur	15956	206672	12.95	15562	19.95	14.00	11953 (76.8)	146935 (12.29)	21.8735	1.07	3609 (23.19)	56734 (15.72)	62.094	0.88
Universities (General)				(n=46136)			(n=33305)				(n=12831)			
IISC	19041	266644	14.00	18281	39.28	15.04	12377 (67.70)	161061 (13.01)	25.726	1.18	5904 (32.29)	100877 (17.08)	64.715	0.84
JNU	5630	73582	13.06	4915	8.16	18.01	3519 (71.59)	36548 (10.38)	24.83	0.95	1396 (28.40)	35794 (25.64)	137.349	0.81
BHU	12601	177104	14.05	12296	7.39	17.49	9375 (76.25)	105987 (11.30)	20.785	0.80	2921 (23.75)	69183 (23.68)	102.254	0.61
CU	7627	107998	14.15	7318	5.17	17.03	5691 (77.76)	71084 (12.49)	19.880	0.79	1627 (22.23)	35088 (21.57)	98.822	0.64
AVV	3426	67768	19.78	3326	2.02	25.67	2343 (70.45)	29087 (12.41)	27.335	0.89	983 (29.55)	38285 (38.94)	177.020	0.67

TP=Total article (Collaborative & non-collaborative both), TC= Total Citations, Art=Only Collaborative Articles, % Art= Percentage of articles out of overall collaborative articles (excluding other forms of publications), CPP=Citation per Article, APF =Average Publications per faculty, SD=Standard Deviation, FIS = Fractional impact Strength, Domestic and International collaboration is based on total collaborative articles only. Faculty data is the total faculty through decades as indicated in NIRF 2021.

Table 1a

Regression analysis with Impact Factor, Author Size

Model Summary				
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**
1	.271[a]	.73	.73	31.76730
a. Predictors: (Constant), Foreign, Impact_factor, Auth_per_art				

ANOVA[a]						
Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	8862473.094	3	2954157.698	2927.340	.000[b]
	Residual	111911930.704	110896	1009.161		
	Total	120774403.798	110899			
a. Dependent Variable: Citation_recvd						
b. Predictors: (Constant), Fore, Impact_factor, Auth_per_art						

Coefficients[a]						
Model B		**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**
		Std. Error	**Beta**			
1	(Constant)	4.188	.140		29.886	.000
	Auth_per_art	.040	.004	.028	9.607	.000
	Impact_factor	2.285	.025	.262	89.657	.000
	Foreign	2.214	.219	.030	10.124	.000
a. Dependent Variable: Citation_recvd						

The results from the above table show that when authors of these institutes collaborated with foreign authors, they gained 2.21 units of more citations (Unstandardized Coefficients-Foreign). When authors published article in a journal having impact factor, gain of 2.28 more citations each (Unstandardized Coefficients - Impact_factor) occurred with the increase of impact factor value 1. Author size of an article does not have that extent of influence in collaboration. From the results of overall regression analysis in terms of authors-size and citation, results although showed the variable is statistically significant with these factors, impact factor of a journal may be considered as a predictor of getting more citation. Therefore, blindly increasing team size will not be conducive to elevation of scientific research influence.

Next, the year-wise growth of collaborative articles as shown in figure 1 indicates that the growth is better explained by linear model and is more prominent in domestic collaboration than foreign collaboration. The difference of growth in IITD and IITB is prominent among engineering institutions. It increased from 797 publications in the year

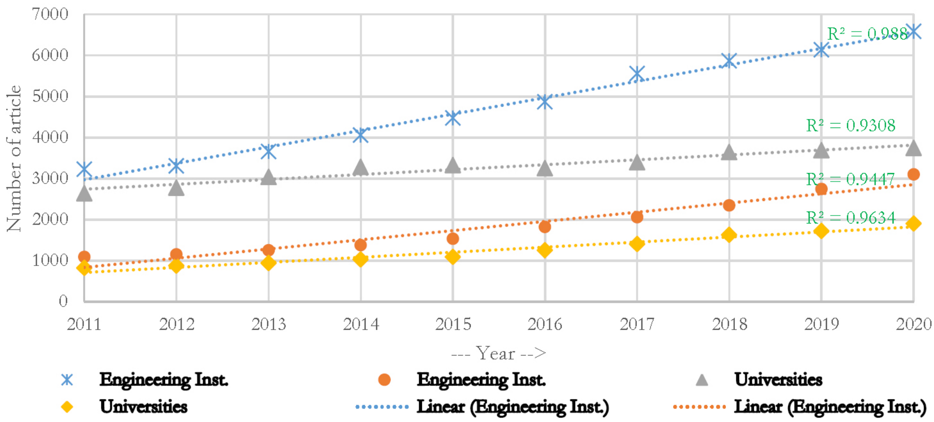

Figure 1

Growth of Collaborative Research in last 10 years in Indian Academic

2011 to 1866 publications in the year 2020 for IITD and 845 publications in the year 2011 to 2045 publications in the year 2020. Among universities, such growth is only observed with IISc, Bangalore, where the growth increased from 1414 publications in the year 2011 to 2115 publications in the year 2020.

To understand the predominant countries in foreign collaboration, we used VOSviewer software. A minimum of 10 documents per country was set as threshold, and 50 countries met the threshold. In this VOSviewer graph, every vertex represents the country; the volume of a vertex (node) is proportional to the number of documents written in collaboration. The lines between countries show the linked countries that co-authored the articles and the colour of vertices and lines are indicators of the relatedness between two vertices. Similar coloured vertices constitute a cluster strongly related to each other and the number of clusters formed is directly proportional to the scattering in collaborative nodes. The international collaboration network for engineering institutions as shown in figure 2 tends to be very dense and diverse compared to universities. The density of the network for engineering institutes is 0.067234 compared to 0.042366 for traditional universities (figure 3) which indicates that the academicians of engineering institutes widely collaborate with other institutions having same subject specialization than for universities. Each node of engineering institutions is close to maximum number of nodes and is linked to almost all other nodes. The average degree of countries is 12.3087 for engineering institutes compared to 8.0732 for universities, which means that each of the countries in the network shared documents with almost 12 and 8 country, respectively. The most prolific relationship is found to be between India and the *USA, Germany, England, South Korea, France, and Japan,* whereas emerging economies also got importance in the category of universities.

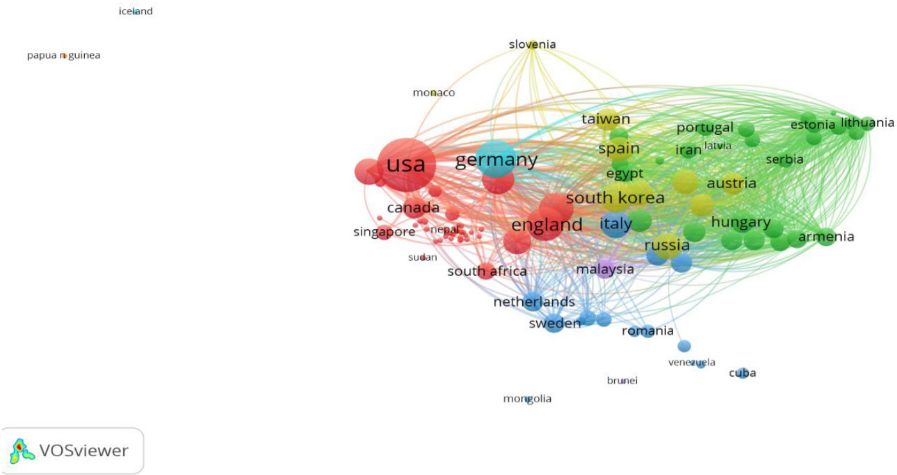

Figure 2

Collaborative Country of Engineering institutes

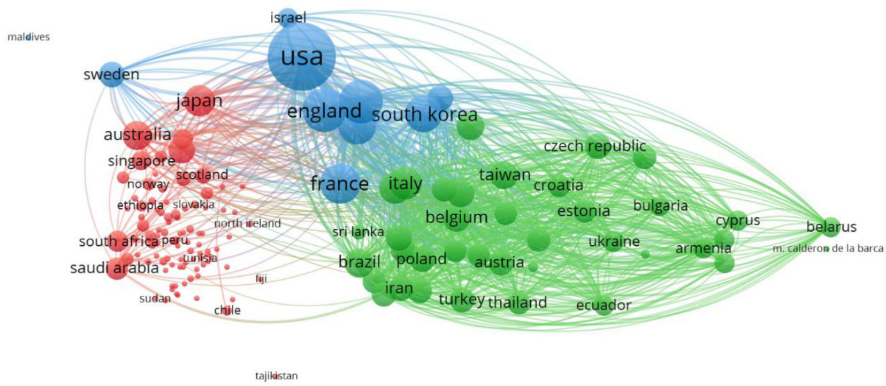

Figure 3

Collaborative Country of Universities

From table 1, it was clear that domestic collaboration was more predominant in top ranked academic institutions. To explore the nature of domestic collaboration, further explored the extent of domestic collaboration by their respective affiliation - academic, government, and industry. As shown in Table 2, intra-university (45.81%) collaboration followed by inter-university (45.33%) collaboration constitute the major portion (almost 91%) of the total domestic collaborative research. The collaborative articles with the government sector was only 6.58%, where the highest University-government collaboration was observed in BHU with 10.17% and IIT Bombay with 9.67%. Collaboration with Indian industries was quite nominal i.e., only 1.84%. IISc, Bangalore among traditional universities and IIT Bombay, followed by IIT Kharagpur among engineering

Table 2

Extent of domestic collaboration and citation impact

	Article & Citation Count									
	Within Univ		Univ-Univ		Univ-Govt.		Univ-Indus		Multiple	
	Art	CPP	Art	CPP	Art	CPP	Art	CPP	Art	CPP
Engineering Institutes										
IIT Madras	5247	11.65	3594	9.27	622	11.62	193	7.14	38	4.76
IIT Delhi	4874	12.50	4217	12.16	518	12.65	138	8.91	41	10.19
IIT Bombay	4442	12.26	3657	10.44	794	11.95	310	10.80	54	9.74
IIT Kanpur	3512	12.24	2941	10.61	401	13.72	157	10.16	25	14.75
IIT Kharagpur	5602	12.80	5447	11.54	621	15.05	239	9.08	44	9.63
Universities (Traditional)										
IISC	5462	13.57	5901	12.38	705	14.93	270	10.1	39	6.64
JNU	1179	9.7	2037	10.25	264	15.24	32	5.96	7	9.57
BHU	3987	11.86	4408	11.26	883	11.86	78	6.5	19	8.85
CU	1818	13.28	3334	11.9	481	13.95	51	10.53	7	17.42
AVV	1012	13.57	1244	11.43	54	18.92	31	4.03	2	15.5

Univ=University, Govt.-Government, Indus=Industry, Art=Article, CPP= Citation per article

institutes had the highest linkages with industries but the figure did not go beyond 4%. No statistically significant correlation has been observed between university-industry or university-government collaboration for both engineering institutes (p=0.3099) and traditional universities (p=0.3125). This may suggest that still the Triple-Helix model of collaboration where industry and government serve as important pillars towards innovation is yet to establish.

Next, we grouped the total article according to the newly developed schema as mentioned earlier. The result is shown in table 3. We observed an uneven distribution of Indian collaborative research across various subject-fields. Civil, Mechanical & Electrical Engineering; Chemical, Material & Environmental Engineering; Chemical Sciences and Theoretical aspects of Physics were the four major fields amongst science disciplines where on an average 12.58% of domestic (collectively 50.35%) and 13.37% of foreign (collectively 53.49% of) collaboration was observed. These findings on disciplinary output support the earlier study done on IITs by Banshal et.al. (2017).

Next, but not too far from above mentioned four fields was Polymer Science including Material science with 9% of domestic and 7% of foreign collaborative articles published. The least researched area was Animal Science with a percentage share of only 0.45-0.75% of the total collaborative research. In each of these fields, when collaboration was made with foreign authors, they received on an average more citations per article. A positive Spearman correlation of 0.964 has been observed between Rank TI and Rank TC, allowing us to conclude that number of articles (volume) in a subject have positive influence in getting citation.

Although, this study identified four major fields where a significant foreign collaboration was made, fields like Clinical Medicine (20.74 citations/article), Agricultural Biotechnology (20.17 citations/articles), Space Physics (18.44 citations/article) were the three other subjects in which average citations per article was quite impressive.

Table 3

Disciplinary output in collaborative publications, foreign and domestic

Subdivision	DC	% of Total	CPP	FC	% of Total	CPP	TA	Rank TI	TC	Rank TC
Agricultural Sciences including Dairy and Veterinary sciences (AG-A)	648	0.80	8.36	244	0.78	16.65	892	21	9485	22
Agricultural Biotechnology (AG-B)	962	1.19	18.05	203	0.65	30.08	1165	16	23472	15
Animal Sciences (BS-A)	410	0.51	10.34	270	0.86	16.04	680	24	8573	23
Biochemistry & Molecular Biology (BS-B)	3723	4.59	10.32	1387	4.43	27.08	5110	8	76102	7
Plant Sciences (BS-C)	812	1.00	11.81	255	0.81	17.5	1067	19	14031	16
Other Biological Sciences (BS-D)	781	0.96	8.01	338	1.08	22.01	1119	17	13641	17
Electrochemistry (cell, energy, and fuels etc) (CH-A)	1638	2.02	18.49	488	1.56	19.83	2126	15	39978	12
Polymer Science including Material science (CH-B)	6577	8.12	13.03	1989	6.35	17.33	8566	5	120210	6
Other Chemical Sciences (CH-C)	10857	13.40	15.02	3094	9.88	19.57	13951	3	223753	1
Geosciences, Meteorology & Atmospheric Sciences (ES-G)	3587	4.43	10.49	1958	6.25	18.55	5545	7	73848	9
Oceanography, Hydrology, Water Resources (ES-W)	449	0.55	8.52	267	0.85	12.23	716	23	7087	24
Civil, Mechanical & Electrical Engineering (ET-A)	14273	17.61	10.36	4167	13.30	14.23	18440	1	207259	2
Chemical, Material & Environmental Engineering (ET-B)	7976	9.84	14.24	2901	9.26	17.21	10877	4	163605	4
Biotechnology & nanotechnology (ET-C)	1944	2.40	12.85	614	1.96	18.84	2558	13	36551	13
Basic Medicine (MH-B)	2468	3.05	16.21	799	2.55	18.16	3267	10	47968	10
Clinical Medicine (MH-C)	2718	3.35	7.41	927	2.96	60.88*	3645	9	75624	8

Contd...

Health science & medical Biotechnology (MH-H)	573	0.71	10.25	308	0.98	16.67	881	22	10895	19
Physics - Theoretical Aspects (PS-A)	9270	11.44	9.54	4836	15.44	17.82	14106	2	174683	3
Physics - Experimental Aspects (PS-B)	899	1.11	9.36	199	0.64	8.43	1098	18	10084	20
Space Physics (PS-C)	778	0.96	8.95	1462	4.67	23.49	2240	14	41310	11
Mathematics (MM)	1654	2.04	4.21	971	3.10	5.97	2625	12	12018	18
Computer Science & Information Sciences (CS)	1800	2.22	9.86	829	2.65	13.98	2629	11	29354	14
Arts & Humanities (History, Archaeology, Languages, Philosophy, etc. (AS-A)	50	0.06	3.04	34	0.11	4	84	26	288	26
Sociology, Psychology, Political Science, Educational sciences, media, and communications, etc (AS-B)	397	0.49	5.26	214	0.68	9.02	611	25	4022	25
Economics & Management Sciences (AS-C)	617	0.76	8.8	392	1.25	10.88	1009	20	9698	21
Many disciplines all from different subject fields (MDS)	5167	6.38	15.73	2173	6.94	21.65	7340	6	128341	5
Not Available	5	0.01	-	3	0.01	-	8	-	-	-

DC=Domestic Collaboration, FC= Foreign Collaboration, % of total= % of the total Collaboration in that type, CPP=Citations per article, TA=Total Article, TC=Total Citation, Note:
* In Clinical Medicine there are 58 articles each of which received 100 to 999 citations/article and 15 articles each of which received 1000 to 3200 citations/article up to 2021.

Further, from the above analysis, we sought major areas of these four highly productive fields where most of the collaboration was done. Each article in WoS contained tags like TI (Article), DE (Author keywords) etc. For this part of the analysis, we explored these two fields to identify the most dominant fronts in collaborative publications and how many citations each front received. To understand network centralities like closeness centrality, betweenness centrality, etc. the Gephi 0.9.2 has been used.

In network structure, the *closeness centrality* (CC) measures how close a vertex/node is to other nodes in the network. Therefore, high closeness score reveals a short distance between nodes. The *betweenness centrality* (BC) measures how many shortest paths connecting any two authors in the dataset run through any single node. On the other hand, *modularity* (Mod. Class) measures the strength of nodes of a network into modules, the higher the modularity nodes denser the connection within the module but the sparse connection between nodes in different modules. The clustering coefficients (CF) measure the average probability that two nodes of a cluster have in neighbouring themselves. A subject having high clustering coefficients means the node has a high probability to collaborate with its neighbour. The Eigen centrality measures the level of

Table 4

The relative importance of major fronts in the fields having greater collaboration

Fronts	Engg. Inst		Trad. Univ		Mod. Class	CC	BC	CF	EF
	Art.	CPP	Art	CPP					
Nanoparticles (Silver, Gold, Cu, Ag, ZnO, Palladium, TiO2, Magnetic, Organic)	283	16.28	194	19.89	60	0.418534	4507065.62	0.014668	0.775807
Microstructure analysis of metal & non-metals, alloys, networks etc.	271	12.96	126	15.34	114	0.39977	4955309.41	0.008778	1
Computational Fluid Dynamics (CFD) mechanism in various objects	241	13.77	21	14.62	156	0.294292	1723107.03	0.036216	0.147608
X-ray diffraction techniques application	159	13.94	134	16.34	115	0.3830485	1801051.26	0.019657	0.519241
Hadron-Hadron scattering experiments in various elements	194	14.26	63	12.74	100	0.9370985	445.370238	0.124523	0.013471
Density Functional Theory (DFD) application	137	12.52	141	11.51	53	0.3560345	1383385	0.016666	0.236025
Photoluminescence properties analysis	142	11.19	98	18.81	115	0.3673995	1877885.16	0.014558	0.411615
Adsorption quality of various composites, substances, molecules etc.	136	27.78	97	40.47	63	0.3713245	2794633.89	0.011349	0.387888
Fluorescence quality of various substances	127	10.44	105	11.18	42	0.3561905	1899904.66	0.017134	0.365053
Finite element analysis	163	10.53	26	9.55	131	0.342244	2813723.79	0.040125	0.361278
Genetic algorithm	151	16.41	38	20.42	72	0.3131725	632082.854	0.046606	0.115737
Crystal Structure	107	7.6	118	10.61	152	0.361791	1368166.23	0.015777	0.366153
Surface roughness study of various materials	150	11.67	27	15.46	59	0.337301	2735306.19	0.026312	0.312005
Nusselt number	145	1.75	10	10.36	82	0.2743925	1134092.46	0.053591	0.105334
Raman Spectroscopy	104	12.46	68	10.17	115	0.3877935	1406733.22	0.023672	0.381673

Engg Inst-Engineering institutes, Trad Univ-Traditional University, Art.=Article, CPP=Citation per article, Mod. Class=Average Modularity Class, CC=Average Closeness centrality, BC= Average Betweenness centrality, CF= Average Clustering Coefficient, EF=Eigen centrality.

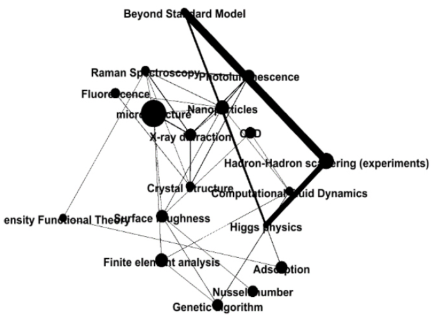

Figure 4

Major research fronts in Engineering institutes and their interconnection

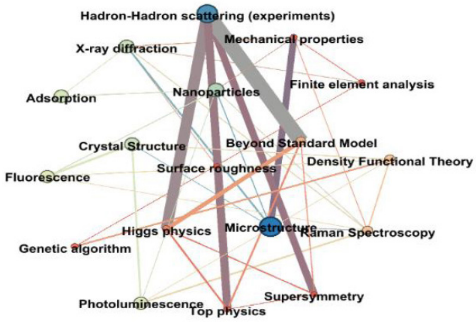

Figure 5

Major research fronts in Universities and their interconnection

influence that a node has within a network of clusters: the higher the score, the greater the level of influence within the cluster.

As shown in Table 4, research fronts like nanoparticles study, DFD, and crystal structure analysis received equal attention in engineering institutes and traditional universities, but a wide gap in research collaboration has been observed for the research fronts like microstructure analysis, genetic algorithm, etc. However, publications related to Microstructure analysis, Adsorption, and photoluminescence received a larger number of citations than articles on these subjects published by traditional universities. The research front 'Hadron-Hadron scattering' having the shortest distance between nodes has more probability to join with its neighbours, therefore collaboration in this field will have a long-term advantage on citation gaining. To show this collaboration visually, the network graph was prepared through Gephi as displayed in Figures 4 & 5.

While the number of nodes and links represent the network size, the thickness of the link represents the intensity of collaboration between two nodes. The size of nodes represents the number of publications that the author has, and if the distance between two nodes is shorter it suggests more collaboration between the two authors. Every node is represented through some colour, similar colours indicate similar groups or clusters that are related to each other.

Discussion & Conclusion

The present study showcases the collaborative practices among Indian authors working in top-ranked engineering institutions and universities using WoS data between 2011 and 2020. Our sample consists of engineering institutions, central and state-funded universities, as well as private universities.

Although the total number of institutions considered in this study seems small, but is not needed the volume of data analysed in this study is substantial. Since all these ten academic institutes are well known in diverse disciplines, they might be considered as a representative sample of a large academic population of India.

The results of the analysis reveal that in the last ten years a steady increase in collaborative publications with both domestic and international collaboration by all type of institutions, with more prominent growth in domestic collaboration. However, a wide difference in publications and citations received has been observed among institutions. Academicians of all engineering institutions published more than those of universities both in total number and per-capita terms. They also received quite a good number of citations. Among universities, IISc performed exceptionally well, even better than existing engineering institutions. The wide difference among universities over time may be due to the number of departments that the IISc has. IISc has nearly 40 departments, majority of which fall in the domain of science. Whereas, universities like BHU, CU have quite a large number of departments and a major chunk is from the disciplines like arts and humanities and social sciences. Studies have also shown that pattern of citation and publication vary substantially across disciplines. Humanities have broader readership which call for books rather than journals. Similarly publication and citation rate in social science are noticeably lower (cf. Huang & Chang, 2008; Bonaccorsi et al., 2016). It was observed that on an average, international collaboration gained more citations than domestic collaboration. This result supports the earlier findings of Puuska, Muhonen & Leino (2014), who suggested that international co-authorship is on an average more cited than publications by only domestic authors. However, the standard deviation value for citations in international collaboration is more than the mean, indicate skewed distribution of citations. The study, does not support earlier studies that states that the number of authors has a positive effect on getting citations (Hsu and Huang 2011). Thus, at research level, very large teams do not necessarily yield the greatest return on investment. The higher fractional impact strength of domestic publications indicate that there were quite a good number of articles published in domestic collaboration by these authors in high impact journals. While considering the predictors of getting more citation for publications, it was seen that impact factor of a journal had more influence than the number of author per article. Therefore, stakeholders of the Indian institutions should insist their authors to publish articles in high impact journals rather than publishing more only with foreign collaborators. This seems to have a positive effect in accomplishing better rank in the rank-list. Therefore, not necessarily only international collaboration, collaboration with domestic partners also yield citation advantage.

Along with the growth of collaborative publishing, there has been an increase in the relative share of domestic inter-organizational publications in a different types of universities. However, domestic university-industry collaboration or university-government publication has not gained enough advantage over the years. The percentage of collaboration with industry is still quite marginal.

Comparing domestic and international publications in various subjects for both universities and engineering institutions, a diverse distribution has been observed. The difference is more pronounced in 'universities' than 'engineering institutes. It is assumed that organizations having diversity in research are better equipped with new ideas, therefore diversity in research is a positive indicator of innovation in the ecological and economic systems. However, universities like BHU or CU having long-standing history in diversified subjects, are still less prepared in harnessing these diversities. We observed foreign authors in the fields like Theoretical physics, Geoscience, Space science, and Mathematics are collaborating more with Indian authors. This may be because India's participation in various global space research programmes has increased in recent days. India is collaborating with many countries like the USA, and China in various space missions. From the network analysis of various research fronts, it was seen that there are more ongoing research activities in the fronts like Computational Fluid Dynamics (CFD) mechanism in various objects, Crystal Structure etc. as the strength of nodes of these fronts were higher than others. But the fronts like nanoparticle, microstructure analysis gain much more attention in variety of fields because of which the Eigen centrality value of these two fronts are higher. Therefore, support from the stakeholders is expected in these fields to improve the image of Indian science system. At the same time, we observed articles published in the fields like Clinical Medicine, Agricultural Biotechnology, Biochemistry & Molecular Biology, etc. received much higher citations per article than in other fields. Therefore, it is expected that Indian universities will increase their participation in these subjects fields for the balanced development of the Indian science system.

Conflict of Interest Statement

Authors do not have any conflict of interest

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