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Research Article

The Diffusion of the Topic Carbon Nanotube Over the Universe of Subjects: A Statistical Analysis

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ABSTRACT

The diffusion is basically a physical process, which is essential in many physical, chemical and biological phenomena. The diffusion of knowledge refers to the interchange and propagation of knowledge through different media, or the transfer of knowledge from one subject to another. The concept of diffusion or dissemination of knowledge eventually gave rise to the concept of the diffusion of any specific topic over the universe of subject. In this paper, the growth of literature and the diffusion of the multidisciplinary topic "Carbon Nanotube" have been discussed since the year 1992 to 2022. The analysis of growth of literature shows the topic "Carbon Nanotube" follows logistic growth pattern over the last thirty years, which accords De Solla Price' theory. The topic "Carbon Nanotube" was born in the subject 'Physics' and then gradually became relevant or contextual with other subjects in due course of time like material science, chemistry, chemical engineering, environmental science, engineering etc. The core journals published the papers on 'Carbon Nanotube' had also been changed over the stipulated time span of thirty years. The diffusion phenomenon has been proved here by the analysis of correlation coefficients between the ranks of the core journals and the ranks of the associated subjects. The proof of diffusion phenomenon of a specific topic over several broad subjects' fields by correlation analysis is a new technique introduced here. This technique can be applied for studying diffusion of other multidisciplinary topics over various broad subjects.

Keywords: Universe of Subject, Diffusion, Knowledge Diffusion, Carbon Nanotube, Diffusion by Correlation Analysis.

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INTRODUCTION

The basic definition of a subject as pointed out by Gopinath (1976) states, "A subject is an organized and systematized body of ideas. It may consist of one idea or a combination of several...". Here idea or human thought is regarded as the fundamental building block of a subject. The collection or set of a number of subjects bearing some identical features indicates a broad discipline like social sciences, pure sciences etc. The "Universe of subject", a term coined by Ranganathan (1967), refers to the set of all possible subjects and facets which existed in past, exist at present and will exist in anticipatable future, which can be included in all possible given fields or domains of knowledge. It encompasses all the possible areas of inquiry and research within any particular field or discipline and the potential intersections and relationships between them. In library and information science, the universe of subject is often represented by a classification system or scheme, such as the "Dewey Decimal Classification" or "Universal Decimal Classification". These classification schemes organize information into subject categories or classes based on the topics or subjects covered and are designed to facilitate information retrieval and access. The universe of subject is not a static entity but highly dynamic one, which constantly evolves to generate new topics and areas of inquiry. As such, classification systems must be flexible and adaptable to accommodate new subject areas along with interdisciplinary fields of study. The concept of the universe of subject highlights knowledge's vast and complex nature and the ongoing need for effective and dynamic systems for organizing and accessing information.

The diffusion is basically a physical process, by which particles, atoms, or molecules move from an area of higher concentration to a place of lower concentration, resulting in a net movement of particles. This process occurs naturally due to the random thermal motion of particles and does not require an external force. Diffusion is essential in many physical, chemical and biological processes. For example, it is involved in exchanging gases in the lungs and absorbing nutrients in the small intestine. It also plays a critical role in transporting substances across cell membranes and spreading diseases and pollutants in the

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environment. The diffusion rate is influenced by several factors, such as the temperature, pressure, size and shape of the particles and the properties of the medium through which the particles are diffusing. Understanding diffusion is important in chemistry, physics, biology and materials science.

The diffusion of knowledge refers to the interchange and propagation of knowledge through different media, or the transfer of knowledge from one subject to another, or the transfer of the link of knowledge between production and application. The main function of the diffusion of knowledge includes the movement of knowledge transmission and circulation. This concept of diffusion or dissemination of knowledge is a vital topic and discussed many times in the context of library and information science. Actually, the knowledge, just after creation, is not widely available. It is transmitted through direct face-to-face interactions at first. Such types of interactions develop networks at first, which transmit the knowledge from originator to final recipient. At this stage, knowledge gradually becomes recorded and documents are created simultaneously. Initially, the particular knowledge bears a particular subjective context, which gradually increases in number. The knowledge gradually becomes relevant to multiple subjective contexts. In this way, the uni-contextual knowledge is transformed into multi-contextual knowledge. The main issue of this paper is to find out how the relevance of the topic "Carbon Nanotube" in different subject domains changed over time, i.e. since 1992 to 2022. The topic "Carbon Nanotube" was initially created in the subject physics in the year 1992. Hence, 'Physics' is the mother or genesis of the topic "Carbon Nanotube". But, after creation it diffused over so many subjects very rapidly, which has been observed from the analysis on "Carbon Nanotube" in Scopus database. Diffusion of knowledge clearly increases aggregate knowledge levels simply through agents acquiring some existing knowledge.

Carbon Nanotube: The Brief Background

Carbon Nanotubes (CNTs) are allotropes of carbon with a cylindrical nanostructure used in fabricating products at nano-scale. Nanotubes have been constructed with length-to-diameter ratio of up to 132,000,000:1, significantly larger than for any other material. These cylindrical carbon molecules have unusual properties, which are valuable for nanotechnology, electronics, optics and other fields of materials science and technology. The material Carbon nanotube thus embraces so many specific subject domains. In particular, owing to their extraordinary thermal conductivity and mechanical and electrical properties, carbon nanotubes find applications as additives to various structural materials (Dutta and Rath, 2013). National Aeronautics and Space Administration (NASA) defined Carbon nanotube as a new form of carbon, configurationally equivalent to two-dimensional graphene sheet rolled into a tube (Kreng and Tsai, 2003). It is grown by several techniques in the laboratory and is few nanometers in diameter and several microns long, which can be metallic or semiconducting and offers amazing possibilities to create future nanoelectronic devices, circuits and computers (Chen and Hicks, 2004).

LITERATURE REVIEW

There are numbers of researches already done on diffusion of knowledge. Kreng and Tsai (2003) demonstrated how the value of knowledge has emerged as a crucial business issue. Their study was based on the diffusion model to build a knowledge diffusion process for a single knowledge because knowledge has characteristics of diffusion, depreciation and growth over time. Chen and Hicks (2004) described the method for studying knowledge diffusion by combining complex network theory, network visualization and patent citation analysis. Singh (2005) looked at whether interpersonal networks could explain two well-known patterns of knowledge diffusion, i.e. 1) the concentration of knowledge flows within firm boundaries and 2) the geographic localization of knowledge flows. Using a novel choice-based sampling regression framework, he used patent citation data to measure knowledge flows and estimate the likelihood of knowledge flow between patent inventors. Gao and Guan (2012) introduced a diffusion network model and examined whether interpersonal networks aid in the explanation of two widespread time-dimensioned individual-citation-based directed network models as a potential method for capturing the spread of research topics. The strategy combines citation analysis, network visualization and social network analysis. From the perspective of a network, the diffusion of knowledge is tracked. They demonstrated the viability of applying the diffusion network model to the spread of research by building complex networks of individual publications and using research on the h-index as a case study. Kim, Feng and Zhu (2021) presented promising approach to understand scientific trends and the intellectual growth of journals. They presented diffusion of knowledge through the model of scattering of journals over different subjects. Yu and Pan (2021) used a citation network technology named main path analysis in their study, which provides a historical perspective of Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS). The citations between related papers are regarded as edges in social network and the corresponding weights are allocated according to their role in knowledge diffusion. Zhu and Yan (2015) used a 15-year citation data set to reveal the characteristics of the subfields of computer science from the aspects of citation characteristics, citation link characteristics, network characteristics and their dynamics. Through a set of indicators including incoming citations, number of citing areas, cited/citing ratios, self-citations ratios, PageRank and betweenness centrality, their study finds that subfields such as Computer Science Applications, Software, Artificial Intelligence and Information Systems possessed higher scientific trading impact.

Amjad and Ali (2019) traced the knowledge diffusion patterns between the publications of top journals of computer science and physics to uncover the knowledge diffusion trends. Chi, Tang and Liu (2022*)* proposed that the awakening effect in knowledge diffusion is ubiquitous, whereas the "prince" paper has the strongest effect. They designed a three-layer super-network model depicting the knowledge diffusion trajectory and the diffusion path of the awakening effect (defined on the basis of influential strength) is simulated. This model is built based on the citation network and collaboration network of 63785 publications in the library and information science domain. Ding, Liu and Yuan (2021) measured the knowledge diffusion from the library and information science to other disciplines over 24 years' time span using indicators in four dimensions: breadth, intensity, speed and theme of knowledge diffusion. An examination of Information Science as a discipline provides data regarding operating theoretical models. Within the great variability, one of the more recent models is that of information transfer. Information transfer includes the following basic components: paradigm identification, creation and production of knowledge, dissemination and diffusion of information and the organization of preservation of knowledge. Of these components, the diffusion of knowledge is particularly troublesome (Newhouse, 1988). Saito (1985) examined the diffusion process of knowledge in the specialty through diachronic citation networks. They discovered the diffusion process of knowledge by diagraming citation linkages, which are networks formed by proceeding from those co-cited papers to those that cite them, then referring to those papers citing the citers and so on. Saracevic, Palmer and Cana (2004) *et al.* discussed on diffusion of knowledge in the field of digital library development. Neelameghan and Seetharama (1972) showed that data dissemination systems at the national, regional and institutional levels should be designed to accelerate the technology diffusion method between countries and enterprises. Neelameghan, Seetharama and Gopinath (1973) discussed the development and diffusion of knowledge, the need for a fast pace and exhaustiveness in information transfer, evolution and the functions of modern documentation systems. The need for planning, the steps in planning and the advantages of planning a library and documentation system were also discussed.

OBJECTIVES

The principal objectives of this paper are as follows:

To find out the growth of literature of the topic Carbon Nanotube as reflected from Scopus database.

To find out how the core journals published the papers on 'Carbon nanotube' were being changed since its inception, i.e. over thirty-one years (1992 to 2022).

To find out how the contextual subjects to the topic 'Carbon nanotube' were being changed since its inception, i.e. over thirty-one years (1992 to 2022).

SCOPE AND METHODOLOGY

The publications on the topic "Carbon Nanotube" as indexed in Scopus database have been retrieved. The query string applied in Scopus was ["Carbon nanotube" OR "Carbon-nanotube"]. From the collected data, the first paper on this topic was observed published in the year 1992. Only six articles were published in 1992. The growth study has been executed with the data retrieved from 1993 to 2022. The core journals and the core relevant subject areas were then found out from the collected data and analysed. The journals have been ranked on the basis of the number of papers published therein. The correlation coefficients between the ranks of the core journals corresponding to different years with respect to the year 2001 are calculated and compared. The consecutive years' correlation coefficients have also been calculated and compared. These comparative studies ensured the shift of core journals with respect to the year 2001. As very little number of papers was published before the year 2000, therefore no correlation analysis between the ranks of the core journals prior to the year 2000 has been carried out. The associated subjects have been ranked on the basis of the number of papers published under the umbrella of the concerned subject domain. The correlation coefficients between the ranks of the core associated subjects corresponding to different years with respect to the year 1993 are calculated and compared, which ensured the shift of core associated subject domains with respect to the year 1993.

Data Analysis

Growth of Literature

First theoretical predictions of the electronic properties of single-walled carbon nanotubes were made by the research groups at Naval Research Laboratory, USA (Mintmire, Dunlap and White, 1992); Massachusetts Institute of Technology (Saito *et al*., 1992) and NEC Corporation (Hamada, Sawada and Oshiyama, 1992) in the year 1992. The Scopus database first indexed six articles on Carbon Nanotube published also in the year 1992. The yearwise variation of the number of research papers on "Carbon Nanotube" is presented in Table 1 and graphically shown in Figure 1. The total number of research publications since the year 1992 upto 2022, i.e. over thirty-one years, figured 183,730, which is the actual figure observed in Scopus database. Also, the total number of estimated research publications over the same period figured 184,836, which has been obtained on the basis of the logistic growth formula represented in equation (1). The overall error for the estimated equation figured 0.6%. Of the total volume of publications, the number of papers published since the year 2014 to 2022 figured more than 50%, i.e. 53.63%. Hence, majority of publications were come out during last ten years only, when the growth curve already attained saturation level. The variation of number of papers with year follows logistic growth pattern that may be represented by the following equation:

$$y = \frac{a}{(1+b*e^{-cx})}, \text{ where a, b and c are constants. .... (1)}$$

The values of the constants are calculated from least-square method as: a=11133.67, b=225.91 and c=0.364. The Coefficient of Determination or R^2=0.9979, which indicates the logistic growth model as the best-fit curve. This growth pattern follows exactly the logistic growth model of De Solla Price. The topic "Carbon Nanotube" was born in the year 1992. The childhood or initial formation phase of "Carbon Nanotube" was spanned upto the year 2002 followed by exponential growth phase upto the year 2013. The growth of literature however attained saturation since the year 2014 till date, though another little growth observed after the year 2020. It indicates, the publication in this domain attained temporary cessation of progression during 2014 to 2019, which was again revamped in 2020. The steady growth is observed since the 2020 to 2022, i.e. over recent three years. The future trend of growth of literature of this topic will be more prominent after getting the complete publications figure of the current year 2023.

Variation of Journals as an Indicator of Diffusion

The science journals represent the most important component for the dissemination of science information. The journals represent

Table 1: Growth of Literature of Carbon Nanotube since 1992 to 2022.

Sl. No.	Year		Actual no. of papers	Estimated no. of papers	% of papers
1	1992		6	70	0.00
2	1993		38	101	0.02
3	1994		84	145	0.05
4	1995		111	207	0.06
5	1996		147	296	0.08
6	1997		210	421	0.11
7	1998		355	596	0.19
8	1999		507	838	0.28
9	2000		829	1168	0.45
10	2001		1413	1606	0.77
11	2002		2166	2174	1.18
12	2003		2801	2882	1.52
13	2004		4045	3724	2.20
14	2005		5076	4672	2.76
15	2006		5948	5678	3.24
16	2007		6689	6676	3.64
17	2008		7707	7605	4.19
18	2009		8238	8419	4.48
19	2010		8770	9096	4.77
20	2011		9865	9634	5.37
21	2012		9772	10047	5.32
22	2013		10416	10355	5.67
23	2014		10323	10581	5.62
24	2015		10348	10744	5.63
25	2016		10545	10860	5.74
26	2017		10634	10942	5.79
27	2018		10709	11000	5.83
28	2019		11339	11040	6.17
29	2020		11210	11069	6.10
30	2021		11371	11088	6.19
31	2022		12058	11102	6.56
Total no. of papers			183,730 (Actual)	184,836 (Estimated)	Overall Error=0.60%

the means for disseminating research findings and are usually specialised for different academic disciplines and sub-disciplines. Different subject-fields have their own specific journals, which are known as core journals. The core journals belonging to the topic "Carbon nanotube" are analysed from the year of inception of the topic, i.e. 1992 to 2022. It is clear from Figure 1, that very feeble number of papers were published on the subject "Carbon nanotube" since 1992 to 2000. This period is thus indicating the formation phase of the topic. The number of journals during this period was very few. Only four journals, viz. *Nature, Physics Letters A, Japanese Journal of Applied Physics* and *Physical Review Letters* published six papers on Carbon Nanotube in the year 1992. In all, 1277 papers were published by 39 journals since 1993 to 2000, i.e. over 8 years. Of these, 1003 (79%) papers were published by only ten journals, viz. *Physical Review B Condensed Matter and Materials Physics, Chemical Physics Letters, Applied Physics Letters, Physical Review Letters, Carbon, Materials Research Society Symposium Proceedings, Applied Physics A Materials Science and Processing, Synthetic Metals, Science* and *Journal of Physical Chemistry B*. These ten journals may thus be reckoned as the core journals of "Carbon Nanotube" during its formation phase. The majority core journals belong to the subject 'Physics' followed by 'Material science', which confirmed that the subject originated from the subject 'Physics'. The changing of ranks of top twenty ranked journals during growth phase over the period of 2001 to 2011 with respect to the year 2001 is presented in Table 2 and the changing of ranks of the top twenty ranked Journals during saturation phase over the period of 2012-2022 with respect to the year 2001 is presented in Table 3.

The list of top twenty ranked journals in the year 2001 has been found at first and then it is observed how these rankings were changed from 2002 to 2022. The ranking of 2001 is compared with the ranking of other years starting from 2002 to 2022 by calculating correlation coefficients between 2001 and the years ranging from 2002 to 2022 each, which is represented by $r_{(2001\text{-}Y)}$. Also, the correlation coefficients between consecutive years are also calculated which is represented by $r_{[Y\text{-}(Y+1)]}$. These two types of correlation coefficients values are presented in Table 4 and Figure 2. The analysis of the variation of correlation coefficients since 2001 to 2022 shows that the $r_{(2001\text{-}Y)}$ values show a steady decline since 2001 to 2022, whereas the $r_{[Y\text{-}(Y+1)]}$ values show a more or less constancy pattern over the said time span. The correlation coefficients between $r_{[Y\text{-}(Y+1)]}$ and $r_{(2001\text{-}Y)}$ has been found as -0.3, which indicates the changing of journals over the years though immediate changing was seldom found. It indicates that the initial core journals did not remain constant but changed with time. But the change did not occur immediately, that's why consecutive correlation coefficients show a nearly constancy pattern. The change of core journals over time indicates that the topic 'Carbon Nanotube' was diffused over journals. This diffusion also indicates that the focal contextual subject of the topic 'Carbon nanotube' also changed over time. It may also be stated that the topic 'Carbon Nanotube' diffused over different subject domains during its growth and saturation phases.

Variation of Subject Domain as an Indicator of Diffusion

The allied subject domains of the topic "Carbon nanotube" are analysed since the year of its inception, i.e. 1992 to 2022. There are so many allied subject areas with which this topic is more or less associated. The rank of any associated subject is determined on the basis of the number of research papers published under that particular subject domain as recorded by Scopus database. Only top 12 major associated subjects are analysed since 1993 to 2022. It is clear from Table 5, that initially the subject *Physics and Astronomy* (PA) was the core subject of 'Carbon Nanotube'. The 'Carbon Nanotube' thus was born in the lap of 'Physics' and gradually diffused to various other subjects in due course of time. The PA is ranked 1 upto 2003, then ranked 2 and 3 and finally

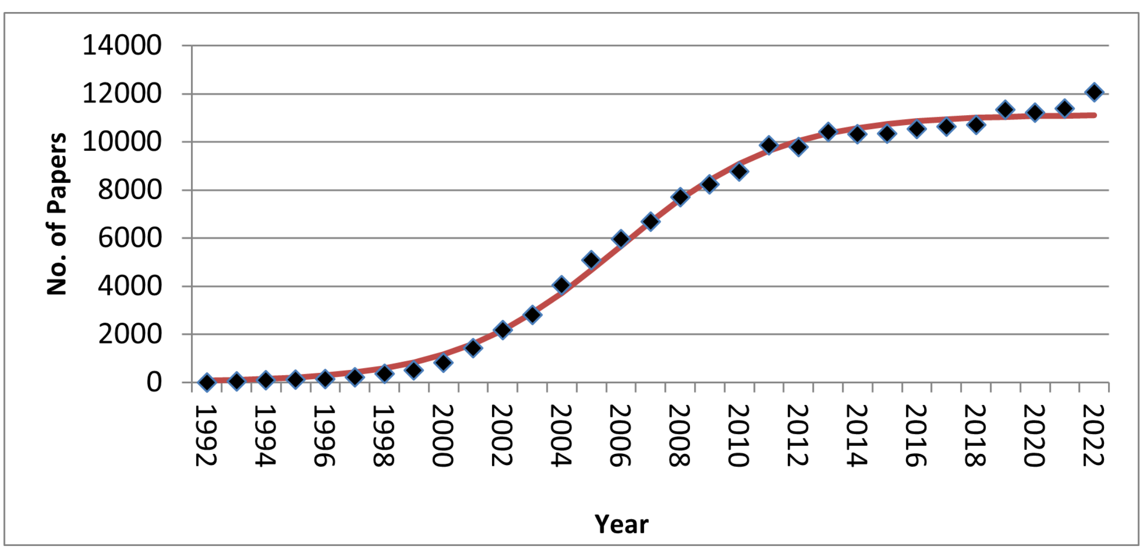

Figure 1: Variation of Actual Number of Papers (y) with Year (x).

Table 2: Changing of Top 20 Ranked Journals during Growth Phase (2001-2011) with respect to 2001.

Sl. No.	List of top twenty ranked journals at per the year 2001	Rankings of the journals from 2002 to 2011 with respect to 2001										
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1	Physical Review B Condensed Matter and Materials Physics.	1	1	1	3	1	3	5	5	6	6	8
2	Applied Physics Letters.	2	2	3	2	2	1	1	3	5	7	10
3	Chemical Physics Letters.	3	5	2	7	11	9	14	26	24	23	34
4	Materials Research Society Symposium Proceedings.	3	3	3	8	9	6	22	10	21	10	13
5	AIP Conference Proceedings.	4	--	33	--	5	35	18	39	15	15	23
6	Physical Review Letters.	5	7	4	5	7	14	16	16	25	32	38
7	Synthetic Metals.	6	28	10	32	20	42	0	6	38	31	47
8	Carbon.	7	6	4	1	3	2	4	8	2	1	1
9	Proceedings of SPIE the International Society for Optical Engineering.	8	9	7	9	6	11	8	8	8	8	10
10	Journal of Physical Chemistry B.	9	10	6	4	4	4	45	38	36	24	55
11	Journal of Vacuum Science and Technology B- Microelectronics and Nanometer Structures.	10	18	8	17	21	17	23	19	46	31	56
12	Journal of the American Chemical Society.	11	14	13	14	10	13	13	4	13	16	26
13	Advanced Materials.	11	11	14	13	17	16	17	13	18	11	20
14	Nano Letters.	12	8	5	6	11	7	7	12	7	13	16
15	Diamond and Related Materials.	13	17	8	10	12	14	12	9	12	24	45
16	Journal of Applied Physics.	14	15	11	11	13	12	10	9	9	10	11
17	SID Conference Record of the International Display Research Conference.	15	30	--	--	--	--	--	47	--	--	--
18	Applied Physics A Materials Science and Processing.	15	15	17	16	27	32	37	--	45	48	53
19	Journal of Chemical Physics.	16	19	17	17	24	20	40	37	32	36	40
20	Journal of the Physical Society of Japan.	17	22	26	31	40	41	--	--	--	--	--
21	Japanese Journal of Applied Physics- Part 2 Letters.	18	24	20	21	28	33	42	--	--	--	--
22	Journal of the Korean Physical Society.	18	--	25	--	35	35	45	34	47	48	--
23	Nature.	18	25	24	28	40	39	--	28	30	30	48

Sl. No.	List of top twenty ranked journals at per the year 2001	Rankings of the journals from 2002 to 2011 with respect to 2001										
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
24	Applied Surface Science.	18	18	18	23	25	31	31	23	19	18	18
25	Chemistry of Materials.	19	19	17	22	18	19	25	32	38	34	49
26	Current Applied Physics.	19	23	--	32	--	29	--	--	37	45	51
27	Japanese Journal of Applied Physics- Part 1.	19	12	12	20	13	15	25	--	--	--	--
28	Thin Solid Films.	19	20	22	19	36	20	48	35	44	27	40
29	Materials Science and Engineering C.	20	28	30	--	--	37	52	54	47	--	--
30	Science.	20	29	17	26	33	33	54	53	47	47	--
31	Chemical Communications.	20	16	16	21	23	31	36	32	31	18	12

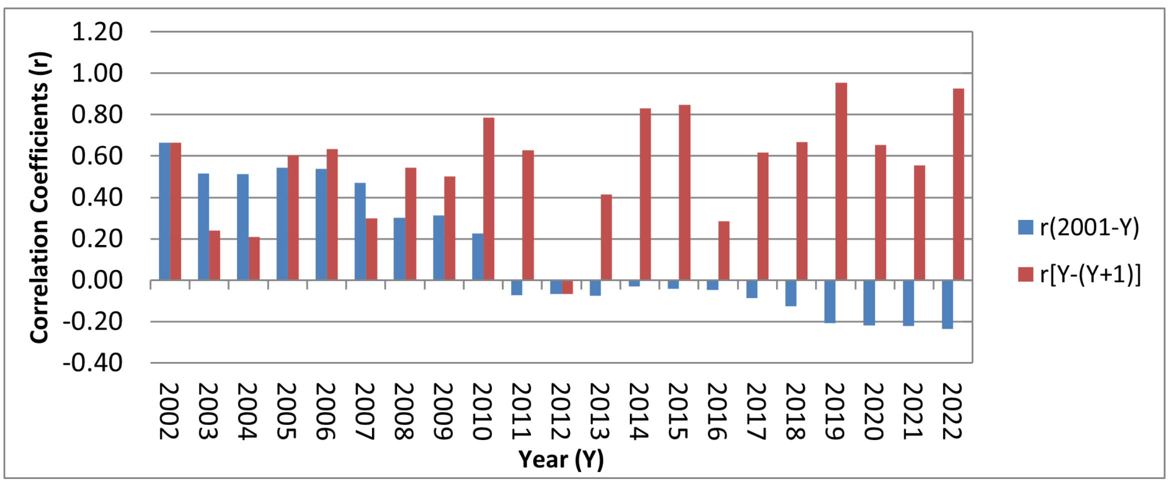

Figure 2: Variation of Correlation Coefficients over 2002 to 2022.

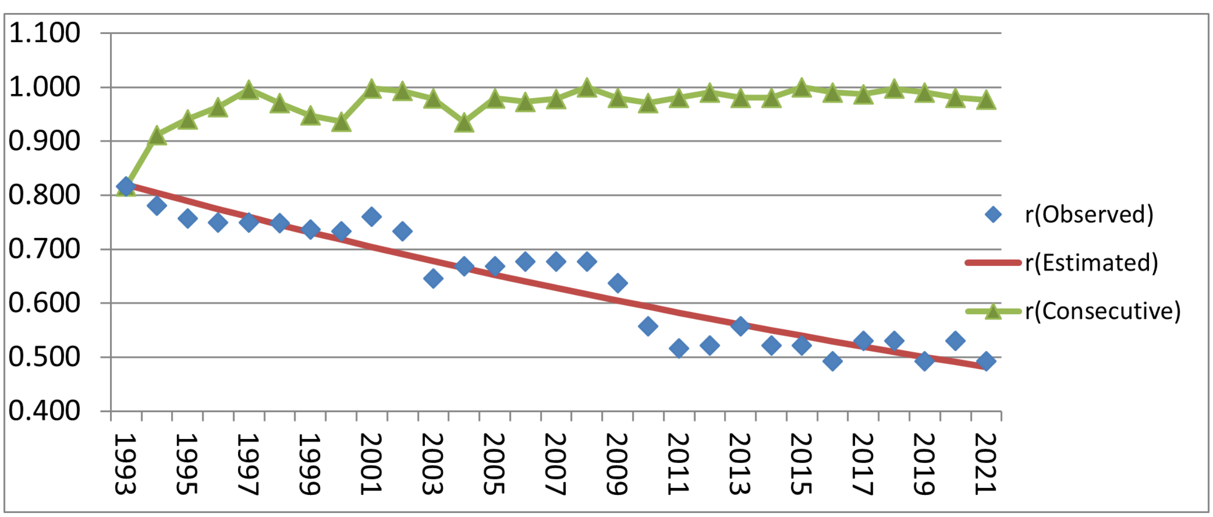

Figure 3: Variation of Correlation Coefficients (Observed, Estimated and Consecutive), 1994-2021.

Table 3: **Changing of Top 20 Ranked Journals during Saturation Phase (2012-2022) with respect to 2001.**

Sl. No.	List of top twenty ranked journals at per the year 2001	Rankings of the journals from 2012 to 2022 with respect to 2001											
		2001	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
1	Physical Review B Condensed Matter and Materials Physics.	1	15	22	27	21	31	30	40	55	59	--	--
2	Applied Physics Letters.	2	6	3	11	19	25	31	42	58	0	60	64
3	Chemical Physics Letters.	3	36	39	44	62	43	53	45	55	58	--	--
4	Materials Research Society Symposium Proceedings.	3	17	17	33	48	48	--	--	--	--	--	--
5	AIP Conference Proceedings.	4	35	30	31	28	9	15	12	15	12	37	35
6	Physical Review Letters.	5	38	50	58	71	0	60	--	--	--	--	--
7	Synthetic Metals.	6	48	54	38	62	44	52	60	55	40	52	64
8	Carbon.	7	1	1	1	2	2	1	1	1	2	3	4
9	Proceedings of SPIE the International Society for Optical Engineering.	8	10	20	16	17	12	13	20	33	31	44	59
10	Journal of Physical Chemistry B.	9	51	47	55	65	--	--	--	--	--	--	--
11	Journal of Vacuum Science and Technology B-Microelectronics and Nanometer Structures.	10	58	--	--	69	--	--	--	--	--	--	--
12	Journal of the American Chemical Society.	11	25	42	42	60	45	47	56	63	--	--	--
13	Advanced Materials	11	23	29	22	29	26	28	28	40	50	53	60
14	Nano Letters.	12	12	21	20	46	20	37	36	35	41	54	55
15	Diamond and Related Materials.	13	42	59	48	62	48	41	45	43	24	26	14
16	Journal of Applied Physics.	14	12	14	15	25	33	33	31	54	48	45	--
17	SID Conference Record of the International Display Research Conference.	15	--	--	--	--	--	--	--	--	--	--	--
18	Applied Physics A Materials Science and Processing.	15	49	48	43	65	43	53	47	62	59	52	56

Sl. No.	List of top twenty ranked journals at per the year 2001	Rankings of the journals from 2012 to 2022 with respect to 2001											
		2001	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
19	Journal of Chemical Physics.	16	51	47	38	65	57	56	0	0	0	0	0
20	Journal of the Physical Society of Japan.	17	--	--	--	--	--	--	--	--	--	--	--
21	Japanese Journal of Applied Physics-Part 2 Letters.	18	--	34	44	64	38	51	46	56	--	--	--
22	Journal of the Korean Physical Society.	18	53	--	--	--	57	--	--	--	--	--	--
23	Nature.	18	49	--	--	--	--	--	--	--	--	--	--
24	Applied Surface Science.	18	18	16	17	11	18	9	2	9	10	10	16
25	Chemistry of Materials.	19	--	--	51	66	52	54	--	--	--	--	--
26	Current Applied Physics.	19	--	49	56	72	--	--	--	--	--	--	--
27	Japanese Journal of Applied Physics-Part 1.	19	--	34	44	64	38	51	46	56	0	0	0
28	Thin Solid Films.	19	42	36	52	69	--	--	--	--	--	--	--
29	Materials Science and Engineering C.	20	54	49	40	59	19	35	55	43	47	--	--
30	Science.	20	--	--	--	--	--	--	--	--	--	--	--
31	Chemical Communications.	20	28	28	26	15	24	41	55	44	42	55	63

was ranked 4 since 2011 to 2022. The subject Material Science (MS) was ranked 1 since 2004 to 2022. Thus, the core contextual subject of 'Carbon Nanotube' is 'Material Science' today. The subject 'Mathematics' is not contextual since 2001. The 'Carbon Nanotube' does not belong to 'Multidisciplinary Studies' since after 2001. The subjects 'Medical Science' and 'Environmental Science' found relevance with 'Carbon Nanotube' since after 2002. The subject 'Chemical engineering' is steadily relevant to Carbon Nanotube. The Biochemistry and Genetics, Engineering, Computer Science and Chemistry are almost steadily relevant to Carbon Nanotube. Therefore, these subject domains may be reckoned as the core contextual subject to 'Carbon Nanotube'. The continuous changing of the ranks of the associated subjects over the years indicates that the contextual relevance of "Carbon Nanotube" changes over time, or it may otherwise be stated that "Carbon Nanotube" continuously diffused over different broad subject domains during said thirty years' time span.

The Correlation Coefficient values given here are calculated with respect to the year 1993, which are represented as "Observed Correlation Coefficients". These values show a steady decline since 1993 to 2022, as represented in Figure 3 and Table 7. This decline pattern may be represented by negative exponential equation represented as: $y = a^{*} e^{-bx}$, where 'a' and 'b' are constants, their values are calculated by method of least-squares and found as: a=0.8354 and b=0.019 with R^2=0.952. The correlation coefficients calculated on the basis of the above negative exponential equation are represented as "Estimated Correlation Coefficients". The Correlation coefficients between the observed and estimated correlation values figures 0.9516 indicating strong positive correlation, or best-fit observed values with the expected values. Besides, the correlation coefficients between consecutive years are also calculated starting from 1993 and '94, 1994 and '95… and so on. These three types of correlation coefficients' values are presented in Table 7 and Figure 2. It is found, that the consecutive correlation values remained almost constant, but vary only between 0.9 and 1.0. While the observed correlation values show greater changes with variations ranging from 0.5 to 0.8. This phenomenon indicates though the topic "Carbon Nanotube" diffused over time, but the diffusion process is slow and gradual. No abrupt diffusion took place.

Table 4: Comparative study between two types of Correlation Coefficients.

Year	$r_{(2001-Y)}$	$r_{[Y-(Y+1)]}$
2002	0.66	0.66
2003	0.51	0.24
2004	0.51	0.21
2005	0.54	0.60
2006	0.54	0.63
2007	0.47	0.30
2008	0.30	0.54
2009	0.31	0.50
2010	0.22	0.79
2011	-0.07	0.63
2012	-0.07	-0.07
2013	-0.07	0.41
2014	-0.03	0.83
2015	-0.04	0.85
2016	-0.05	0.29
2017	-0.09	0.62
2018	-0.12	0.67
2019	-0.21	0.95
2020	-0.22	0.65
2021	-0.22	0.56
2022	-0.24	0.93

CONCLUSION

The diffusion of knowledge refers to the interchange and propagation of knowledge through different media, or the transfer of knowledge from one subject to another. The concept of diffusion or dissemination of knowledge eventually gave rise to the concept of the diffusion of any specific topic over the universe of subject. In this paper, the growth of literature and the diffusion of the multidisciplinary topic "Carbon Nanotube" have been discussed. The analysis of growth of literature shows the logistic growth pattern of 'Carbon Nanotube' over the last thirty years, which accords De Solla Price' theory. Apparently, it seems this subject domain has attained saturation, but slight hike of the number of papers in 2022 compared to its previous year signals this subject may continue growing even after the year 2023. The actual picture will be clear at the end of 2023.

This topic was born in the subject 'Physics' and then gradually became relevant or contextual with other subjects in due course of time like material science, chemistry, chemical engineering, environmental science, engineering etc. The core journals published the papers on 'Carbon Nanotube' had also been changed over the stipulated time span of thirty years. The diffusion phenomenon has been proved here by the analysis of correlation coefficients between the ranks of the core journals

Table 5: Change of Ranking of top 12 allied subject domains of Carbon Nanotube since 1993 to 2022.

Allied Subjects (Abbr.)	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
BG	--	6	6	7	9	10	8	9	8	8	8	8	6	6	6
CE	5	6	7	5	5	5	5	5	5	5	5	5	5	5	5
CH	3	4	3	3	3	3	3	3	4	4	4	4	4	4	4
CS	5	7	--	8	8	8	9	7	6	6	6	6	7	7	7
EN	5	--	8	8	9	9	9	8	10	9	10	9	9	9	8
EG	2	3	4	4	4	4	4	4	3	3	3	3	3	3	3
ES	--	--	--	--	--	--	--	--	--	12	11	11	12	10	12
MS	4	2	2	2	2	2	2	2	2	2	2	1	1	1	1
MT	--	6	9	8	7	7	7	6	--	--	--	--	--	--	--
MD	4	5	5	6	6	6	6	7	--	--	--	--	--	--	--
MC	--	--	--	--	--	--	--	--	13	12	12	14	10	11	10
PA	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
Correlation Coeff. Values (Observed)		0.816	0.780	0.757	0.750	0.750	0.748	0.736	0.733	0.760	0.733	0.645	0.668	0.668	0.677

Allied Subjects (Abbr.)	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
BG	6	6	6	6	6	6	6	6	6	7	7	7	7	8	8
CE	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
CH	4	4	4	3	2	2	3	2	2	2	3	3	2	3	2
CS	7	7	8	7	8	9	8	9	9	9	9	9	9	9	9
EN	8	8	7	8	7	7	7	7	7	6	6	6	6	6	6
EG	3	3	2	2	3	3	2	3	3	3	2	2	3	2	3
ES	10	10	10	9	9	8	9	8	8	8	8	8	8	7	7
MS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MT	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MD	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
MC	11	11	11	12	12	12	12	12	12	12	11	12	12	12	10
PA	2	2	3	4	4	4	4	4	4	4	4	4	4	4	4
Correlation Coeff. Values (Observed)	0.677	0.677	0.637	0.557	0.517	0.522	0.557	0.522	0.522	0.492	0.530	0.530	0.492	0.530	0.492

(The abbreviations used for allied subjects are presented in Table 6).

Table 6: Abbreviations of the allied subjects.

Sl. No.	Subject Name	Abbreviation Used
1	Biochemistry, Genetics and Molecular Biology	BG
2	Chemical Engineering	CE
3	Chemistry	CH
4	Computer Science	CS
5	Energy	EN
6	Engineering	EG
7	Environmental Science	ES
8	Materials Science	MS
9	Mathematics	MT
10	Multidisciplinary	MD
11	Medicine	MC
12	Physics and Astronomy	PA

Table 7: Comparative study between observed, estimated and consecutive correlation coefficients.

Sl. No.	Year	$r_{(Observed)}$	$r_{(Estimated)}$	$r_{(Consecutive)}$
1	1994	0.816	0.820	0.816
2	1995	0.780	0.804	0.912
3	1996	0.757	0.789	0.941
4	1997	0.750	0.774	0.963
5	1998	0.750	0.760	0.996
6	1999	0.748	0.745	0.970
7	2000	0.736	0.731	0.948
8	2001	0.733	0.718	0.936
9	2002	0.760	0.704	0.998
10	2003	0.733	0.691	0.993
11	2004	0.645	0.678	0.979
12	2005	0.668	0.665	0.935
13	2006	0.668	0.653	0.979
14	2007	0.677	0.640	0.973
15	2008	0.677	0.628	0.978
16	2009	0.677	0.616	1.000
17	2010	0.637	0.605	0.980
18	2011	0.557	0.593	0.971
19	2012	0.517	0.582	0.981
20	2013	0.522	0.571	0.990
21	2014	0.557	0.561	0.981
22	2015	0.522	0.550	0.981
23	2016	0.522	0.540	1.000
24	2017	0.492	0.529	0.990
25	2018	0.530	0.520	0.987
26	2019	0.530	0.510	0.997
27	2020	0.492	0.500	0.990
28	2021	0.530	0.491	0.981
29	2022	0.492	0.482	0.977

and the ranks of the associated subjects. The proof of diffusion phenomenon of a topic over several broad subjects by correlation analysis is a new technique introduced here. This technique can be applied for studying diffusion of other multidisciplinary topics over various broad subjects.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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