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# Bibliometric Analysis of Scientific Collaboration in Quantum Dots Literature

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***Abstract* - The field of quantum dots has grown significantly in recent years. A quantitative and comprehensive analysis of this research domain is essential for understanding current trends and future directions. Given the progress made so far, this work aims to facilitate scientific collaboration in the field of quantum dots through a systematic review of 4,176 scientific articles published in the Web of Science database between 2014 and 2023. The study utilized various bibliometric methods, including year-wise publications, annual growth, relative growth rate, doubling time, citation analysis, authorship pattern, collaborative index, identifying co-authorship and collaboration country, top most bibliographic coupling document, and most cited reference. The study period from 2014-2023 has evinced a mean relative growth rate of 0.84 and a doubling time of 3.89. Secured the topmost publication, 519 (2018), simultaneously with a relative growth rate of 12.43.18%. As predicted by the highest citation rate of 25094, an average citation per paper of 51.74% was produced in 2014. The trend of multi-authored papers has significantly increased to 4187 (97.87%), compared to just 89 (2.31%) single-authored papers. Notably, the degree of collaboration was recorded at 0.12% from 2014 to 2018. Additionally, the highest collaboration coefficient, 17.37, was observed in 2023. China had the highest number of publications during this study period. The USA secured the first position in co-authorships and country collaboration at the international level. In addition, the top bibliographic coupling documents are Lim, 2015 and the most cited reference Murray CB, 1993, Journal of the American Chemical Society, VII5, P8706 2023.**

***Keywords:* Quantum Dots, Bibliometric Indicators, Authorship Pattern, Collaborative Index, Co-authorship, Cited Reference, Bibliographic Coupling, and VOSviewer**

## I. Introduction

Quantum dots (QDs), essentially tiny semiconductor particles, stand at the forefront of nanotechnology with their unparalleled optical and electronic properties derived from quantum mechanical behaviour (Reed, 1993; Bosco et al., 2023). These Nanoscale particles, constructible from various materials like cadmium selenide (CdSe) and indium phosphide (InP), exhibit unique abilities such as light absorption and re-emission in different colours, pivotal for myriad applications from biomedical imaging to energy solutions (Kumar et al., 2018; Bryant, 1996). Their size-related tunable optical characteristics underscore the vast potential in quantum computing and other key industrial sectors, highlighting the significance of ongoing research and development in quantum dot technology (Sood & Chauhan, 2023).

In addition, Quantum dots is also known as semiconductor nanocrystals, nanoparticles, clusters, colloidal nanostructures, and zero-dimension objects. These are nanosized crystals made up of tens to thousands of atoms (Craddock et al., 2019). Quantization of electrons occurs in all three directions with diameters ranging from 2 to 10 nanometers (10-50 atoms) (Maxwell et al., 2019), mentioned most visible result is fluorescence, which occurs when nanocrystals produce different shades based on particle size and quantum dots are used to improve solar cells, lasers, memory, LEDs, photovoltaics, photodetectors, photocatalysts, synthesis, antibody probes, biosensors, pH sensors, metalion sensors, DNA sensor, and drug delivery systems for cancer therapy, quantum computers, and many other applications (Podvalny et al., 2021).

Several studies, quantum dots in India (Gupta et al., 2021) quantum sensing research (Gupta et al., 2022); toxicity of QDS (Zhong et al., 2021); quantum Cryptography (Gupta et al., 2021); Quantum Communication & Networking Gupta et al; quantum optics research (Gupta et al., 2022); quantum machine learning to other domains (Gupta et al., 2021b), quantum computing Wang, Shen, and Zhou (2021), and quantum technology (Scheidsteger et al., 2021) analyzed the research publications of quantum dots different perspective. But no attempt was made to study the quantum dots scientific collaboration. Hence, a bibliometric analysis of scientific collaboration is applied to the quantum dots literature (Tohma & Kutlu, 2020).

## II. Literature Review

"Bibliometric" is described as "the use of mathematical and statistical methods applied to books and other forms of communication (van Eck & Waltman, 2010). According to

(Broadus, 1987) bibliometrics is “the quantitative study of physical published materials, bibliographic units, or surrogates for either.” In addition, bibliometrics involves organizing and linking fundamental information from publications, including citations, authors, co-authors, journals, and keywords, to analyze and track research development (Ferreira, 2018; Koseoglu et al., 2016; Utomo & Latukismo, 2022), and bibliometric analysis employs various methodologies, including bibliographic coupling, co-citation network analysis, and co-occurrence analysis (Sahu, 2021). Specifically, bibliometrics is among the most precise interdisciplinary research fields, extending across all scientific disciplines (Glänzel & Thijs, 2012). and the bibliometric examination has been utilized in different exploration fields of development (Subandi et al., 2023; Hakkaraki, 2023).

Another measure used is the co-authorship pattern, which examines the types of co-authored works, the degree of collaboration, and local and international collaborative activities among authors within and across faculties, universities, institutions, and countries (Zainab et al., 2009) similarly found that from 1985 to 1989, the level of collaboration ranged from 0.25 to 0.95 and was inconsistent. Similar to most scientific fields, joint authorship in computer science publications in MJCS has risen since 1995. Thirunavukkarasu et al., (2024) study found that the majority of contributors to collaborative papers 91.3%, and only 8.7% by a single author. The researcher identified the most collaborative years 2014, 2016, and 2017, and Lamont BB, the most productive author, with 50 articles. Secured the first position citation 3495 for publication 37 in Shewry PR, affiliated with Rothamsted Research in Harpenden, England.

Ramalingam & Elangovan, (2018) The study utilized the PubMed bibliographic database to explore bibliometrics, examining 35,912 citations to analyze co-authorship patterns and collaborative practices among scientists. The research identified seven authors who collaborated on papers within the chosen subject area. The study found that collaborators encompassed individuals offering technical and instrumental support, and specialists in chromosome anomaly analysis. (Hussain & Chetia, 2022) conducted a scientometric analysis of Nephrology research using the Web of Science database spanning from 2012 to 2021. The study found that the utmost produced in the year 2020 was 1166 (15.4%) publications, 90.16% of Nephrology research publications were multi-authored papers, and 9.84% of publication single author papers, as well as the degrees of collaboration (0.94%), are significantly the year 2021 same year collaborative index (6.47%), and collaborative co-efficient (0.75%) increased

In addition, the study explored co-authorship patterns between countries and international collaborations. Tolcheev, (2018) conducted a scientometric analysis of the current state and prospects of quantum technologies, using the Web of Science database from 2000 to 2016. The study revealed that the most rapidly advancing research areas are in quantum technologies, with the leading countries being the United States and China. Special attention was given to the publication activities of Russian scientists in Web of Science-indexed journals. The United States secured the first position in Co-authorship country. Especially at the same time, the highest growth rates of publication activity are observed in Asian countries, China, India, and the Republic of Korea.

Furthermore, another frequent measure used is citation count: (Gupta et al., 2021) analysed the Quantum Cryptography Research 1992-2019. The study revealed that the top most productive countries, organizations, authors, highest cited papers, and keywords in the context of collaborative research. They found that 24.76% annual average growth accrued an average of 23.01 citations per paper (CPP), and scholarly journals accounted for 59.61% of global publications world share, as well as nearly 29% of the quantum cryptography research publication from projects funded papers and China leads the global rankings with a 27.65% world share, followed by the USA second position (17.92%).

Finally, (Kumar et al., 2023) highlighted collaborations, co-authorships, citations, and published papers from the top 10 nations engaged in aerosol research. The United States leads in all four categories with 8,486 papers, 323,157 citations, 94 international collaborations, and 7,714 co-authorships. China ranks second with 6,087 published articles, 130,378 citations, and 6,087 co-authorships. Hence, the articles that mention similar sources are likely to have conceptual overlap, and the more references the two articles share, the stronger their relationship in a bibliographic network. (Thanuskodi, 2010; Montecchi et al., 2021; Nishavathi & Jeyshankar, Oh. 2022). Numerous studies employ authorship patterns, collaboration index, bibliographic coupling documents, and co-citation cited references as scientometric indicators to assess research production across different domains. This study addresses a gap in the literature by analyzing research output on quantum dots.

## III. Objectives of the Study

The present study aims to identify scientific collaboration of quantum dots literature from 2014-2023:

- To explore the relative growth rate and doubling time of the literature on quantum dots.
- To identify the year-wise distribution of citation analysis.
- To observe the authorship patterns in the literature on quantum dots.
- To determine collaborative metrics such as the Collaborative Index, Degree of Collaboration, Collaborative Coefficient, and Moderate Coefficient in the field of quantum dots.
- To identify co-authorship countries and international collaborations.
- To explore bibliographical coupling documents in the literature on quantum dots.
- To identify and rank the most cited references in quantum dots literature.

## IV. METHODOLOGY

This study aims to analyze the current utilization of the term "quantum dots research" from a bibliometric analysis and outline global research trends on this topic. Data retrieved from the Web of Science database spanning 2014 to 2023, employing the central theme of "quantum dots". The query string used for this investigation is as follows: Step: 1# identified TOPIC-ABSKEY (“quantum dots*) = records 159318 identified (ALL DOCTYPE) OR (semiconductor) 374677, OR (nanoparticles) 933744, OR (nanomaterials) 107072, OR (nanocrystals) 139863, OR (nanocluster) 8286. However, in Step: 2# additional filtering was needed to maintain the query string AND semiconductor, AND nanoparticles AND nanomaterials Step 3: 1# AND 2# OR. Finally, the screening process resulted in 4176 records retrieved. Hence, the methodology involved a three-stage process of identifying, screening, and examining related publications on quantum dots research based on publications indexed in the Web of Science database and using the PRISMA methods (Moher et al., 2009), and bibliometric mapping research approach by (Svobodová & Bednarska-Olejniczak, 2020) were adopted in this review-based article. In addition, Microsoft Excel, and Bibexcel are used to process the bibliographical analysis, and VOSviewer software measures to bibliographic coupling document and most cited reference.

## V. RESULTS AND DISCUSSIONS

TABLE I RELATIVE GROWTH RATE (RGR) AND DOUBLING TIME (DT) OF RESEARCH ON QUANTUM DOTS.

| Year | Output | Cumulative Output | AGR | Log 1 | Log 2 | RGR | Mean RGR (5 year) | Dt | Mean Dt (5 years) |
|---|---|---|---|---|---|---|---|---|---|
| 2014 | 485 | 485 | 0.00 | 0 | 6.18 | 6.18 | 0.618 | 0.11 | 0.01 |
| 2015 | 497 | 982 | 11.61 | 6.18 | 6.89 | 0.71 | | 0.98 | |
| 2016 | 502 | 1484 | 12.02 | 6.89 | 7.3 | 0.41 | | 1.69 | |
| 2017 | 495 | 1979 | 11.85 | 7.3 | 7.59 | 0.29 | | 2.39 | |
| 2018 | 519 | 2498 | 12.43 | 7.59 | 7.82 | 0.23 | | 3.01 | |
| 2019 | 405 | 2903 | 9.70 | 7.82 | 7.97 | 0.13 | 0.013 | 5.33 | 0.53 |
| 2020 | 393 | 3296 | 9.41 | 7.97 | 8.1 | 0.15 | | 4.62 | |
| 2021 | 310 | 3606 | 7.42 | 8.1 | 8.19 | 0.13 | | 5.33 | |
| 2022 | 321 | 3927 | 7.69 | 8.19 | 8.28 | 0.09 | | 7.70 | |
| 2023 | 249 | 4176 | 5.96 | 8.28 | 8.33 | 0.09 | | 7.70 | |
| **Total** | **4176** | **AAGR** | **8.81** | | **Mean RGR** | **0.84** | **Average Dt** | **3.89** | |

**AAGR:** Average Annual Growth Rate, **RGR**: Relative Growth Rate

Table I depicts the productivity of quantum dots research RGR measures the rate of growth of output from year to year. It's calculated as the natural logarithm of the output of the current year divided by the output of the previous year. The RGR values in the table range from 0.09 to 0.71, indicating fluctuations in the growth rate over the years, and the mean RGR over 5 years is 0.84, suggesting an overall moderate growth rate in quantum dots research during this period. Hence, the initial RGR (0.618) suggests a slow but positive growth rate in 2014, and the RGR peaks in 2015 (0.71) and gradually declines over the subsequent years, indicating a slowing down of the growth rate. It is observed that the Dt values in the table range from 0.01 to 7.70, and the mean Dt over 5 years is 3.89. Overall, the data suggests a steady but moderate growth in quantum dots research output over the last 5 years, with fluctuations in growth rate from year to year.

TABLE II YEAR-WISE DISTRIBUTION OF CITATION ANALYSIS QUANTUM DOTS LITERATURE

| Year | Publications | Total Citations | Citation Cumulative Output | Citation AGR | Citation ACPP |
|---|---|---|---|---|---|
| 2014 | 485 | 25094 | 25094 | 18.89 | 51.74 |
| 2015 | 497 | 22624 | 47718 | 17.03 | 45.52 |
| 2016 | 502 | 20758 | 68476 | 15.62 | 41.35 |
| 2017 | 495 | 17860 | 86336 | 13.44 | 36.08 |
| 2018 | 519 | 16954 | 103290 | 12.76 | 32.67 |
| 2019 | 405 | 13120 | 116410 | 9.88 | 32.40 |
| 2020 | 393 | 8603 | 125013 | 6.48 | 21.89 |
| 2021 | 310 | 4680 | 129693 | 3.52 | 15.10 |
| 2022 | 321 | 2689 | 132382 | 2.02 | 8.38 |
| 2023 | 249 | 473 | 132855 | 0.36 | 1.90 |
| Total | 4176 | 132855 | AAGR | 10.00 | |

Table II shows the annual count of publications along with the total citations and cumulative citations over the years. It is observed ranges from 0.36% to 18.89% across the years, indicating fluctuations in the growth rate, and the AAGR over the period is 10.00%, suggesting a steady increase in citations on average. Citation ACPP represents the percentile position of the cumulative citations for each year relative to the total citations. However, it ranges from 1.90% to 51.74% across the years, indicating the distribution of citations over the years, while the utmost citation is ACPP 2014 (51.74%). Overall, the data suggests a growing interest in quantum dots research as evidenced by increasing citations and a steady AAGR, while the distribution of citations becomes more evenly spread across the years as the field natures.

TABLE III DISTRIBUTION OF YEAR-WISE AUTHORSHIP PATTERN QUANTUM DOTS LITERATURE

| Year | Single Author | Two Author | Three Author | Four Author | Five Author | above 5 authors | Total publications |
|---|---|---|---|---|---|---|---|
| 2014 | 10 | 62 | 83 | 65 | 71 | 194 | 485 |
| 2015 | 9 | 45 | 77 | 80 | 76 | 210 | 497 |
| 2016 | 10 | 40 | 71 | 89 | 92 | 200 | 502 |
| 2017 | 10 | 58 | 65 | 73 | 53 | 236 | 495 |
| 2018 | 10 | 48 | 63 | 68 | 74 | 256 | 519 |
| 2019 | 11 | 32 | 47 | 63 | 65 | 187 | 405 |
| 2020 | 7 | 38 | 54 | 44 | 62 | 188 | 393 |
| 2021 | 8 | 31 | 43 | 48 | 39 | 141 | 310 |
| 2022 | 6 | 17 | 47 | 47 | 39 | 165 | 321 |
| 2023 | 8 | 17 | 41 | 29 | 32 | 122 | 246 |
| Total author-wise pub. | 89 | 388 | 591 | 606 | 603 | 1899 | 4176 |
| % of Pub | 2.13 | 9.29 | 14.15 | 14.51 | 14.44 | 45.47 | 100.00 |

Table III presents the distribution of authorship patterns in quantum dots publications over the years from 2014 to 2023. The study consists of 4087 authors for 4176 publications. The majority of publications have multiple authors, with 4 authors 606 (14.52%), followed by papers with 5 authors 603 (14.44%), 3 authors 591 (14.15%), and single authors 89 (2.13%). It is observed out of a total of 4176 papers 4187 (97.87%) papers multi-authored publications, and the papers with a single author were only 89 (2.13%). It indicates that there is a consistent trend of multi-authorship over the years, indicating collaboration in the quantum dots literature; it indicates that collaboration and information sharing among researchers have steadily increased throughout the study period. (Thanuskodi, 2010; Sumathi, 2020).

TABLE IV COLLABORATIVE INDEX FOR RESEARCH OUTPUT IN QUANTUM DOTS DURING 2014 -2023

| Year | Multi-author papers (NM) | Single author papers (NS) | NM+MS | Degree of Collaboration | Collaborative Index | Collaborative Co-efficient | Moderate Co-efficient |
|---|---|---|---|---|---|---|---|
| 2014 | 475 | 10 | 485 | 0.12 | 8.81 | 0.12 | 0.11 |
| 2015 | 488 | 9 | 498 | 0.12 | 8.58 | 0.12 | 0.12 |
| 2016 | 492 | 10 | 502 | 0.12 | 8.51 | 0.12 | 0.12 |
| 2017 | 485 | 10 | 495 | 0.12 | 8.63 | 0.12 | 0.12 |
| 2018 | 509 | 10 | 519 | 0.12 | 8.23 | 0.12 | 0.12 |
| 2019 | 394 | 11 | 404 | 0.10 | 10.63 | 0.10 | 0.09 |
| 2020 | 386 | 7 | 396 | 0.09 | 10.85 | 0.09 | 0.09 |
| 2021 | 302 | 8 | 312 | 0.07 | 13.86 | 0.07 | 0.07 |
| 2022 | 315 | 6 | 325 | 0.08 | 13.29 | 0.08 | 0.08 |
| 2023 | 241 | 8 | 251 | 0.06 | 17.37 | 0.06 | 0.06 |
| Total | 4087 | 89 | 4187 | 0.06 | 8.23 | 0.06 | 0.06 |

Table IV indicates the variations in publication productivity, represented by the average number of authors per paper. The Collaborative Index (CI) for quantum dots research output from 2014 to 2023 is 8.23. Collaboration in 2022 is highest (13.29) than in 2023 (17.37). However, DC has decreased from 0.06 to 0.08 throughout the same year. It explicitly states that the proportionate rise in multi-authored publications from 2014 to 2023 (4087) is greater than the effect of utmost levels of multi-authorship in the year (2018). The prevalence of multi-author papers has risen over time, indicating a trend towards collaborative research. Additionally, both the Collaboration Coefficient (CC) and the Modified Collaboration Coefficient (MCC) have been decreasing over time, indicating a decrease in the average number of collaborators per author, which could be due to a higher number of single-authored papers or less collaboration per paper.

TABLE V: TOP 10 COUNTRIES BY NUMBER OF CO-AUTHORSHIPS AND COLLABORATIONS

| Relative Influence | Country | Total No. Documents | Total No. Citations | Country | Co-authorship | Country | Country Collaboration |
|---|---|---|---|---|---|---|---|
| 1 | China | 1329 | 51812 | USA | 443 | USA | 435 |
| 2 | USA | 714 | 31519 | China | 432 | China | 170 |
| 3 | India | 556 | 13395 | Germany | 274 | UK | 159 |
| 4 | Germany | 270 | 7919 | France | 194 | Spain | 110 |
| 5 | Russia | 222 | 3507 | India | 193 | Russia | 109 |
| 6 | South Korea | 215 | 7604 | Spain | 154 | South Korea | 89 |
| 7 | Japan | 170 | 4627 | Russia | 148 | Saudi Arabia | 81 |
| 8 | France | 157 | 6418 | South Korea | 136 | Germany | 61 |
| 9 | Canada | 148 | 6602 | Canada | 125 | Sweden | 59 |
| 10 | Spain | 123 | 7753 | Japan | 81 | Italy | 57 |

The minimum number of documents and citations for a country is set at 5, and of the 95 countries, 58 meet the threshold. The total number of bibliographic coupling links with other countries will be computed for each of the 58 countries. Table V represent the China Leads in both the total number of documents published (1329) and total citations (51812). It has a significant collaboration with the USA in terms of co-authorships (435), followed by India, Germany, and Russia. The USA secured the second position in documents (714), and citations (31519). It collaborates closely with China in terms of co-authorships (432), and the USA plays a significant role in quantum dots literature country collaboration (435), while China is ranked second with 432 co-authorships and 170 collaboratively published documents, followed by Germany with 174 co-authorship documents, and UK 159 country collaboration publications. In particular, India collaborates with 42 countries, with a total link strength of 25427.26, while having fewer documents and citations compared to China and the USA, India still maintains a significant presence in scientific publications, and it collaborates most closely with Germany in terms of co-authorships, with 193 co-authorship countries. The data on co-authorship collaboration suggests that quantum dots research is often conducted collaboratively across borders. The high numbers of co-authorships between countries like the USA and China indicate strong international collaboration in quantum dots research, which is beneficial for the advancement of science and technology innovation.

TABLE VI TOP MOST BIBLIOGRAPHIC COUPLING DOCUMENT

| Relative Influence | Document | Citations | Total Link Strength |
|---|---|---|---|
| 1 | Lim (2015) | 3372 | 777 |
| 2 | Koppens (2014) | 2768 | 702 |
| 3 | Ding (2016) | 1713 | 550 |
| 4 | Kovalenko (2015) | 924 | 490 |
| 5 | Bai (2015) | 873 | 382 |
| 6 | Howes (2014) | 779 | 346 |
| 7 | Liu (2016b) | 669 | 309 |
| 8 | Ma (2017a) | 578 | 290 |
| 9 | Zhang (2018b) | 574 | 290 |
| 10 | Fernando (2015) | 541 | 286 |

Table VI It is observed that bibliographic coupling among authors who cite the same documents, based on citation weight. The minimum number selected is 5 citations for documents. Of the 4174 documents, 3245 meet the threshold, item 1000, clusters 6, links 218070, and total link strength 467692. It is found that Lim (2015) secured the highest linked document entitled: Carbon Quantum Dots and their Applications published in Chemical Society Reviews, Volume 44, Issue 1, Pages 362–381, in the year 2015. The second most linked document is Koppens (2014) citations with and total link strength of 702, as well as this document, follows Lim's (2015) and is closely comparable in terms of influence, with the highest number of citations and significant total link strength.

TABLE VII TOP 10 MOST LINKED AND CITED REFERENCES

| S No | Cited reference | Citations | Total Link Strength |
|---|---|---|---|
| 1 | MURRAY CB, 1993, J AM CHEM SOC, V115, P8706, DOI 10.1021/JA00072A025 | 366 | 364 |
| 2 | BRUCHEZ M, 1998, SCIENCE, V281, P2013, DOI 10.1126/SCIENCE.281.5385.2013 | 340 | 340 |
| 3 | YU WW, 2003, CHEM MATER, V15, P2854, DOI 10.1021/CM034081K | 304 | 297 |
| 4 | MEDINTZ IL, 2005, NAT MATER, V4, P435, DOI 10.1038/NMAT1390 | 296 | 292 |
| 5 | ALIVISATOS AP, 1996, SCIENCE, V271, P933, DOI 10.1126/SCIENCE.271.5251.933 | 289 | 286 |
| 6 | MICHALET X, 2005, SCIENCE, V307, P538, DOI 10.1126/SCIENCE.1104274 | 251 | 246 |
| 7 | CHAN WCW, 1998, SCIENCE, V281, P2016, DOI 10.1126/SCIENCE.281.5385.2016 | 226 | 226 |
| 8 | RESCH-GENGER U, 2008, NAT METHODS, V5, P763, DOI [10.1038/NMETH.1248 10.1038/NMETH.1248] | 190 | 185 |
| 9 | TALAPIN DV, 2010, CHEM REV, V110, P389, DOI 10.1021/CR900137K | 190 | 190 |
| 10 | DABBOUSI BO, 1997, J PHYS CHEM B, V101, P9463, DOI 10.1021/JP971091Y | 180 | 178 |

Table VII illustrates the density map of the cited reference in the quantum dots literature. The relationships between the cited references were examined using co-citation analysis. The minimum number of citations for cited references is fixed at 20, and the minimum citation threshold for referenced citations is set at 20. A total of 156,096 citation references were generated, with 822 meeting the threshold, resulting in 7 clusters, 119670 links, and 15934.22 total link strengths. Table 6 clearly shows Murray CB, 1993, The Journal of the American Chemical Society (JACS) Volume 75, Page 8706, recorded the highest link strength (364) and citations (366). Following this, Bruchez M., 1998, Science, Volume 281, Page 2013, had 340 citations and a total link strength of 340, and Yu Ww, 2003, Chemistry of Materials, V15, P2854, citations 304, 297 total link strength. In particular, most co-citations cited reference sources in science journals. conducted with other studiesby (Sahu, 2021; Li et al., 2014).

## VI. Discussion and Conclusion

The article mainly aims at the effect of scientific collaboration in quantum dots literature from a bibliometrics perspective. To achieve the same, year-wise growth in publications, citations, authorship pattern, collaborative various indicates, co-authorship country, collaboration country, bibliographic coupling documents, and cited reference analysis were conducted using VOSviewer and the

Bibexcel, MS Excel, as well as these methods were applied to 4174 documents retrieved from the Web of Science database using Boolean search techniques. It was observed that various indexes and measurements of collaboration define the relationships and connections among authors, aiding in identifying the most productive authors and their social networks.

The present study found that the RGR (0.618) suggests a slow but positive growth rate in 2014, and the RGR peaks in 2015 (0.71) and gradually declines over the subsequent years, indicating a slowing down of the growth rate. It is observed that the doubling time (Dt) ranges from 0.01 to 7.70, and the mean value of Dt over 5 years is 3.89%. Aravind, (2024) conducted a study on RGR, which fell from 0.08 to 0.12 between 2000 and 2022. The growth rate progressively decreased. The doubling time grew from 2000 to 2022, reaching 13.9 in 2006, 15.4 in 2012, and 15.4 in 2012. The overall doubling time, Dt, is 31.21, with the average mean doubling time, Dt, being 2.71.

It is identified that ranges from 1.90% to 51.74% across the years, indicating the distribution of citations over the years, while the utmost citation is ACPP 2014 (51.74%). Sridhar, (2020) indicated that there were 5626 citations obtained throughout the ten-year research period (2009-2018), with a total contribution of 1843 articles. In 2009, the paper garnered the most citations (1204), with an average citation rate of 6.21%.

The results show that out of a total of 4176 papers, 4187 (97.87%) were multi-authored publications, while only 89 papers (2.13%) were authored by a single author. In addition, the study highlights the Collaborative Index for research output on quantum dots from 2014 to 2023 is 8.23. Collaboration in 2022 is higher (13.29) than in 2023 (17.37). However, DC has decreased from 0.06 to 0.08 throughout the same year. Previous research by (Thirunavukkarasu et al., 2024) observed that collaborative authorship was predominant, accounting for 91.3% of publications, whereas single-author publications constituted only 8.7%. The top three years for collaboration were identified as 2014, 2016, and 2017. Similarly, the data suggest that multi-authored papers outnumber single-authored articles by 93.08% to 6.19%, with a degree of collaboration of 0.93. The Indian research output in this publication is 2.81%.

The current study's primary collaborator countries and papers were the United States and China followed by India, Germany, and Russia. Secured the first and second-position citations for China and the USA. Moreover, India collaborates with 53 countries, with the highest total link strength among countries being 25427.26. Yu et al., (2020) focused on identifying recent research on COVID-19 global literature 2019–2020, which was retrieved from the WOS database. The researcher identified 44 collaborative partners with China, resulting in a total connection strength of 487 across 838 publications. China's primary collaborators include the United States, England, and Germany. Additionally, the study identified, (Gupta et al., 2021) performed a bibliometric analysis of quantum dots research in India. The study found that China received the highest number of citations (61,790) and achieved the highest H-index (119). The United States ranked second in both citation count (48,664) and H-index (112) (Rofaie et al., 2023).

Our analyses specifically targeted the quantum dots literature in bibliographic coupling analysis, highlighting prominent documents. Lim 2015 emerged as the most cited document titled "Carbon Quantum Dots and their Applications," published in Chemical Society Reviews, Volume 44, Issue 1, Pages 362–381, in 2015. Further reviews explored emerging research areas, including those that methodologically diverge from traditional approaches, such as quantum probability theory (Hancock et al., 2020; Haghani et al., 2021). Guleria & Kaur, (2021) conducted a bibliometric analysis of ecopreneurship using VOSviewer and R Studio from 1989 to 2019. The study employed bibliographic coupling to analyze authors citing specific documents. The analysis revealed that the most prominent cluster, represented by the citation score of Dean (2007) in orange, is linked to Cohen (2007), Meek (2010), and others. Another significant cluster, represented in blue and centered on Schaltegger (2011), is connected to Santini (2017) and Cral (2005).

This study reveals that a total of 156,096 citation references were generated, with 822 cited references meeting the threshold criteria. The analysis identified seven clusters, 119,670 links, and a total link strength of 15,934.22. The study found that the top most cited reference, Murray CB, 1993, Journal of the American Chemical Society VII5, p. 8706, appeared to have the highest link strength (364) and citations (366). Consequently, previous research aimed at (Li et al., 2014) investigated bibliometric analysis of Nanosafety research spanning from 2003 to 2013. The study highlighted a significant work by Wick, Peter, titled "The degree and kind of agglomeration affect carbon nanotube cytotoxicity," published in Toxicology Letters in 2007. This publication emerged as the most referenced, cited 318 times between 2007 and 2014.

## VII. Conclusion

In terms of practical ramifications, academics should perform more studies on broader issues, with findings that may benefit more stakeholders. It may be necessary to establish an appropriate science and technology network among researchers worldwide, particularly in poor countries. In terms of policy recommendations, governments around the world, including developing countries, should implement policies and programs to expand research and the network for quantum dots marketing. A significant finding was the dominance of multi-authored papers, accounting for 97.87% of publications, underscoring the trend towards collaborative research in this field. The Collaborative Index for research output from 2014 to 2023 was 8.23, with higher collaboration observed in recent years. The primary countries collaborating on quantum dots research were the United States and China, followed by India, Germany, and Russia, with China securing the most citations and the highest H-index. Moreover, this study provides valuable insights into the collaborative nature and growth patterns of quantum dots research, identifying key contributors, trends, and areas of focus within the field. The findings can help guide future research directions and foster further collaboration among scientists globally.

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