Galileo as viewed through scientometric looking glass

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ABSTRACT

The scientometric study of individual scientists was started in around early 80's of last century that required in-depth data on the concerned person only. Such kinds of studies involved contemporary scientists only. No such attempt for any classical scholar or scientist has ever been noticed. This paper attempts to develop the scientometric portrait of Galileo Galilei, Father of Modern Science. The study of impact of classic scientists like Copernicus, Galileo, Newton *et al.,* through scientometric methodology bears significant implication in the context of history of science, genesis and evolution of scientific thought, sociology of science, etc., The inception of modern science was laid down with the wave of Copernican revolution in Europe in 15th century, with the publication of the book *De revolutionibus orbium coelestium* in 1543 by Nicholus Copernicus that challenged Aristotelian model. Later Galileo's telescopic observations and other experimental results added new dimensions to this revolutionary movement. Several new scientific thought contributions to this revolution were continued till Isaac Newton's work over more than a century later. This study has been executed by studying citations of Galileo's 11 publications (books, pamphlets and manuscripts) from *Web of Science* over a time span of 58 years, that is, since 1955–2013. It has been observed that these 11 publications received 338 citations over the said time span from 227 source items including articles, conference papers, review, editorial material, etc. The subject areas of the source items have been studied through keyword analysis and it has been found that Galileo received citations from a wide range of subjects. The co-cited authors, cited documents, and citation ages are also studied. The substantive numbers of classic scientists such as Einstein, Newton, and Poincare have been found as co-cited authors of Galileo.

Keywords: Bibliometrics, citation age, citation analysis, Copernican revolution, Galileo Galilei, history of science, informetrics, scientometrics, scientometric portrait, sociology of science

INTRODUCTION

The research papers contributed by scientists and scholars are the fundamental bricks of the World of Science and Technology Communication. The literature pertaining to any subject reflects the trend of research over years. The science and technology publications form the most rigid foundation for measuring research output. The individual scientists contribute papers to form the multitude of primary sources of information eventually that turns science information just like sea-shells on the sea-shore, a stage appears when primary information bits are consolidated and repackaged into secondary sources like indexing and abstracting services to make it easily retrievable. A snapshot of research publications is thus available from secondary sources. The publication information is searchable here by various metadata such as author, editor, title, source, subject domain, and keywords. Any analytical study about research output is generally carried out by the secondary sources, because the individual's contribution could be picturesquely manifested there. The individual scientists' contribution analysis thus forms an inseparable part of research trend study. This study is usually done by scientometric tools and techniques. An individual scientist's research output profile analysis through scientometric technique builds up the scientometric portrait.

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RELATED WORKS

The scientometric study of individual scientists was started around early 80's of last century. Earlier the same kind of study on any subject domain or broad discipline was usually carried out that required gross statistical or "macro" data. But an individual scientist's scientometric profile analysis demands in-depth data on the concerned person only.[1] There are so many studies carried out till date with individual scientists from versatile disciplines. Angadi *et al*.[2] developed scientometric portrait of Nobel Laureate Leland H. Hartwell (physiologist). Baby[3] carried out bio-bibliometric analysis of literature output of Prof. M. Lakshmanan in the Subject of Nonlinear Dynamics. Hazarika *et al*.[4] developed scientometric portrait of Nayana Nanda Borthakur (biometeorologist). Sinha and Bhatnagar[5] analyzed the scientometric profile of R. C. Sinha, a renowned plant pathologist of Canada. Derec de Solla Price, the stalwart information scientist wasthe focus of two different studies. Laitko and de Solla Price[6] showed the relevance of classic works of Price. Skalka-Zlatt and Zbikovska-Migon[7] on the other hand analyzed the presence of Price's contributions in Polish scientific literature. Koganurmath[8] analyzed scientometric profile of Wolfgang Ketterle (physicist). Kalyane and Kademani executed a lot of scientometric studies on individual scientists, for instance, K. S. Krishnan (physicist),[9] Harold W Kroto (chemist),[10] Ahmed Hassan Zewail (chemist),[11] Pierre-Gilles De Gennes (physicist)[12] Vinodini Reddy (medical scientist),[13] V. S. Ramachandran (cementand concrete chemist),[14] P. K. Iyenger (nuclear scientist),[15] R. Chidambaram (nuclear scientist)[16,17] M. S. Swaminathan (genetics and agricultural scientist),[18] C. S. Venkata Ram (Botanist),[19] K. Ramiah (agricultural scientist),[20] C. R. Bhatia (genetics and plant scientist),[21] T. S. West (analytical chemist),[22] Barbara McClintock (physiologist),[23] P. M. Bhargava (biologist),[24] Vikram Ambalal Sarabhai (space physicist),[25] C. V. Raman (physicist),[26] S. Chandrasekher (physicist),[27] Dorothy Crowfoot Hodgkin (biochemist),[28] Tibor Braun (chemist-cum-scientometrician),[29] and Munnolli *et al*.,[30] analyzed scientometric profile of Nobel Laureate Haraldzur Hausen (physiologist). Munnoli and Kalyane[31] analyzed scientometric profile of Ram Gopal Rastogi (physicist and geoscientist). Parvathamma and Banu[32] developed scientometric portrait of Atul H. Chokshi (material scientist). Mariraj[33] developed scientometric portraits of selected Nobel Laureates in physics. Sen and Gan[34] discussed a general method to study the productivity of scientists that is known as *biobibliometrics*. Sinha and Ulla[14] carried out scientometric profile of Dr. V. S. Ramachandran through analysis of his highly cited articles and books in the area of cement and concrete chemistry. Sinha and Bhatnagar[5] developed scientometric profile of R. C. Sinha (plant pathologist). Varaprasad *et al*.[35] executed scientometric study of research contributions of J. S. Yadav (chemist).

It is, however, a notable feature that individual scientists' scientometric portrait build-up so long carried out centered around the contemporary scientists only. No such attempt for any classical scholar or scientist has yet been noticed. It is very interesting to note that the classic pieces like Copernicus' *De revolutionibus orbium coelestium*, Galileo's *Dialogue of two chief world systems*, and Newton's *Principia Mathematica* are cited even today. This paper attempts to develop the scientometric portrait of Galileo Galilei, Father of modern science. The inception of modern science was laid down with the wave of Copernican revolution in Europe in 15th Century, which was the paradigm shift from the Ptolemaic model of the geocentric universe to the heliocentric universe model with the Sun at the center of the solar system. This revolution was started with the publication of the book *De revolutionibus orbium coelestium* by Nicolaus Copernicus that challenged Aristotelian model. Later Galileo's telescopic observations and other experimental results added new dimensions to this revolutionary movement. It was a revolution in the idea plane consisting of scientific and logical thoughts and concepts. Several new scientific thought contributions to this revolution were continued till Isaac Newton's work over more than a century later.

Kademani and Kalyane[36] designed indicators for productivity analysis of a scientist. Kalyane and Rao[37] proposed a new Positionwise Count system and compared it with three known credit systems, viz. Normal Count, Fractional Count and Straight Count. The merit of this method is that, it takes into account the author's placement (position) among the contributors and allots proper weightage. Kalyane, Madan and Kumar[38] developed a database on eminent Indian role model scientists like Homi Jehangir Bhabha, Satyendra Nath Bose, Rajagopala Chidambaram, Prasanta Chandra Mahalanobis, Jayant Vishnu Narlikar, Chandrashekhar Venkata Raman, Raja Ramanna et al with their number of publications during five-year periods starting from the first publication year and it was processed for their central tendency values. The Reference Curve was developed and the best fit was observed for median values.

GALILEO GALILEI: A BRIEF BIOGRAPHY

Galileo Galilei is one of the earliest and greatest of the experimental philosophers of the modern world. He is known as the Father of observational astronomy or broadly speaking, Father of the modern experimental science or modern science. He was a physicist, mathematician, engineer, astronomer, and at the same time, philosopher also. He was the eldest son of six siblings and born in Pisa, Italy on February 15, 1564 to a Florentine musician Vincenzo Galilei, who was a cloth merchant by profession and a famous lute composer, music theorist, and mathematician. He had important contributions to the theory and practice of music and also performed some experiments with Galileo in 1588–1589 on the relationship between pitch and the tension of strings. From this musician and mathematician father Galileo acquired an excellent knowledge of mathematics and his lifelong enthusiasm for music, with a particular devotion to the lute, of which he became a master later on.

The first decade of Galileo's life, that is, down to around 1575, was passed at Pisa. Galileo received his early education partly at the school of one Jacopo Borghini and partly at home, where his father helped him with his Greek and Latin lessons. The Galilei family then moved to Florence, where they lived for generations. At the age of around 13, Galileo was admitted to the monastery school at Vallombrosa, near Florence, and then in 1581 he appeared in matriculation examination at the University of Pisa. He became enamored with mathematics and decided to make the mathematical subjects and philosophy his profession. In 1585 Galileo left the university without having obtained a degree, and for several years he gave private lessons in the mathematical subjects in Florence and Siena. During this period he designed a new form of hydrostatic balance for weighing small quantities and wrote a short treatise, *La bilancetta* (*The Little Balance*), which was circulated in manuscript form. Once he watched a suspended lamp swing back and forth in the cathedral of Pisa that sketched a pendulum on his mind. Another mystery of nature in the form of a new discovery was unveiled. However, the most notable discovery about the pendulum, that is, the period (the time in which a pendulum swings back and forth) does not depend on the arc of the swing (the isochronism) was made in 1602. Eventually, this discovery would lead to Galileo's further study of time intervals and the development of his idea for a pendulum clock. He also began his studies on motion, which he pursued steadily for the next two decades. He argued the Aristotelian approach to physics that believed faster falling of the heavier objects through a medium than lighter ones. Galileo eventually disproved this idea by asserting that all objects, regardless of their density, fall at the same rate in a vacuum. To determine this, Galileo performed various experiments in which he dropped objects from a certain height. In one of his early experiments, he rolled balls down a gently sloping inclined plane and then determined their positions after equal time intervals. He recorded his discoveries about motion in his book, *De Motu*, which means "On motion." Galileo was appointed as a professor of mathematics at the University of Padua in 1592. In 1594, he developed a model for a pump that could raise water by using only one horse.

Besides the pump, Galileo invented many other mechanical devices, such as the hydrostatic balance. But his epoch-making invention was the telescope. Galileo made his first telescope in 1609 that could magnify objects three times. Later he upgraded the same upto 20 times magnification. With this telescope, he was able to look at the moon and discovered the four satellites of Jupiter, observed a supernova, verified the phases of Venus, and discovered sunspots. These four satellites, that is, Io, Europa, Ganymede, and Callisto are known as Galilean moons of Jupiter. His discoveries proved the Copernican system which states that the earth and other planets revolve around the sun, that is, the heliocentric model of the universe. Prior to the Copernican system, it was held that the universe was geocentric, meaning the sun revolved around the earth. Galileo's belief in the Copernican system eventually brought conflict with the Catholic Church. He faced inquisition that declared the Copernican proposition as a heresy. Due to support on Copernican system, Galileo was warned by Cardinal Bellarmine, under order of Pope Paul V, that he should not discuss or defend Copernican theories. In 1624, Galileo was assured by Pope Urban VIII that he could write about Copernican theory as long as he treated it as a mathematical proposition. However, with the printing of the book, *Dialogue Concerning the Two Chief World Systems*, Galileo was called to Rome in 1633 to face the Inquisition again. He was found guilty and was sent to his home near Florence where he was to be under house arrest for the remainder of his life. In 1638, he shifted to Florence for medical check-up. Afterward he became totally blind. On January 8, 1642, Galileo breathed his last at his home near Florence.[39-42]

Objectives

The main objectives of this work are:

- To highlight several quantitative aspects of the research communications contributed by Galileo
- To enumerate list of publications of Galileo along with years of publications, varying titles, no. of times cited, and subject areas covered
- To find out number of citations received by the documents authored by Galileo
- To find out the source items and its subject domains that included Galileo's books and writings in its reference lists
- To find out other major authors also co-cited with Galileo and to test the viability of Lotka's Law therein
- To find out other major documents also co-cited with Galileo's books and writings and to test the viability of Bradford's Law therein
- To find out the age of all cited items.

Scope and Methodology

The data has been collected for this study from *Web of Science*, where the name *Galileo Galilei* was put as the search term in the field of *Cited Author Search*. The name Galileo Galilei occurred in various forms like *G Galilei, Galilei, Galilei G, Galileo G,* etc. All these forms have been combined through OR Boolean operator to execute the search to get the results with maximum recall and precision. It has been observed that in all, 227 source articles cited Galileo's books and writings 338 times since 1955–2013, that is, on average each source item cited Galileo's works 1.5 times during 58 years of time span. Besides Galileo, these 227 source items cited another 13,177 items, of which 18 citations were received by the books written about Galileo. Galileo authored nine documents in total that include books, collection of letters, and pamphlets as listed in Table 1. The cited authors, cited documents and the ages of the cited items have also been analyzed and the applicability of Bradford's and Lotka's Laws were tested.

PUBLICATIONS OF GALILEO CITED SINCE 1955 TO 2013

Galileo started writing on science in 1580 just at his mid-teens but his first publication, *Sidereus Nuncius* (usually *Sidereal Messenger*, also *Starry Messenger* or *Sidereal Message*) came out in March, 1610, just thirty years later.Galileo's first written work on motion, *De Motu* was never published during his lifetime but first released in 1687, 45 years after his death. As it was never published during his lifetime, he never composed a final draft. In *De Motu*, Galileo firmly discarded Aristotle's views on the physics of motion and his astronomical views. On January 7, 1610, Galileo noticed three bright objects close to Jupiter. After repeated observations over a number of nights, he observed that the pattern changed and a fourth bright object became visible thereafter. Galileo explained this phenomenon as there were four satellites which revolved about Jupiter and Jupiter and its satellites revolved around the sun. To Galileo, this observation unveiled the fact that the Sun must be the center of the universe. His first publication was a brief astronomical treatise in the form of apamphlet published in Latin and it was the first published scientific work based on observations made through a telescope, which contains the results of Galileo's early observations of the mountainous Moon, the hundreds of stars that were hitherto unseen with the naked eye along with some other constellations and the stars that appeared to be circling Jupiter.

His next publication entitled *Discourse on Floating Bodies* came out in 1612, which also attacked Aristotelian physics. In 1613 Galileo published *Letters on Sunspots*in Italian, which resulted in acontroversy with Father Christopher Scheiner, a Jesuit astronomer. Galileo argued that the Sun, like the moon was not free from flaws. But Scheiner believed in the perfection of the heavens just like an Aristotelian. He attributed sunspots to small planets obstructing our view of the sun as they passed close to it. His next publication includes a series of correspondence with the Grand Duchess Christina since 1615.

In 1619, Galileo wasagain involved in a controversy with Father Orazio Grassi, professor of mathematics at the Jesuit Collegio Romano. It started as a dispute over the nature of comets, but by the time Galileo had published *The Assayer* (*Il Saggiatore*) in 1623, which contained basic arguments over the very nature of science itself. The book entitled *The Assayer* contains Galileo's ideas on how science should be practiced. It is referred to as his scientific manifesto that paved the way for modern scientific thinking.

The two prime books of Galileo were *Dialogues Concerning Two Chief World Systems* and *Dialogue Concerning Two New Sciences* first published in the years 1632 and 1638, respectively. In the former book he showed the logical and some observational evidences in support of Copernicus' heliocentric model of the solar system while in the later he presented ideas about physical properties of solids like size effect. The famous Square-Cube law was introduced in

Table 1: List of publications of Galileo cited by different source items since 1955 to 2013 at per Web of Science

Year of first publication	Cited version published in the year	Original title of document	Title of cited version	No. of times cited at per Web of Science	Subject domain covered	Topic discussed
1610	1610	Sidereal Messenger (Starry messenger)	Sidereus Nuncius (in Latin)	18	Telescopic observations	Qualitative observations of the stars, moon, Venus, moons of Jupiter, and the 'handles' on Saturn were polemical ammunition for Copernicanism
1612	1960	Discourse on floating bodies	Discourse on bodies in water	4	Hydrostatics	Discussed about things that float on water
1613	1613	Letters on sun spots	Letters on sun spots	1	Telescopic observations and mathematical analysis of sunspots	Demonstration of solar 'imperfections', axial rotation, and contiguous nature of sunspots
1615		Letters to the Grand Duchess Christina	-	-	Science and religion; philosophy of science	Attempt to separate scientific concerns from theological dogma; the strengths and limits of scientific inquiry
1623	1960	IL Saggiatore; The Assayer	Controversy on the comets	20	Philosophy of science; wide discussion of troublesome physical phenomena	Polemic on the nature of scientific investigation, particularly astronomical phenomena, based on observation and descriptive mathematics
1632	1967	Dialogues concerning Two Chief Systems of the World	Dialogues concerning Two Chief Systems of the World	136	Cosmology in the broadest sense; Copernicanism; kinematics	Brilliant literary polemic against Aristotelians in favour of Copernicus and the physics of a moving earth: inertia, relativity, and conservation of motion
1634	1960	Les Mechaniquus	Motion Mechanics	13	Mechanics	Mechanics of particles and solid bodies
1638	1954, 1974, 1989	Dialogues concerning/ Discourses and Mathematical Demonstrations on the Two New Sciences	Dialogues concerning/ Discourse on the Two New Sciences; Discorsi Demostrazio	84	Terrestrial kinematics; theory of matter, strength of materials	Mathematical (kinematic) demonstration and systematization of the science of motion and a discussion of the strength of materials
1687	1687	De Motu	De Motu	2	Motion and mechanics	From Archimedean Hydrostatics to Post-Aristotelian Mechanics
1856	1890	Le Opere di Galileo Galilei	Le Opere di Galileo Galilei	17	Collection of manuscripts of Galileo on astronomy, philosophy of science and physics	
1956	1956 and 1957	Discoveries and Opinions of Galileo	Edited by Stillman Drake	33	Collection of four books: The Starry Messenger (1610), Letter to the Grand Duchess Christina (1615), Excerpts from Letters on Sunspots (1613), The Assayer (1623)	

this classic piece. Meanwhile, in 1634 another publication entitled *Les Mechaniquus* came out that dealt with mechanics of particles and solid bodies. The comprehensive list of publications of Galileo is presented in Table 1. The years of first publication, varying titles are also incorporated. It is observed that the book *Dialogues Concerning Two Chief World Systems* was mostly cited (136 times) since 1955–2013 followed by *Dialogue Concerning Two New Sciences* (84 times) and *Discoveries and Opinions of Galileo* (33 times), which is a collection of four documents entitled *The Starry Messenger* (published in 1610), *Letter to the Grand Duchess Christina* (published in 1615), *Excerpts from Letters on Sunspots* (published in 1613), and *The Assayer* (published in 1623). The first book *Sidereal Messenger* was cited 18 times and the book *Saggiatore; The Assayer* was cited 20 times. Only one publication entitled *Letters to the Grand Duchess Christina* published in 1615 has never been cited at per *Web of Science*.

It is clear from a look at the columns of *subject domains* and *topic discussed* in Table 1 that Galileo's books and other documents touched more or less all major areas of the basic science. The period of citation started since 1955 and it is quite interesting that even after more than three hundred years of first publications these books received quite a good number of citations.

Table 2: Relative share of source document types

Type of source documents	No. and % of corresponding documents
Article	136 (60)
Proceedings Paper	46 (20)
Review	28 (12)
Editorial Material	12 (5.3)
Book Review	2 (0.9)
Discussion	1 (0.4)
Note	1 (0.4)
Reprint	1 (0.4)
All	227 (100)

Table 2a: Years of publication of source documents

Year of publication	Frequency	Year of publication	Frequency
1961	1	1994	2
1963	2	1995	3
1965	2	1996	3
1966	1	1997	4
1967	1	1998	5
1968	2	1999	2
1969	1	2000	15
1970	3	2001	9
1971	3	2002	10
1972	3	2003	14
1973	2	2004	10
1974	4	2005	12
1975	2	2006	10
1984	2	2007	10
1985	4	2008	12
1987	1	2009	19
1989	2	2010	11
1990	3	2011	5
1991	2	2012	18
1992	1	2013	11

RESULTS AND ANALYSIS

Source Documents

Of the 227 source documents, 60% (136) items comprise research articles followed by 20% (46) proceedings paper, 12% (28) review items, and 5.3% (12) editorial materials as clear from Table 2. Other types of documents are negligibly small. The majority of source documents (166, 73%) were published in 21st century, that is, since 2000–2013, while only 27% (61) of source documents was published in the last century, that is, from 1955 to 1999 as evident from Figure 1 and Table 2a. The highest number of source items were published in the year 2009 (19) followed by the year 2012 (18), 2000 (15), and 2003 (14). The newly published source articles cited Galileo much more compared to old source articles, which is an interesting finding. The context of Galileo thus seems to be attained significance in 21st century. Another notable point is that the United Nations, International Astronomical Union, and UNESCO declared the year 2009 as The International Year of Astronomy, which was a year-long celebration of astronomy to commemorate the 400th anniversary of the first recorded astronomical observations with a telescope by Galileo and the publication of Johannes Kepler's *Astronomia nova* in the 17th century. Galileo's highest citations in the year 2009 may be accounted for this incidence.[43]

Table 3: Frequency-analysis of words in titles and author-assigned keywords

Rank	Words in titles of 227 articles	Frequency	Words in author-assigned keywords from 227 articles	Frequency
1	Science	20	Bone	23
2	Bone, Galileo, Scale	17	Theory	18
3	Theory	13	Mechanics	17
4	Size	12	Adaptation, Gravitation, Relativity, Scaling	11
5	Effect	11	Fracture, History	10
6	Structure	10	Density, Dynamics, Flow, Model	9
7	History, New	9	Space, Strain	8
8	Design, Mechanics	8	Cortical, Energy, Galileo, Probability, Star, Structure, Time	7
9	Early, Relativity, System, Teach	7	Elasticity, Function, Mass, Method, Simulation, Strength, Stress, System	6
10	Fracture, Life, Study, Earth, Philosophy	6	Concrete, Element, Growth, Laws, Magnetism, Size, Surface	5

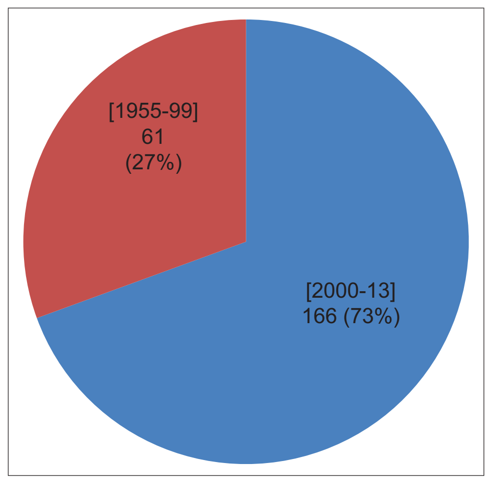

Figure 1: Distribution of publication period of source documents

Table 4: List of documents co-cited with Galileo's books and writings

Rank	No. of documents cited	Cited documents' titles	No. of times cited each
1	1	Nature	181
2	1	Science	147
3	1	Dialogues Concerning Two Chief Systems of the World	136
4	1	Journal of Biomechanics	135
5	1	Journal of Biological Chemistry	123
6	1	Journal of Bone and Mineral Research	117
7	1	Proceedings of the National Academy of Sciences, USA	109
8	1	Bone	95
9	1	Biophysical Journal	88
10	1	Discourse on the Two New Sciences	84
11	1	Physical Review Letter	77
12	1	Lunar and Planetary Science	70
13	1	Textile Research Journal	63
14	2	American Journal of Physiology, Journal of The American Chemical Society	62
15	1	The Journal of Experimental Biology	59
16	4	American Journal of Physics, The Astrophysical Journal, The Journal of Chemical Physics, The Journal of Physiology- London	57
17	1	The Journal of General Physiology	55
18	1	IEEE Xplore: Information Theory	54
19	1	Journal of Engineering Mechanics (ASCE)	50
20	2	Biochemistry-USA, Calcified Tissue International	49
21	1	International Journal of Fracture	48
22	1	Biochimica et Biophysica Acta	47
23	1	Journal of Applied Physiology	43
24	2	ISIS, The Journal of Membrane Biology	37
25	1	Physical Review D	36
26	1	The Journal of the Textile Institute	35
27	2	Philosophical Transactions, Royal Society of London	34
28	1	Discoveries and Opinions of Galileo	33
29	2	Annalen der Physik, Biochemical Journal	32
30	2	Astronomy and Astrophysics, Journal of Orthopaedic Research	31
31	1 document was cited 30 times		
32	4 documents were cited 29 times each		
33	2 documents were cited 28 times each		
34	3 documents were cited 27 times each		
35	2 documents were cited 26 times each		
36	1 document was cited 25 times		
37	4 documents were cited 22 times each		
38	4 documents were cited 21 times each		
39	4 documents were cited 20 times each		
40	6 documents were cited 19 times each		
41	5 documents were cited 18 times each		
42	6 documents were cited 17 times each		
43	8 documents were cited 16 times each		
44	10 documents were cited 15 times each		
45	13 documents were cited 14 times each		
46	10 documents were cited 13 times each		
47	8 documents were cited 12 times each		
48	10 documents were cited 11 times each		
49	18 documents were cited 10 times each		
50	28 documents were cited 9 times each		
51	42 documents were cited 8 times each		
52	34 documents were cited 7 times each		
53	50 documents were cited 6 times each		
54	71 documents were cited 5 times each		
55	122 documents were cited 4 times each		
56	257 documents were cited 3 times each		
57	696 documents were cited 2 times each		
58	4931 documents were cited 1 time each		

Contd...

Table 4: Contd...

Source Articles

The subject areas of 227 source items have been analyzed by frequency-analysis of words in titles and words in author-assigned keywords. Of the high frequency words, some pieces are common, like *theory*, *bone*, *scale,* etc. The occurrence of words signals history of science, relativity, gravitation, etc., as close relevant areas in the context of Galileo. Apart from astronomy, Galileo was the maestro in some other areas of basic sciences also like physical properties and structure of solids, size effect, scaling theory, and hydrostatics. These areas have applications in all major science disciplines like physics, chemistry, physiology, life sciences, and structural engineering.

The titles and author-assigned keywords of the 227 source items that cited Galileo's works have been analysed and the words in titles and author-assigned keywords along with their respective frequencies are presented in Table 3. The ranking of words are shown where so many words showed degenerate ranking. The word *Science* was topper in the list of words in title, while the word *Bone* was topper in the list of words in keywords. The same word held second in the list of words in titles with other two words, Galileo and Scale. The high frequency of the word *Bone* indicates an interesting phenomenon. All major science and engineering disciplines, starting from aerodynamics to nanotechnology encounter scaling problems. Galileo realised that the nature is not scale invariant and discovered scaling laws.

Galileo's square-cube law embodies a picturesquely natural concept that helps to understand our reality. The Square-cube law is universal to all science. The phenomenon like Size effect is clarified on the basis of this law that answers some physiological queries. This explains high frequency of the word *Bone*.

Cited Documents and Bradford's Law

The documents cited by 227 source items along with Galileo's works are listed in Table 4. In all, 6388 documents received 13,526 citations from 227 source articles, that is, on average each document received 2.1 citations. It means, 227 source items provided 6388 references with the total frequency of 13526, that is, 28.1 numbers of references are listed on average per source item. The highest cited journal is *Nature* (181 times cited) followed by *Science* (147 times cited) and *Dialogues Concerning Two Chief Systems of the World* (136 times cited). The third cited item is a book authored by Galileo. The next cited journals are *Journal of Biomechanics* (135 times cited), *Journal of Biological Chemistry* (123 times cited) and *Journal of Bone and Mineral Research* (117 times cited), which belong to the subject areas of biological sciences, biochemistry and physiology. Galileo's works on basic science thus have strong relevance with these areas also.

Here 6388 documents received 13526 citations. If the citations are divided in three equal zones of 4509 numbers each, then the ratio of the numbers of documents in decreasing order of rank in three consecutive zones are, 162:1717:4509, or 162* (1:11:28). This ratio is not in consonance with Bradford's distribution pattern, that is, k* (1:n: n^2), where k is the Bradford's multiplier and n is an arbitrary integer.

Galileo's co-cited Authors and Lotka's Law

The list of authors co-cited with Galileo is provided in Table 5. Of these authors the topper one is Z. P. Bazant (181 times cited) followed by A. Einstein (76 times cited), I. Newton (46 times cited), H. Poincare (46 times cited) and S. Drake (44 times cited). There are several pioneer scientists in this list, that is, G. W. Leibniz, R. S. Westfall, J. Kepler, C. H. Turner, R. Descartes, L. Euler, R. Boyle, and C. Huygens *et al.* The topmost cited author Zdeněk PavelBažant (born December 10, 1937) is McCormick School Professor and Walter P. Murphy Professor of Civil Engineering and Materials Science in the Department of Civil and Environmental Engineering at the Northwestern University's Robert R. McCormick School of Engineering and Applied Science.[44] He is regarded as the world leader in research on scaling in the mechanics of solids. He has remarkable works

Table 5: List of co-cited authors of Galileo

Rank	No. of authors	Co-cited authors' names	No. of times cited each
1	1	Bazant Z P	181
2	1	Einstein A	76
3	2	Newton I, Poincare H	46
4	1	Drake S	44
5	1	Carpinteri A	39
6	2	Leibniz G W, Tomalia D A	35
7	1	Westfall R S	34
8	1	Quack M	32
9	1	Turner C H	31
10	1	Kepler J	29
11	2	Herschel W, West J B	28
12	2	Rubin C T, Weibull W	25
13	2	Borodich F M, Carter D R	24
14	5	Kailath T, Nottale L, Rayner J M V, West B J, Yarman T	21
15	3	Decoursey T E, Jaekel M T, Matthews M R	20
16	2	Descartes R, Euler L	18
17	4	Biewener A A, Boyle R, Dalembert J, Dugas R	17
18	2	Frost H M, Pan N	16
19	4	Alexander R M, Cohen I B, Currey J D, Mandelbrot B B	15
20	8	Burr D B, Cowin S C, Daudreville D, Forwood M R, Huygens C, Koyre A, Mihashi H, Wallis J, Wolff J	14
21	3 authors were cited 13 times each		
22	9 authors were cited 12 times each		
23	13 authors were cited 11 times each		
24	14 authors were cited 10 times each		
25	13 authors were cited 9 times each		
26	22 authors were cited 8 times each		
27	44 authors were cited 7 times each		
28	50 authors were cited 6 times each		
29	85 authors were cited 5 times each		
30	190 authors were cited 4 times each		
31	392 authors were cited 3 times each		
32	1076 authors were cited 2 times each		
33	6064 authors were cited 1 times each		

Table 6: Frequencies of years of publications of cited documents

Year	Freq	
1420-99	5	
1500-49	16	
1550-99	29	
1600-49	169	
1650-99	151	2436 (18%)
1700-49	100	
1750-99	120	
1800-49	151	
1850-99	497	
1900-49	1198	
1950-99	8494 (64%)	
2000-13	2442 (18%)	

Year	Freq
1950-59	732 (9%)
1960-69	1313 (15%)
1970-79	1412 (17%)
1980-89	1842 (22%)
1990-99	3195 (38%)

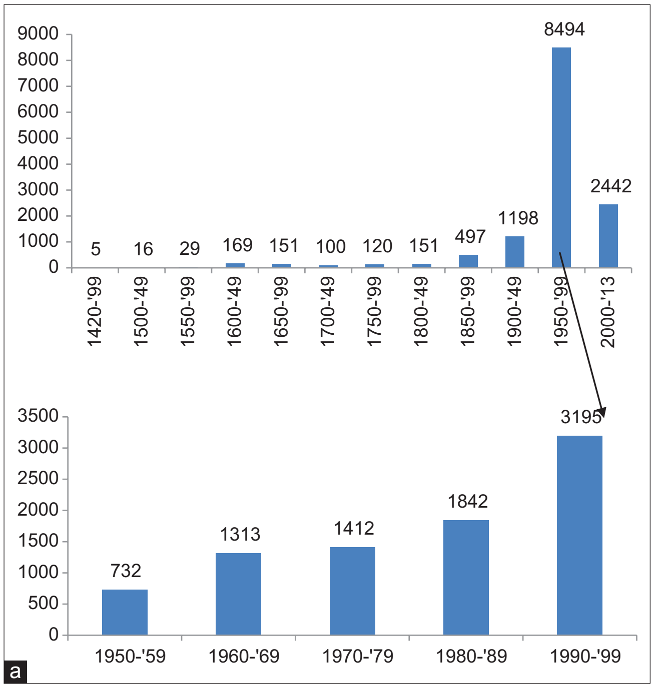

Figure 2: Frequencies of publication years of cited documents (a) Frequencies of publication years ranging from 1950 to 1999

in the areas of stability of structure, fracture, size effect etc. Galileo started research on these areas around three centuries back. Galileo's Square-Cube Law explains different aspects of size effects that is, why size matters and also its impact on living world. This law is such a fundamental scientific truth that science is hardly science without it.

Lotka's law empirically states that the number of authors cited is about $1/n^2$ of those making one; and the proportion of all single citations is about 60%. This means that out of all the cited authors in a given field, 60% will receive just one citation, 15% will receive two citations ($1/2^2$ times of 60), 7% authors will receive three citations ($1/3^2$ times of 60), and so on. According to Lotka's law, only 6% of the authors in a field will receive more than 10 citations. Lotka's law, when applied to large bodies of literature over a fairly long period of time, can be accurate in general, but not statistically exact. The general form of Lotka's law can be expressed as $y = c/x^n$ where y = percentage of authors, x = number of citations received by an author, c = constant and –n = slope of the log-log plot. In this study, 8023 authors received 13,526 citations; on an average 1.7 citations per author. Among 8023 authors, 6064 authors (76%) received one citation; 1076 authors (13%) received two citations and 392 (5%) authors received three citations. The percentage values of single, twice, and thrice citation recipients thus deviate from Lotka's permissible values. Hence the cited author pattern in this study is not in conformation with Lotka's law.

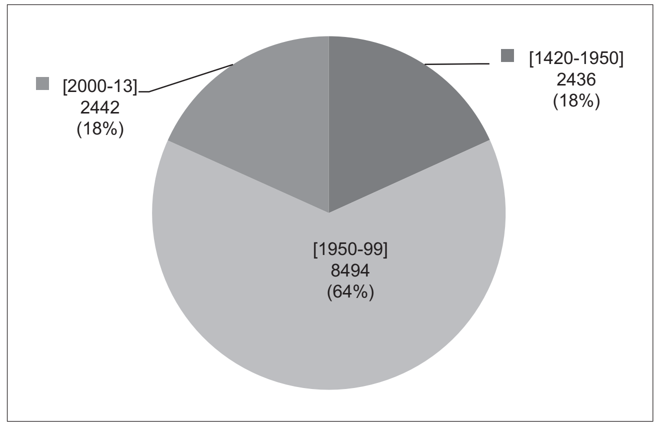

Figure 3: Relative share of frequencies of publication years over the time span of 593 years ranging from 1420 to 2013

Citation Age

The years of publications of the cited documents are presented in Table 6, Figures 2, 2a, and 3, which shows that of the total 13,526 cited items, the dates of publications are available for 13,399 references. Of this cited sample, 2436 (18%) documents were published since 1420 to 1949, 8494 (64%) documents were published between 1950 and 1999 and 2442 (18%) documents were published in 21st century, that is, since 2000–2013. Out of 8494 documents the maximum number of publications (3195, 38%) was appended to the time period ranging from 1990 to 1999.

CONCLUSION

Galileo is known as the Father of modern science. His ideas ignited scientific revolutionary thought, the revolution that is famous in history of science as Copernican revolution. Galileo's ideas initiated a large-scale revolution in human thinking. He changed the way we see the world and more importantly, how we perceive ourselves within it. He was the first who took attempt for a direct observation of the sky. He was sure that only such direct observation would answer the questions that crowded his mind. He wrote that, "Thought is the most pleasing ability granted to human kind." Many artists were inspired by his revolutionary scientific thought and applied Galileo's observations to their work. Galileo's friend Ludovico Cigoli, a contemporary artist, sketched realistic depictions of Galileo's telescopic observations. Galileo's discoveries also had a distinguished impact in the area of philosophy. Francis Bacon remarked in this context, "There are men who are praised because they meticulously lend reason to their discoveries and then go on to navigate celestial spaces in small boats. This is Galileo." Bacon equated Galileo's exploration via telescope with that of famous travelers of the Earth's seas, such as Christopher Columbus.

Galileo's studies left demoralizing consequences on a Christian theosophical and religious level; nothing could ever be the same as before. The Copernican cosmology was not in accordance with the Church and the Holy Scriptures. The Church understood the risk of Galileo's theories. Its principal fear was that his theories would inspire humanity to think freely. But still the value of Galileo's theories has been recognized as irrefutable over time. In 1835, almost 200 years after its original publication, the "Dialogue Concerning the Two Chief World Systems" was removed from the Vatican's list of banned books. After another 150 years, the Church surrendered its rejection of Galileo's views of the solar system and deemed them correct (Conti, 2010).[45] The valuable studies resulting from Galileo's thoughts are above all the basis of modern science today.

Galileo investigated nature to find answers to phenomena via experimentations. After getting results he developed scientific models by mathematical tools to endorse his observations. As the first modern physicist, Galileo has offered important contributions to the study of Dynamics. In the "Dialogues" he brought conceptual developments of the mathematical entities, "infinite" and "infinities," or "infinitesimal." These concepts later formed the basis of differential calculus, developed by Newton and Leibnitz. Galileo discovered a unique thing, what is called experiment to do practical observations. He is thus the Father of experimental science. There was no concept of practical experimentation prior to Galileo. The cultivation of knowledge was solely based on idea and concept. Such experimental approach advanced the studies of astronomy and science since Galileo's time, but his idea of heliocentric universe was the most elegant piece.

There are lots of examples of Galileo's legacy till date. It was Galileo's telescope that switched on the signal of today's Hubble and Herschel telescopes, which observe the infinity of the universe. The Copernican revolution got its smooth terminating pavement only after Galileo's *Dialogues* that also opened the gate thereafter for the Newtonian era. Galileo was a man "before his time." He said, "Facts, which at first seem improbable will, even on scant explanation, drop the cloak which has hidden them and stand forth in naked and simple beauty."

This paper presents the scientometric portrait of the Father of modern science. Scientometric portraits have been so long built up for contemporary scientists and scholars, while the same for a classical foundation scientist, who started science and paved the way for experimentation shows that even after more than 350 years of demise Galileo receives quite a fair number of citations. This evergreen doyen of basic sciences is still relevant in different contexts.

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