H.J. Bhabha: A case study of synchronous references

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Abstract: Quantitative analysis of the events of synchronous references in the research papers followed throughout the publishing career of an individual scientist revealed interesting highlights on the knowledge-generating-system. In the case study of Homi Jehangir Bhabha, the first quinquennium and fifth quinquennium of his research career had low self-references; the third quinquennium and the fourth quinquennium had moderate self-references; whereas the second quinquennium had the highest number of self-references. The two major clusters of self-references occurring during the second and third quinquenniums were indicators of active periods of knowledge-generating and faster communications.

Keywords: author self-citations; bibliometrics; embryology of knowledge; H.J. Bhabha; nuclear knowledge generating system; publication as intellectual output; publication productivity; scholarly communications; synchronous self-citations; temporal profile of self-references.

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1 Introduction

Self-references form a significant portion of the reference network. Self-references are indicative of the continuity of pursuing one's own research. While self-references enrich personal intellectual growth, references to Others (other than the author/s of the citing paper) amounts to import of intellectual experiences from other contemporary researchers. Studies show that the rate of self-referencing vary between 10% and 20%, depending on the field and development of research in that field. Author self-references pattern has been studied across one or more disciplines (Snyder and Bonzi, 1998; Tagliacozzo, 1977). One of the reasons to self-cite is that reference needs to be made to previous works on which the present work is being built (Borgman and Furner, 2002). The reasons for authors to refer to their own works and works by Others are very similar (Bonzi and Snyder, 1991). Lawani (1982) has classified references into four species of which Species I is where the first author of the citing paper is also the first author of the cited paper, and it is called as "classic-author self-citation". Publications sharing at least one identical author in the citing paper and the cited paper are called author self-references (Garfield, 1979a).

An individual scientist is considered as a unit of generating knowledge (Swarna et al., 2003). An author who includes a particular reference is announcing to readers the relevance of the reference to the citing paper at some point, while conducting the research or during the writing process (Harter, 1992). Referencing behaviour may be a specific characteristic, like any other behaviour specific to an individual. Garfield (1994) and Aksnes (2003) had felt the need for systematic studies considering self-references. Comprehensive study of self-referencing behaviour of an individual scientist has not been noticed till date; hence, the present case study was undertaken.

2 Objectives

The knowledge organisation system in the contents of a research paper and the ideas investigated are reflected in the references. The present paper attempts to explore synchronous references in the life-time publications of an individual scientist with the objectives of:

- knowing dynamic association pattern of self-references and references to Others
- correlating collaborative levels with synchronous references
- quantifying recency in synchronous references
- identifying connectivity networks of citing and cited documents
- differentiating high publication production periods from moderate and low productivity periods and establishing its relationship with self-references.

3 Materials and methods

The present paper is a unique case of the 'Classic-Author Synchronous Self-References (C-ASS-R)' because Homi Jehangir Bhabha (http://www.barc.ernet.in/webpages/about/)

was either the sole author or was the first author in all collaborations, except one of his papers (Taylor et al., 1950). The objective of the study was exploratory basic research into the process of generating knowledge at an individual scientist level.

The source used for this study was *Homi Jehangir Bhabha: Collected Scientific Papers* (Sreekantan et al., 1985). The year of publication was taken into consideration while arranging the papers sequentially.

The data collection technique involved quantitative content analysis of all references (purposive) referred to (in text, as footnotes, and at the end of the text) in each of the papers of H.J. Bhabha. These were categorised into:

- the C-ASS-R as recommended by Aksnes (2003) by considering only the first-author in self-references
- the references to Others (i.e., all references except the C-ASS-R, in the present case who is H.J. Bhabha).

An author, while referring to his own works also refers to the works of Others. Synchronous Self-Referencing Rate (SSRR) is the percentage of self-references by the author in a paper to the total number of references in the same paper. According to Lawani (1982) SSRR of 100% is very rare. For example, P.A.M. Dirac had referred only to himself in many of his papers (Kragh, 1990).

The Synchronous Self-Referencing Rate (SSRR) varies from individual to individual as a unique behaviour of each individual. The same researcher may have changes in SSRR from time to time when shifts occur in working from one domain to another domain in his lifetime. The SSRR may change as per the channel of communications preferred over a period of time.

The Synchronous Self-Referencing Rates (SSRRs) for S. Chandrasekhar (Kademani et al., 1996a) in various domains were: Plasma physics (20.4%); Stochastic, statistical hydromagnetic problem in physics and astronomy (19.6%); Mathematical theory of black holes and colliding waves (19.4%); Stellar structure and stellar atmosphere (17.8%); Radiative transfer and negative ion of hydrogen (14.9%); Tensor-virial theorem (14.3%); Relativistic astrophysics (12.6%); and Hydromagnetic and hydrodynamic stability (10.5%); the SSRRs for C.V. Raman (Kademani et al., 1994) in various domains were: Floral colours and visual perception (26.9%); Physics of crystals (26.4%); Optics (19.7%); Optics of minerals and diamonds (19.6%); Acoustics (11.7%); and Scattering of light (5.6%). The SSRRs for K.S. Krishnan (Kademani et al., 1996b) for various domains were: Thermionics (19.0%); Magnetism (14.8%); and Spectroscopy (9.8%). The SSRRs for R.K. Mitra (Kalyane et al., 2001b), calculated domain-wise, were: Methodology (16.7%); Biochemical genetics (14.8%); Molecular biology (11.6%); Bioenergetics (9.7%); Plant biochemistry (4.2%); and Biotechnology (0.0%). The mean SSRR for C.R. Bhatia was 0.5% (Kalyane and Sen, 1998). The overall SSRR for the following scientists were: Vikram Sarabhai – for Cosmic rays, 16.5% (Kademani et al., 2000); R. Chidambaram – for highly cited and/or most significant publications, 12.2% (Kademani and Kalyane, 1996); and R.G. Rastogi – for Geomagnetism, 25.1% (Munnolli and Kalyane, 2003). For the papers of Tibor Braun published in the core journals preferred by him to channelise his publications, SSRR was found to vary from 19% to 70% (Kalyane and Sen, 2003) as follows: *Journal of Radioanalytical and Nuclear Chemistry Letters* (70%); *Trends in Analytical Chemistry* (30%); *Scientometrics* (28%); *Analytica Chimica Acta* (22%); and *Fresenius Zeitschrift fur Analytische Chemie*,

renamed as *Fresenius Journal of Analytical Chemistry* (19%). Scientometric analysis of synchronous references (Upadhye et al., 2004) in the nine Physics Nobel lectures (Frangsmyr, 1993): Nicolaas Bloembergen (1981), Arthur L. Schawlow (1981), Kai M. Siegbahn (1981), Kenneth G. Wilson (1982), Subrahmanyan Chandrasekhar (1983), William A. Fowler (1983), Carlo Rubbia (1984), Simon van der Meer (1984) and Klaus von Klitzing (1985) indicated high variations: the number of Synchronous References ranged from 24 (Meer) to 283 (Siegbahn); Synchronous Self-References ranged from 5 (Rubbia) to 88 (Siegbahn); synchronous references to Others ranged from 10 (Chandrasekhar) to 255 (Wilson); Synchronous Self-referencing Rates ranged from 6.66% (Rubbia) to 65.51% (Chandrasekhar); Single-Authored References ranged from 15 (Klitzing) to 160 (Wilson); Multi-Authored References ranged from 4 (Chandrasekhar) to 194 (Siegbahn); the Collaboration rate in the synchronous references ranged from 0.14 (Chandrasekhar) to 0.75 (Klitzing); and Recency (age of 50% of the latest references) ranged from 2 years (Klitzing) to 18 years (Chandrasekhar).

Bhabha received two diachronous citations in the Nobel Lecture (Sen, 1969) by Yukawa (Yukawa, 1949) and Blackett (Blackett, 1948).

The difference between the publication year of the referring paper and the publication year of the referred paper (Δt) may throw light on the interdependence of research programmes of individual scientists. References are generally backward in time. If referring and referred papers are published in the same year, the age of the reference is zero. The average age of references within a particular referring paper or series of papers reflects how modern the paper is or how integrated it is in the evolving research forefront. In rapidly evolving 'hot' areas, the age of the references will be very low and in many cases, zero. If the average age of references is high, it usually indicates that the paper, or series of papers, belong to a stagnating research area or is out of contact with the mainstream research (Kragh, 1990).

The present paper attempts to visualise temporally (Price, 1986; Belew, 2000), the self-references profile by linking the citing papers by H.J. Bhabha with the cited papers by H.J. Bhabha.

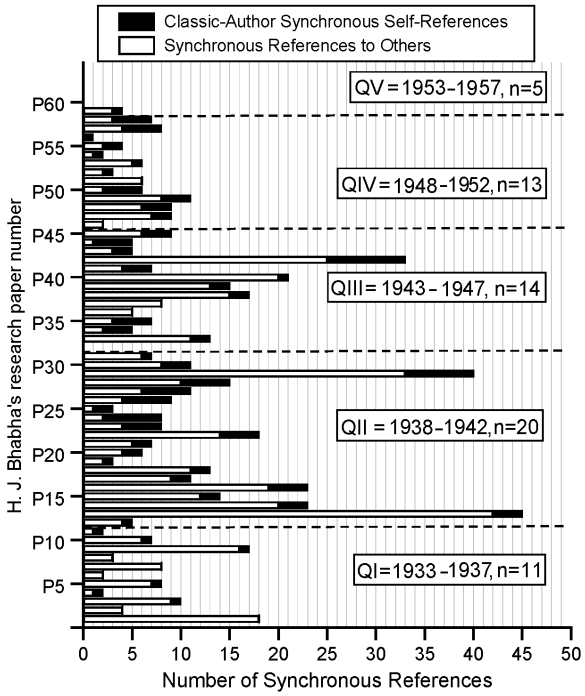
4 Results and discussion

4.1 Pattern of Synchronous Self-References and references to Others

Sixty-three papers by H.J. Bhabha had a total of 589 references of which 131 were self-references and 458 were references to Others. The overall Classic-Author Synchronous Self-Referencing (C-ASS-R) Rate for H.J. Bhabha was 22.2%. Five papers did not have any references and one paper (Bhabha, 1951) had only one reference and that too, self-reference. The C-ASS-Rs were in his 48 (76.2%) papers. Snyder and Bonzi (1998) reported the rate of self-referencing in physical sciences as (15%), social sciences (6%), and humanities (6%).

Self-references and references to Others in each of the 63 papers of H.J. Bhabha are chronologically profiled in Figure 1. His paper 'The theory of the elementary particles' (Bhabha, 1946) had maximum eight C-ASS-Rs. The maximum number of references to Others was 42 in his paper titled 'On the penetrating component of cosmic radiation' (Bhabha, 1938).

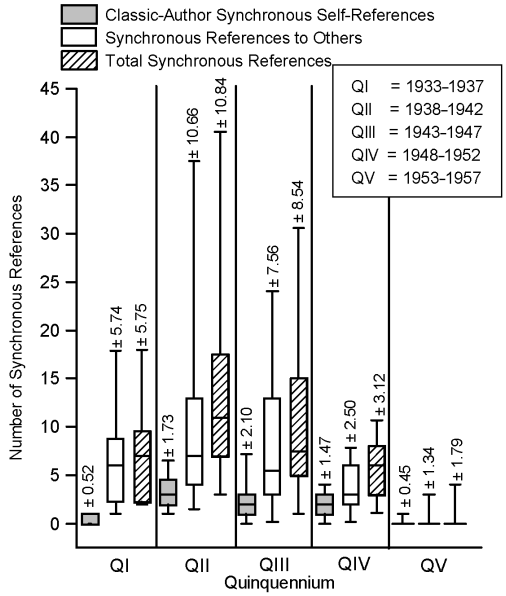
Figure 1 Number of synchronous references in the papers by H.J. Bhabha



Self-references ranged from 0–8, the mean being 2.1, the mode 1, the median 2, and SD 1.9. These values for references to Others were: range (0–42), mean (7.3), mode (2), median (5), and SD (6.3). The data reveal positively skewed curves for C-ASS-R, references to Others, and total references. For C-ASS-R rate the range was 0–100%. The high rate of synchronous self-referencing indicates the extent of self-consistency in the research of the author during that period. This also indicates that the focus of the researcher was in a micro-domain that had proportionately few scientists working at the global level and very few were associated with him. Moreover, confidentiality of the research endeavour was the prime consideration at that time.

Publishing career quinquenniumwise (QI = 1933–1937, QII = 1938–1942, QIII = 1943–1947, QIV = 1948–1952 and QV = 1953–1957) data for papers were sorted for plotting Figure 2. QII had high productivity of 20 papers with 64 self-references and 216 references to Others.

Figure 2 Research publishing career, quinquenniumwise statistics for the synchronous references in the papers by H.J. Bhabha



The bottom of the box marks the 25th percentile, the median line marks the 50th percentile, the top of the box marks the 75th percentile. SD values are atop.)

Categorised data for the number of papers having C-ASS-R, references to Others, and total number of references are provided in Table 1.

Table 1 Synchronous references profile in the papers by H.J. Bhabha

Number of synchronous references class (c)	*Number of papers considering the*			*Total number of references*		
	Classic-author self-references in each paper (s)	*References to others in each paper* (o)	*Total references in each paper* (t)	*Self* ($c \times s$)	*Others* ($c \times o$)	*Total* ($c \times t$)
0	14	6	5	0	0	0
1	15	5	1	15	5	1
2	12	8	5	24	16	10
3	8	5	4	24	15	12
4	8	7	3	32	28	12
5	3	3	5	15	15	25
6	1	6	4	6	36	24
7	1	2	6	7	14	42
8	1	4	6	8	32	48
9	0	2	4	0	18	36
10	0	1	1	0	10	10
11	0	2	4	0	22	44
12	0	1	0	0	12	0
13	0	1	2	0	13	26
14	0	1	1	0	14	14
15	0	1	2	0	15	30

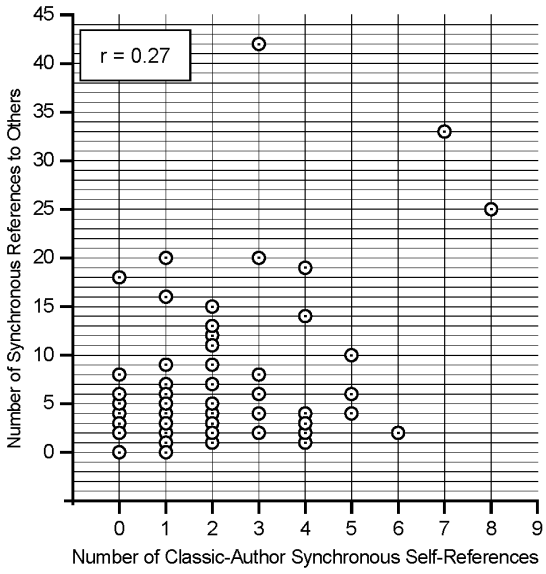
Table 1 Synchronous references profile in the papers by H.J. Bhabha (continued)

Number of synchronous references class (*c*)	*Number of papers considering the*			*Total number of references*		
	Classic-author self-references in each paper (*s*)	*References to others in each paper* (*o*)	*Total references in each paper* (*t*)	*Self* ($c \times s$)	*Others* ($c \times o$)	*Total* ($c \times t$)
16	0	1	0	0	16	0
17	0	0	2	0	0	34
18	0	1	2	0	18	36
19	0	1	0	0	19	0
20	0	2	0	0	40	0
21	0	0	1	0	0	21
23	0	0	2	0	0	46
25	0	1	0	0	25	0
33	0	1	1	0	33	33
40	0	0	1	0	0	40
42	0	1	0	0	42	0
45	0	0	1	0	0	45
Total	63	63	63	131	458	589

There were no C-ASS-Rs in 14 papers. Only one C-ASS-R was present in another 15 papers. Two C-ASS-Rs were in 12 papers. Three and four C-ASS-Rs were in eight papers each. There were five C-ASS-Rs in three papers. Six, seven, and eight C-ASS-Rs were found in one paper each.

Correlation between C-ASS-Rs and references to Others is very low ($r = 0.27$) and reveals independence of each set of statistical data (Figure 3), as the occurrence of one event does not influence the probability of occurrence of the other event.

Figure 3 Scattergram for number of Classic-Author Synchronous Self-References in each paper and corresponding number of synchronous references to Others in the papers by H.J. Bhabha



4.2 Collaborative level and synchronous references

The collaborative level i.e., by considering the number of author(s) in the byline of the publications (host papers of H.J. Bhabha) and correspondingly sorting data for the number of C-ASS-Rs per paper, number of references to Others per paper, and total number of references per paper, the data were plotted in Figure 4. The correlations are presented in Table 2. The number of C-ASS-Rs and the synchronous references to Others per paper and the total number of synchronous references per paper continued to increase with the rise in the number of authors (two to four portion of the data) per host paper; hence, a high positive correlation was observed for this portion of data.

Figure 4 Average number of Classic-Author Synchronous Self-References, synchronous references to Others, and number of synchronous references per paper, as a function of number of author(s) per paper as per the by-line of the publications by H.J. Bhabha

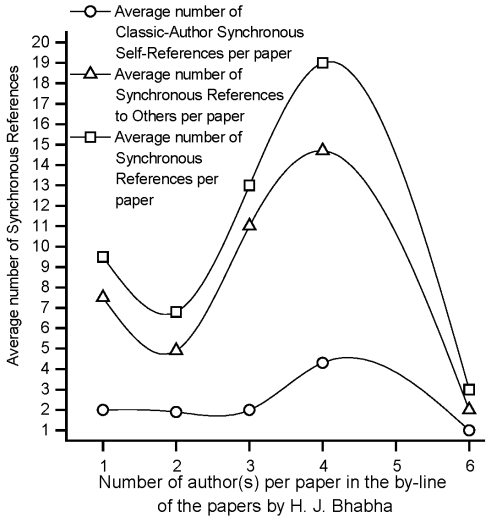


Table 2 Number of Classic-Author Synchronous Self-References, number of synchronous references to Others, and number of synchronous references per paper, as a function of number of authors per paper as per the byline of the publications by H.J. Bhabha

Collaborative level i.e., number of authors per host paper	*Average number of classic-author synchronous self-references per paper*	*Average number of references to others per paper*	*Average number of references per paper*
1	2.0	7.5	9.5
2	1.9	4.9	6.8
3	2.0	11.0	13.0
4	4.3	14.7	19.0
6	1.0	2.0	3.0
Correlations with various considerations of the data			
1 to 6 authors	–0.089	–0.188	–0.172
1 to 4 authors	0.774	0.839	0.850
2 to 4 authors	0.884	0.990	1.000
2 to 6 authors	–0.208	–0.293	–0.282

When only run-of-the-mill papers were considered, Tagliacozzo (1977) did not find any relationship. However, when the diachronous self-citations of a random sample and two quality samples of cancer research papers were studied (Lawani, 1980), statistically significant positive correlations between mean self-citations and collaborative levels were obtained for each of the quality samples.

More cumulativeness of research papers at the level of individual researchers are likely to cause more self-references. Here, explanation, and thus building on earlier work are important (Aksnes, 2003). At micro-domain levels one would find that scientists working in narrow specialities have the highest self-references counts (Garfield, 1979b). Self-referencing is natural and inevitable when a researcher is involved in in-depth research in a micro-domain (Pichappan and Sarasvady, 2002).

In some way Garfield is also responsible for triggering the trend of citing each other (just for increasing citations), and citing oneself at the least relevant situations and is also self-motivated due to the forces (publish or perish syndrome) of evaluating for promotions based on citations to the credit of the individual, particularly in some universities and R&D institutions or while making decisions to select awardees. This situation did not exist during the period of H.J. Bhabha. Hence, Bhabha was not motivated by any other criteria but the thought contents of the documents cited, irrespective of whether the source belonged to himself or to Others. Hence, his bias towards self-references is ruled out.

4.3 Recency in referencing

The age (Δt) of each reference (588) cited by H.J. Bhabha in his papers (Table 3) was calculated. One reference to Others whose year of publication could not be ascertained was omitted. The age of the references ranged from zero years to 27 years for references to Others, and from 14 years to +1 year (+ indicates reference forward in time i.e., one cited paper was published one year following the citing paper) for self-references. The proportion of C-ASS-Rs is more recent than references to Others. About 50% of the latest C-ASS-Rs were just one year old, whereas 50% of references to Others were three years old.

Table 3 Recency of synchronous references in the papers by H.J. Bhabha

Recency	*Age** (Δt)	*Self-references*			*Reference to Others*		
		Freq.	*%*	*Cumulative*	*Freq.*	*%*	*Cumulative %*
Very recent	+1	1	0.8	0.8	0	0.0	0.0
	0	25	19.1	19.9	50	10.9	11.1
	–1	39	29.8	49.7	110	24.0	35.1
	–2	24	18.3	68.0	60	13.1	48.1
	–3	10	7.6	75.6	48	10.5	58.6
Less recent	–4	11	8.4	84.0	35	7.6	66.2
	–5	5	3.8	87.8	25	5.4	71.7
	–6	5	3.8	91.6	37	8.1	79.7
	–7	5	3.8	95.5	23	5.0	84.7
	–8	2	1.5	97.0	25	5.4	90.2

Table 3 Recency of synchronous references in the papers by H.J. Bhabha (continued)

Recency	*Age** (Δt)	*Self-references*			*Reference to Others*		
		Freq.	*%*	*Cumulative*	*Freq.*	*%*	*Cumulative %*
Old	–9	2	1.5	98.5	10	2.2	92.4
	–10	0	0.0	98.5	12	2.6	95.0
	–11	1	0.8	99.3	4	0.9	95.8
	–12	0	0.0	99.3	4	0.9	96.7
	–13	0	0.0	99.3	4	0.9	97.6
	–14	1	0.8	100.0	4	0.9	98.5
	–15	0	0.0	100.0	2	0.4	98.9
	–16	0	0.0	100.0	1	0.2	99.1
	–25	0	0.0	100.0	1	0.2	99.3
	–26	0	0.0	100.0	1	0.2	99.6
	–27	0	0.0	100.0	1	0.2	99.8
	Total	131	100.0		457	99.6	

*Age = the number of years the cited paper antedated or preceded the citing paper, +Age = forward or in-press or antenatal reference, 0 Age = current reference i.e., having same publication year for citing and cited paper, –Age = Backward in time or publication of cited paper antedated the citing paper.

The recency in self-references is expected since authors are aware of their own publications. Having considered C-ASS-Rs of only one researcher, self-references are under the constraint of the researcher's age, which is explained by Aksnes (2003) as the author has no relevant former works within the micro-domain, C-ASS-Rs at the beginning of the researcher's initial career were naturally more recent and fewer than references to Others.

Three publications had exceptionally high time-lags for references to Others of 25 years (Bhabha, 1941a), which refers to Lorentz transformation (Lorentz, 1916); 26 years and 27 years (Bhabha, 1936) which refers to the invariance in the Maxwell equations, as was proved by a direct transformation by Cunningham (1909) and Bateman (1910).

The proportions of C-ASS-Rs and references to Others (Figure 5) clearly illustrate the age of references with reference to the publication year of the citing paper.

4.4 Temporal profile of Classic-Author Synchronous Self-References

Usually references given by authors run backwards in time, whether C-ASS-Rs or references to Others. Bhabha has also cited his works that were in-press at the time of publishing his citing paper. These linked citing-cited network of documents are indicated (Figure 6), by rings (for the published papers) and by bullets (for the in-press papers) linking the events of occurrence of the C-ASS-Rs to the cited papers by H.J. Bhabha. Five of these in-press papers were published in the same year as the citing paper but while arranging the papers in chronological order, such papers were arranged after the respective citing paper.

Figure 5 Agewise proportion of synchronous references to Others and Classic-Author Synchronous Self-References depicted temporally in backward and forward (in-press) directions in the papers by H.J. Bhabha

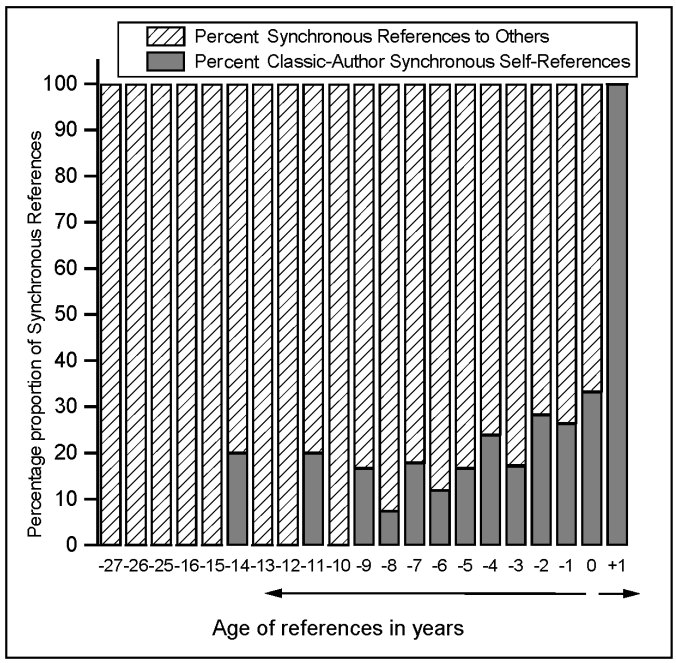
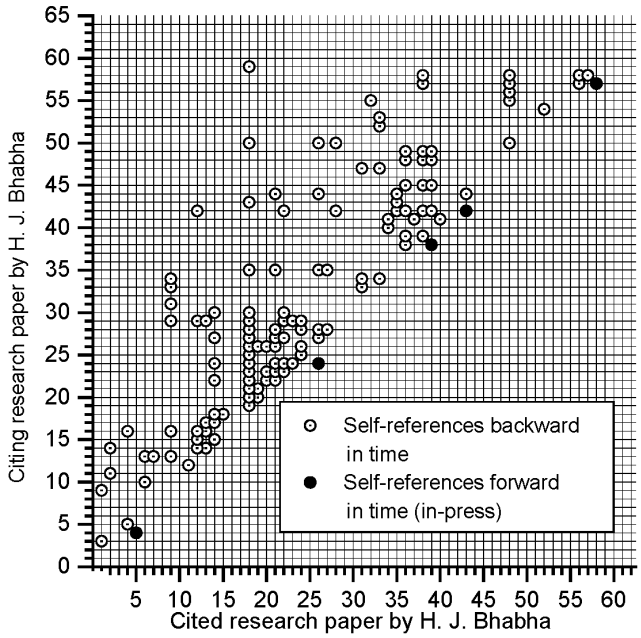


Figure 6 Temporal profile of Classic-Author Synchronous Self-References linkages in the citing and the cited papers by H.J. Bhabha



The publication productivity in Quinquennium I shows only a few cross-linked papers, which is expected, at the beginning of a researcher's career. The density of cross-linked papers increased in the QII and QIII and then decreased in the QIV and QV.

Two major clusters of self-references in 11 papers with 46 self-references and 12 papers with 33 self-references were indicators of focus in research activity where high C-ASS-Rs were found in association with one in-press and two in-press papers respectively. Pichappan and Sarasvady (2002) have stated that one of the reasons to self-cite is to alert researchers about their forthcoming work (i.e., in-press). Such references have been termed as 'forward citations' (Baird and Oppenheim, 1994).

Circulation of 'in-press' publications in print media is considered as 'preprints'. Pre-print circulation was not much in vogue during the time of Bhabha. However, Bhabha had personal contacts with his contemporaries and some of his papers were communicated by well known scientists. Number of papers communicated by R.H. Fowler were five, one by N.F. Mott, four by C.V. Raman and three by P.A.M. Dirac.

In the digital era eprints include 'preprints / and / or / postprints' versions which are posted by researchers in author-self-archives, institutional-self-archives or the internet-based-archives. Print journals are being considered as traditional journals. According to Harnad and Carr (2000), preprint (in-press) is considered as one of the embryological stages of the pedigrees of ideas. Preprint eprints play major role in the embryology of knowledge because of their instantaneous exposure to international peer-reviewing. Preprint eprints can make claims for documenting priority of ideas as the author gets the copyright. Postprint eprints have a major role as digital archival enabling Open Access.

Another small cluster of C-ASS-Rs was in seven papers having 12 self-references of which one was in-press. Hence, in-press self-references can be taken as indicators of highly active period(s) of the researcher with focus in the nuclear science micro-domain.

H.J. Bhabha had referred to his paper 'Classical theory of mesons' (Bhabha, 1939a) maximum 16 number of times. So it is considered as classic paper (Price, 1986; Belew, 2000). First self-reference to this classic paper was in the same year (Bhabha, 1939b). Subsequently he continued to refer to this paper in his 11 consecutive papers (Bhabha, 1940a, 1940b, 1940c, 1941a, 1941b, 1941c, 1941d; Bhabha and Corben, 1941; Bhabha and Madhava Rao, 1941; Bhabha, 1941–1942; Bhabha and Basu, 1942); followed by four other papers (Bhabha and Harish-Chandra, 1944, 1946; Bhabha, 1950, 1953), which were published within a span of 15 years from 1939 to 1953. This shows his consistency in pursuing research in the domain of mesons. The nomenclature 'meson' itself is due to Bhabha, Kemmer and Pryce as stated in the Preface (Sreekantan et al., 1985). Dieks and Slooten (1986) commented that when a paper can be regarded as a pioneering work in a certain discipline, the citation scores are determined more by the dynamics of the relevant scientific disciplines than by the ageing of the papers.

After India's independence in 1947, Pandit Jawaharlal Nehru became the first Prime Minister of India and entrusted H.J. Bhabha with the responsibilities of building R&D facilities in atomic research for peaceful purposes. This involved Bhabha more in administrative activities. Hence, he had very few publications and self-references after 1947.

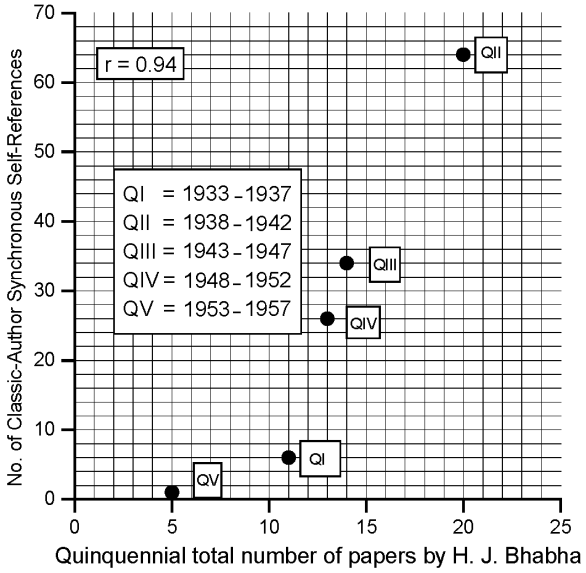
The vast literature on citation ageing covers items such as research front specialities, information life-expectancy, obliteration, delayed recognition, longevity and life-time citation, and also citation induced differences by discipline, type and quality of the

publication, and socio – historical aspects of the community's stratification (Vlachy, 1985).

4.5 Quinquennial publication productivity in relation to self-references

The quinquennial publication productivity of H.J. Bhabha was correlated with his corresponding quinquennial Classic-Author Synchronous Self-References (Figure 7), which revealed high positive correlation ($r = 0.94$).

Figure 7 Correlation of quinquennial publication productivity of H.J. Bhabha with his Classic-Author Synchronous Self-References



Only high publication productive authors can have expertise and high self-references. So publication productivity is an independent variable and self-references are dependent variables in publication productivity. Expertise is directly related to self-references. The publication productivity reference curve (Kalyane et al., 2001a) of a role model researcher may be parallel and followed by Synchronous Self-References as an indication of continuity of the research, which needs to be explored.

In addition to these self-references analyses documented in present study, it is contextual to note that H.J. Bhabha is being cited by Others even now, which is the direct indicator of the relevance of his research. The study (Swarna et al., 2004) documenting 427 records to his credit retrieved from *Science Citation Index* (1982–2002) found that a majority of the non-indexed eponymal citedness (NIEC) belonged to the eponyms: Bhabha scattering (290), angle Bhabha scattering (42), small angle Bhabha scattering (21), radiative Bhabha scattering (17), large-angle Bhabha scattering (16), resonant Bhabha scattering (12), and low-angle Bhabha scattering process (10).

5 Conclusions

A scientist continues progress in his research activity by building on his/her own previous research and research by his contemporaries. H.J. Bhabha focused his research activity on nuclear science.

Self-references are an indication of expertise in the field. In the present context, Classic-Author Synchronous Self-References (C-ASS-R) should be viewed as building-blocks in the recurrent and cumulative process of self-learning and in the mechanism of generating new knowledge. The C-ASS-R rate of H.J. Bhabha was 22.2%. There was positive but low correlation ($r = 0.27$) between C-ASS-R and references to Others. Positive correlation was obtained as the number of authors per host paper increased from two to four for: average Classic-Author Synchronous Self-References; average synchronous references to Others; and average references per paper.

Recency (50% of the latest references) in references is an indicator of mainstream and frontier leadership in the domain. Recency in the papers of H.J. Bhabha was one year for C-ASS-R and three years for references to Others. Temporal self-references network depicts the thought content connectedness of the documents. High positive correlation ($r = 0.94$) was observed for quinquennial publication productivity vs. corresponding quinquennial C-ASS-Rs.

The two clusters of 12 papers each had concentrations of C-ASS-Rs (46 and 33) associated with the in-press self-references and were indicators of the periods of high focus and creativity (during 1939–1942 and 1945–1949) in generating new scientific knowledge at a faster rate than before-and-after the episodes at an individual scientist micro-level. On a temporal scale, scientific discoveries often occur in a relatively short period of time since an important breakthrough in an idea or an appropriate new facility makes new advancements possible. This period where the research career of an individual scientist seems to be the most productive for knowledge-generating activity needs attention for further research in human resource harnessing.

Hence, administrators of science should identify such scientists and institutions at the Nurturing Phase (Mabe and Amin, 2002) for providing appropriate facilities required for their advancements.

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