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Bibliometric profile of top-cited single-author articles in the Science Citation Index Expanded

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ABSTRACT

In this study, we identified and analyzed characteristics of top-cited single-author articles published in the Science Citation Index Expanded from 1991 to 2010. A top-cited single-author article was defined as an article that had been cited at least 1000 times from the time of its publication to 2012. Results showed that 1760 top-cited single-author articles were published in 539 journals listed in 130 Web of Science categories between 1901 and 2010. The top productive journal was *Science* and the most productive category was multidisciplinary physics. Most of the articles were not published in high-impact journals. Harvard University led all other institutions in publishing top-cited single-author articles. Nobel Prize winners contributed 7.0% of articles. In total, 72 Nobel Prize winners published 124 single-author articles. Single-authored papers published in different periods exhibited different patterns of citation trends. However, top-cited articles consistently showed repetitive peaks regardless of the time period of publication. "Theory (or theories)" was the most frequently appeared title word of all time. Leading title words varied at different time periods, and only five title words, method(s), protein(s), structure(s), molecular, and quantum consistently remained in the top 20 in different time periods.

1. Introduction

Completion of a research paper requires time and hard work. Hence, a single-author paper demands tremendous efforts from an individual, and is less common than multiple-author papers. Papers with multiple authors may have the advantage of higher citation rates compared to single-authored papers (Abt, 1984), but may take longer as far as the speed of refereeing is concerned (Hartley, 2005). Although in some areas of research, such as linguistics, single-authored papers were more common than multiple authored papers (Ezema & Asogwa, 2014), as research has become more complex, requiring a variety of expertise, coupled with globalization of research collaboration and publishing, the average number of authors per paper has increased (Li, Ding, Feng, Wang, & Ho, 2009; Xie, Zhang, & Ho, 2008). The frequency of single-authored papers is diminishing (Sampson, 1995), but it was speculated that there would always be single-authored papers, and the frequency may never reach zero (Abt, 2007).

The percentage of single-authored research papers among highly cited publications is also quite small. For instance, the average number of authors per Essential Science Indicators (ESI) papers in chemical engineering was 3.6, and only 13% of the papers were single-author papers (Chuang, Wang, & Ho, 2013). The percentage is higher among review papers. It was

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found that 33% of highly cited reviews in the Science Citation Index Expanded (SCI-EXPANDED) were single-author reviews (Ho & Kahn, 2014).

Conventionally, in a multiple-author paper, every author makes an independent material contribution to the manuscript (Coats, 2009). The identity and order of authors provide information about who deserves credit for the work and who is accountable for its integrity (Rennie & Flanagin, 1994; Savitz, 1999). However, unethical authorship practices, including ghost authorship and gift authorship, are also common in academia (Martinson, Anderson, & de Vries, 2005; Smith & Boulanger, 2011). Gift or honorary authorship is defined as inclusion of an individual as an author who did not adequately contribute to a project (Bennett & Taylor, 2003; Singh, 2009). However, honorary authorship is regarded as a minor digression, even though honorary or gift authorship is unacceptable to the Lancet (2008). While the increase in numbers of authors per article has tended to dilute accountability, it scarcely seems to have diminished credit (Rennie, Yank, & Emanuel, 1997). Previous research indicated that the number of equally credited authors' articles tended to significantly increase yearly in four major anesthesiology journals, and the first two authors in the byline received equal credit in most cases (Tao, Bo, Wang, Li, & Deng, 2012). The percentage of articles with more than one corresponding author or with several authors that contributed equally, leading to so-called "equal first authors;" has also been on the rise (Hu, 2009). Due to the practice of explicitly giving authors equal credit is increasingly common in original research publications, and it was recommended that the potential impact of this practice on evaluations for academic promotion be assessed (Akhabue & Lautenbach, 2010), and guidelines for assigning "equal" authorship be established (Wang, Tang, Bo, Li, & Deng, 2012). With the increasing number of authors and increasing occurrence of "equal contributions", a single-author paper is often looked upon as the gold standard and as a strong testament of an individual's efforts.

One way to identify the impact of an author or article in the research world is to analyze citations in the SCI-EXPANDED (Cawkell & Garfield, 1980). The number of citations received by an article reflects its scientific impact (Gisvold, 1999), and also provides an objective methodology for ranking articles (Picknett & Davis, 1999). Top-cited articles are used to recognize scientific advancement and give a historic perspective on scientific progress (Baltussen & Kindler, 2004; Ohba, Nakao, Isashiki, & Ohba, 2007). A top-cited single-author paper is an outstanding scientific achievement for a researcher.

The purpose of this paper is to present a bibilometric analysis of top-cited single-authored papers. Top-cited single-author articles in SCI-EXPANDED were analyzed in terms of authors and institution affiliations. Four indicators of total citations, citations in the publication year, citations in recent years, and total citations per year are also presented.

2. Methodology

This is a retrospective study using secondary data analysis. Bibliometric information of documents was retrieved from the SCI-EXPANDED of the Web of Science of Thomson Reuters. The SCI-EXPANDED index includes 8471 journals with citation references across 174 scientific disciplines, according to Journal Citation Reports (JCR) of 2012. As of January 22, 2014, a total of 27,878,725 articles, published from 1900 to 2012, were included in the index. For the purpose of this research, a top-cited article was defined as one with at least 1000 citations from Web of Science Core Collection by the end of 2012. Out of 27,878,725 articles, only 8865 qualified as top-cited articles. Among the 8865 top-cited articles, 1760 were single-author articles, and hence, were included in the subsequent analysis.

The annual citation frequency for each top-cited article was collected. The number of citations from Web of Science Core Collection in its first year of article life, i.e., in its publication year, was defined as *C0* (Ho & Kahn, 2014); *C2012* is the number of citations from Web of Science Core Collection in the year 2012 (Ho, 2012); *TC2012* is the total number of times from Web of Science Core Collection article cited from publication to 2012 (Chuang, Wang, & Ho, 2011; Wang, Li, & Ho, 2011); and *TCPY* is the total citations from Web of Science Core Collection per year (Ho, 2012). Records were downloaded into spreadsheet software, and additional coding was manually performed using Microsoft Excel 2007 to obtain frequency distributions and percentages. Articles originating from England, Scotland, Northern Ireland, and Wales were reclassified as being from the United Kingdom (UK) (Chiu & Ho, 2005). Affiliations in the Federal Republic of Germany (Fed Rep Ger), Bundes Republik, and Germany were reclassified as being from Germany (Ho, 2012). The USSR and Russia were reclassified as being from Russia (Ho, 2012). Acad. Sci. USSR was also reclassified as being the Russian Academy of Sciences. Affiliations in Holland, Netherlands, and the Netherlands were reclassified as being from the Netherlands. In addition, articles from the Univ. Calif. were reclassified as being from either the Univ. Calif. Los Angeles, Univ. Calif. Berkeley, or Univ. Calif. Davis. Univ. Calif. Lawrence Livermore Natl. Lab and Lawrence Livermore Natl. Lab were reclassified as being Lawrence Livermore Natl. Lab. The impact factor (*IF2012*) of a journal was determined for each document as reported in the JCR 2012.

3. Results and discussion

Of the 1760 top-cited single-author articles published in SCI-EXPANDED from 1901 to 2010 with a *TC2012* of $\geq$1000, 98% (1726 articles) were published in English followed by 1.6% (29) in German, and 0.28% (5) in French. Fig. 1 shows the worldwide distribution of these articles. North America and Western Europe were the main areas that produced top-cited single-author articles. Southeast Asia, the Middle East, Africa, and Eastern Europe had few single-author top-cited articles. This pattern was similar to previous finding regarding highly cited research work in the SCI-EXPANDED (Ho, 2013).

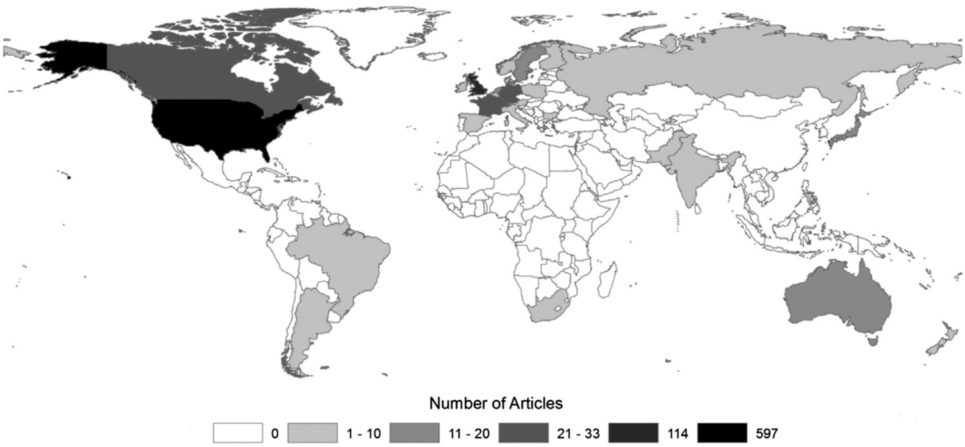

Fig. 1. Distribution of top-cited single-author articles in the world.

3.1. Journals and Web of Science categories

Articles were published in 539 journals and in 130 Web of Science subject categories in the science edition. Of these 539 journals, 302 (56%) journals contained only one top-cited single-author article; 94 (17%) journals contained two articles; and 42 (7.8%) journals contained three articles. Table 1 shows the top 10 leading journals, which accounted for 28% of the top-cited single-author articles. *Science* published the most articles with 103 articles (5.9% of 1760 articles), followed by *Physical Review* with 83 articles (4.7%), *Journal of Chemical Physics* with 73 articles (4.1%), and *Nature* with 47 articles (2.7%). Earlier research indicated that leading journals attracted the most-cited publications, which in turn helped maintain the high impact factors of those journals (Schein & Fingerhut, 2000). However, research also showed that there was no correlation between the journal impact factor and the citation frequency of the article in question (Walter, Bloch, Hunt, & Fisher, 2003). Consistent with previous findings, top-cited single-author articles were published in both high- and low-impact journals. Nevertheless, journals with high impact factors were more likely to publish more top-cited articles. Journals with the highest impact factor were *New England Journal of Medicine* with 11 articles (*IF2012* = 51.658), followed by *Reviews of Modern Physics* with 10 articles (*IF2012* = 44.982), *Lancet* with five articles (*IF2012* = 39.060), *Nature* with 47 articles (*IF2012* = 38.597), *Advances in Physics* with four articles (*IF2012* = 34.294), *Cell* with four articles (*IF2012* = 31.957), *Science* with 103 articles (*IF2012* = 31.027), and *Physiological Reviews* with nine article (*IF2012* = 30.174). However, articles were also found in journals with lower impact factors, such as *Theoretical Computer Science* with *IF2012* = 0.489 in the category of theory and methods of computer science; *Communications in Soil Science and Plant Analysis* with an *IF2012* of 0.420 in the categories of agronomy, plant sciences, analytical chemistry, and soil science; *Indiana University Mathematics Journal* with an *IF2012* of 0.416 in the category of mathematics; *Ferroelectrics* with an *IF2012* of 0.415 in the categories of multidisciplinary materials science, physics, and

Table 1
Characteristics of the top ten journals with the top-cited single-author articles.

Journal	*IF2012*	Rank	*TP* (%)	Web of Science category (journal rank in categories)
Science	31.027	20	103 (5.9)	Multidisciplinary sciences (2/56)
Physical Review	N/A	N/A	83 (4.7)	Multidisciplinary physics
Journal of Chemical Physics	3.164	1393	73 (4.1)	Atomic, molecular, and chemical physics (8/34)
Nature	38.597	7	47 (2.7)	Multidisciplinary sciences (1/56)
Physical Review Letters	7.943	230	40 (2.3)	Multidisciplinary physics (5/83)
Journal of Biological Chemistry	4.651	648	33 (1.9)	Biochemistry and molecular biology (62/290)
Journal of the American Chemical Society	10.677	142	28 (1.6)	Multidisciplinary chemistry (11/152)
Psychological Review	9.797	163	28 (1.6)	Psychology (4/75)
Biochemical Journal	4.654	645	27 (1.5)	Biochemistry and molecular biology (61/290)
Proceedings of the National Academy of Sciences of the United States of America	9.737	168	21 (1.2)	Multidisciplinary sciences (4/56)

Rank, rank of impact factor in 8471 journals in the JCR in 2012; *TP*, total number of top-cited single-author articles; *IF2012*, impact factor in 2012; N/A, not available, Physical Review was not listed in Web of Science after 1969.

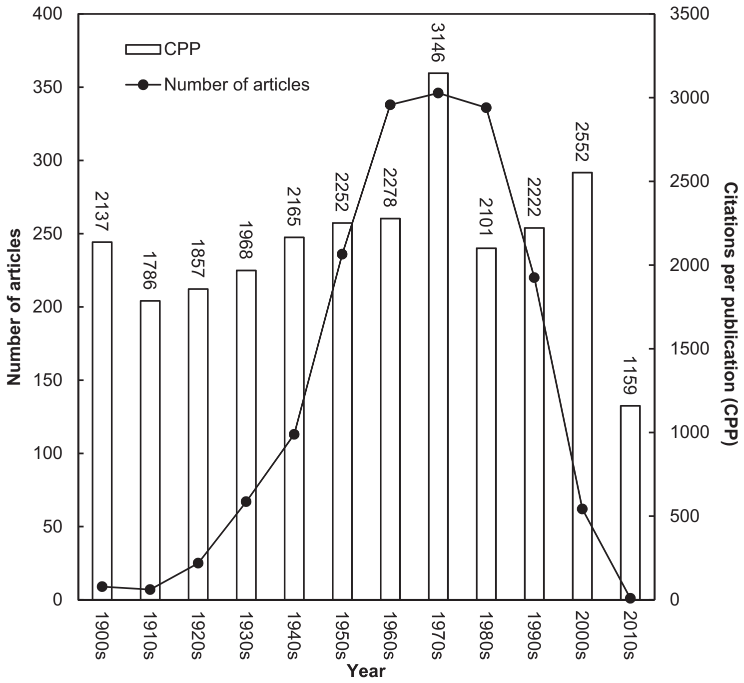

Fig. 2. Number of the top-cited single-author article and citation per articles by decade.

condensed matter; *Food Technology* with an *IF2012* of 0.363 in categories of food science and technology; and *Annales de Chimie France* with an *IF2012* of 0.0960 in the category of multidisciplinary chemistry.

Articles were distributed across 130 categories, based on the Web of Science categories in the JCR science edition in 2012. Among them, 63 categories (48% of 130 categories) contained one to five top-cited single-author articles, 19 categories (15%) contained six to ten articles, 26 categories (20%) contained 11–30 articles, and 22 categories (17%) contained more than 30 articles. The leading 22 categories contained 77% of all articles. The category of multidisciplinary physics had 243 articles (14% of 1758 articles), followed by multidisciplinary sciences (13%), biochemistry and molecular biology (10%), atomic, molecular and chemical physics (4.9%), statistics and probability (4.3%), multidisciplinary chemistry (3.7%), biology (3.5%), electrical and electronic engineering (3.3%), ecology (3.1%), and psychology (3.1%).

3.2. Effect of time on the citation analysis

The earliest top-cited single-author articles were "On the question of speed of growth and dissolution of crystal surfaces" (Wulff, 1901) in *Zeitschrift für Krystallographie und Mineralogie* and "On lines and planes of closest fit to systems of points in space" (Pearson, 1901) in *Philosophical Magazine*. The most recent one was "*publCIF*: Software for editing, validating and formatting crystallographic information files" (Westrip, 2010) in the *Journal of Applied Crystallography*. Fig. 2 shows the number of top-cited single-author articles and citations per publication (CPP) by decade. It shows an increasing trend prior to the 1960s but a decreasing trend after the 1980s. Recent decades did not have as many single-author top-cited articles since there may not have been sufficient time to accumulate 1000 citations. No top-cited single-author articles have yet emerged in the most recent three years (2010–2012). Similar results of a lack of recent classic articles were also found for top-cited articles in chemical engineering in the SCI-EXPANDED (Ho, 2012). The highest *CPP* was in the 1970s, at 3146, much higher than in other decades. Five of the top ten most-often cited single-author articles were published in the 1970s: Laemmli (1970) ranked 1st with a *TC2012* of 207,869; Bradford (1976) ranked 2nd with a *TC2012* of 145,031; Southern (1975) ranked 4th with a *TC2012* of 31,799; Cox (1972) ranked 6th with a *TC2012* of 26,921; and Shannon (1976) ranked 7th with a *TC2012* of 24,997. The figure also showed that the 1960s, 1970s, and 1980s were clearly the most productive decades. Among 1760 articles, 58% were published in this period, an indication that 20 years may be needed to accumulate 1000 citations. Moreover, the three decades may have produced a greater number of significant scientific advances and discoveries compared to earlier decades.

Fig. 3 shows the average annual citations per publication relative to article life for articles published in three different time periods: the 1900–1950s, 1960–1980s, and 1990–2010s. The three time periods showed distinctive patterns. Articles published in the 1900–1950s showed a gradual and steady increase in annual citations. No distinctive peak year was observed. This parameter seemed to reach a temporary peak, to slow down for a few years, and then to reach a higher peak. The sample size decreased as the article life reached ≥80 years, as did fluctuations in annual citations. Nevertheless, it continued

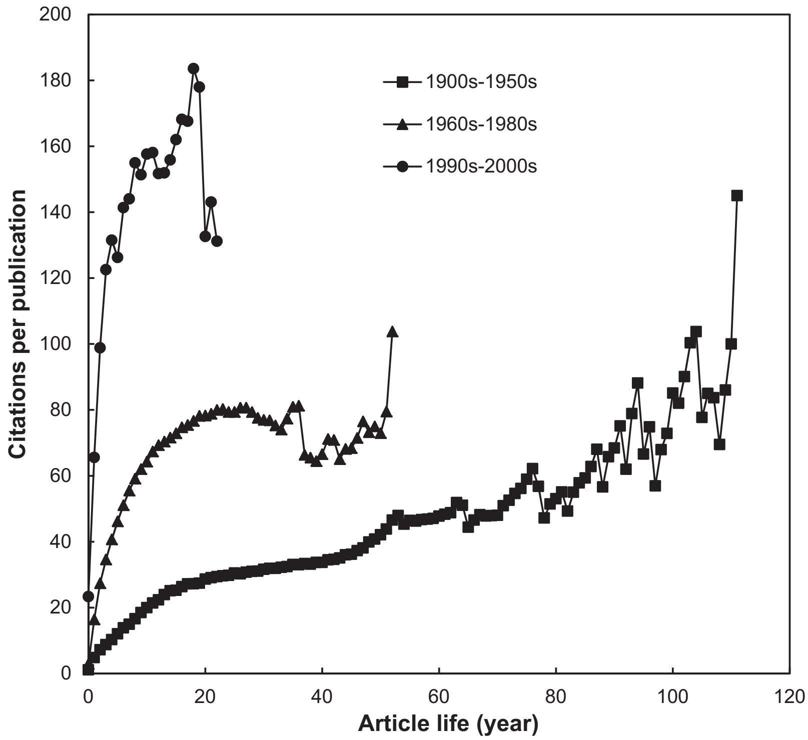

Fig. 3. Average annual citations of articles published in three different time periods.

to trend upwards even after 100 years of article life, indicating that there were a few "classic" articles that still received a high number of citations each year. Articles published in the 1960–1980s showed a much-higher rate of increase compared to those published before 1960. This parameter reached a peak at around 25 years, then trended downward. It did show another upward trend after 40 years, similar to articles published in a earlier decades. The sample size was small for those with an article life of ≥40 years. For articles published after 1900, it had a much higher rate of increase in citations, showing a peak at around 15 years, and then another peak at 20 years. From Fig. 3, it is apparent that annual citations relative to article life exhibited distinctive patterns for articles published in different periods. Earlier articles seemed to show a slower rate of increase. However, what appeared to be common among the three trends was a pattern of repetitive peaks. Once a peak was reached, it trended down for a few years, then trended upwards again to a higher peak.

3.3. Publication performances: countries, institutions, and authors

Among the 1760 top-cited single-author articles, 929 (53%) articles had author affiliation information in the Web of Science, and were analyzed for publications by country and institution. These articles were published by 452 institutions in 29 countries. Eleven countries published only one article, and six countries published two to nine articles. The US was the most productive country with 597 top-cited single-author articles (64% of 929 articles) followed by the UK with 114 articles, Canada (33 articles), Germany (31), France (28), Switzerland (25), Sweden (19), Japan (18), Australia (14), Netherlands (14), Israel (11), and Russia (10).

Table 2 shows that the top 16 institutions published at least ten top-cited single-author articles, ranked according to the total number of articles. Among the top 16 institutions, 14 (88%) of them were US institutions. Harvard University ranked 1st with 41 articles by 37 authors, followed by Stanford University with 27 articles by 23 authors, University California Berkeley with 21 articles by 15 authors, and Princeton University with 20 papers by 13 authors. The two non-US institutions were the University of Cambridge and University of Oxford in the UK, respectively ranked in 8th and 13th. IBM and Bell Telephone Laboratories were the only two non-academic institutions. Although the institutions in Table 2 were leaders in publishing top-cited single author articles, none of the top ten articles with the highest *TC2012* was published by them. The highest *TC2012* from the leading institutions was 18,723, ranked 12th, and was published by Felsenstein in 1985 from the University of Washington. Non-academic institutions also published some of the leading papers. For example, from DuPont of the US, Shannon (1976) published the 7th ranked article, "Revised effective ionic radii and systematic studies of interatomic distances in halides and chalcogenides" with a *TC2012* of 24,997 and from NEC of Japan, Iijima (1991) published the 10th ranked article, "Helical microtubules of graphitic carbon" with a *TC2012* of 20,027.

Table 2
The top 16 productive institutions with a total number of top-cited single-author articles (*TP*) of ≥ 10.

Institution	*TP*	*TP R* (%)	*AU*	Author* (*HP*)	*RC* (*HTC*)
Harvard University, USA	41	1 (4.4)	37	Weinberg, S (3)	41 (7889)
Stanford University, USA	27	2 (2.9)	23	Andersen, HC; Donoho, DL; Choi, DW; Susskind, L (2)	36 (9218)
University of California Berkeley, USA	21	3 (2.3)	15	Slatkin, M; Zadeh, LA (3)	61 (6127)
Princeton University, USA	20	4 (2.2)	13	Witten, E (6)	96 (5169)
Massachusetts Institute of Technology (MIT), USA	19	5 (2.0)	18	Brooks, RA (2)	92 (5277)
University of Chicago, USA	19	5 (2.0)	17	Wright, S; Lande, R (2)	70 (5883)
Cornell University, USA	14	7 (1.5)	13	Kirkwood, JG (2)	252 (3030)
University of Cambridge, UK	14	7 (1.5)	12	Hawking, SW (3)	135 (4294)
University of Washington, USA	14	7 (1.5)	11	Felsenstein, J (4)	12 (18,723)
Yale University, USA	14	7 (1.5)	12	Onsager, L (3)	123 (4554)
IBM Corporate, USA	12	11 (1.3)	12	–	269 (2936)
California Institute of Technology (Caltech), USA	11	12 (1.2)	10	Hopfield, JJ (2)	63 (6053)
Columbia University, USA	11	12 (1.2)	9	Hotelling, H; Avrami, M (2)	72 (5848)
University of California Los Angeles, USA	11	12 (1.2)	10	Depaolo, DJ (2)	77 (5700)
Bell Telephone Laboratories Inc., USA	10	15 (1.1)	8	Hopfield, JJ; Brus, LE (2)	63 (6053)
University of Oxford, UK	10	15 (1.1)	10	–	225 (3206)

R, rank among all institutions; * author who published the most top-cited single-author articles in an institution; *AU*, number of authors in an institution; *HP*, the highest number of most top-cited single-author articles; *RC*, rank in terms of *TC2012*; *HTC*, the highest *TC2012* in an institution; -, all authors published only one top-cited single-author article.

Several authors had published more than one single-author articles. Of the 1760 top-cited single-author articles in SCI-EXPANDED, there were 1460 authors. The percentages of authors who published one, two, three, and four top-cited single-author articles were 72%, 7.4%, 2.4%, and 0.85%, respectively. Only six (0.34% of 1760) authors published at least five top-cited single-author articles: E. Witten (11 articles), P.W. Anderson (10), A.D. Becke (seven), R.S. Mulliken (seven), L. Onsager (six), and P.A.M. Dirac (five). Four of the top six authors were Nobel Prize winners. P.W. Anderson at Bell Telephone Laboratories in the US received the Nobel Prize in physics in 1977 "for their fundamental theoretical investigations of the electronic structure of magnetic and disordered systems". R.S. Mulliken of the University of Chicago in the US received a Nobel Prize in chemistry in 1966 "for his fundamental work concerning chemical bonds and the electronic structure of molecules by the molecular orbital method". L. Onsager at Yale University in the US received a Nobel Prize in chemistry in 1968 "for the discovery of the reciprocal relations bearing his name, which are fundamental for the thermodynamics of irreversible processes". P.A.M. Dirac at the University of Cambridge in the UK received a Nobel Prize in physics in 1933 "for the discovery of new productive forms of atomic theory". In total, 4.9% of 1460 authors, who published 7.0% of the 1760 top-cited single-author articles, were Nobel Prize winners: 28 authors in physics, 23 authors in chemistry, and 21 authors in physiology or medicine. The high percentage of Nobel Prize winners was consistent with findings from previous research, in which among the top 0.1% of authors, a significant percentage had won the Nobel Prize or went on to win the prize in later years (Garfield & Welljamsdorof, 1992). A high correlation between bibliometric indicators and the number of Nobel Prize achievements was also observed in chemistry, medicine/physiology, and physics (Rodríguez-Navarro, 2011).

3.4. Leading articles

Table 3 shows the ten articles with a *TC2012* of >20,000. Both citation numbers and rankings for the *TC2012*, *C2012*, and *C0* are displayed. The article "Cleavage of structural proteins during the assembly of the head of bacteriophage T4", by U.K. Laemmli (1970) from the MRC Laboratory of Molecular Biology in the UK, had the highest *TC2012* of 207,869. This article was the only single-author article that was cited more than 200,000 times. Several leading articles still had high rankings in *C2012*, indicating that these articles continued to receive a high number of citations in 2012. Six of the top ten articles still had a *C2012* ranked in the top 10. Not all top-cited single-author articles continued to have high citations in 2012. Among them, 1.5% had no citations (*C2012* = 0), 0.91% articles had one citation, and 0.74% articles had two citations.

Of these ten articles, seven were published before the 1980s, and three were published after the 1980s. The earliest article with more than 20,000 citations was published in 1949, while the most recent one was published in 2008. Eight of the 10 articles were published in journals with an *IF2012* of <5, ranging 2.244–4.810. None of them was published in a journal with a high impact factor. The correlation between the journal impact factor and single-author articles with more than 20,000 citations seemed small. The indicator of average citations per year (*TCPY*) was applied to evaluate top-cited single-author

Table 3
The ten most frequently cited single-author articles in the SCI-EXPANDED (total number of citations by 2012 since publication (*TC2012*) > 20,000).

Rank (*TC2012*)	Rank (*C2012*)	Rank (*C0*)	Peak year (%)	Rank (*TCPY*)	Article information
1 (207,869)	4 (3277)	253 (4)	22 (52)	2 (4834)	Laemmli, U.K. (1970). Cleavage of structural proteins during the assembly of the head of bacteriophage T4. *Nature*, **227** (5259), 680–685
2 (145,031)	1 (6314)	895 (0)	36 (100)	3 (3920)	Bradford, M.M. (1976). Rapid and sensitive method for quantitation of microgram quantities of protein utilizing principle of protein-dye binding. *Analytical Biochemistry*, **72** (1–2), 248–254
3 (38,694)	3 (4358)	322 (3)	19 (100)	4 (1935)	Becke, A.D. (1993). Density-functional thermochemistry. III. The role of exact exchange. *Journal of Chemical Physics*, **98** (7), 5648–5652
4 (31,799)	793 (68)	583 (1)	12(32)	8 (837)	Southern, E.M. (1975). Detection of specific sequences among DNA fragments separated by gel electrophoresis. *Journal of Molecular Biology*, **98** (3), 503–517
5 (29,574)	2 (5065)	1 (3521)	3 (75)	1 (5915)	Sheldrick, G.M. (2008), A short history of SHELX. *Acta Crystallographica Section A*, **64** (1), 112–122.
6 (26,921)	18 (974)	895 (0)	27 (68)	14 (657)	Cox, D.R. (1972), Regression models and life-tables. *Journal of the Royal Statistical Society Series B-Statistical Methodology*, **34** (2), 187–220
7 (24,997)	6 (1824)	895 (0)	36 (100)	11 (676)	Shannon, R.D. (1976), Revised effective ionic radii and systematic studies of interatomic distances in halides and chalcogenides. *Acta Crystallographica Section A*, **32**, 751–767
8 (23,284)	617 (89)	895 (0)	37 (59)	27 (364)	Scatchard, G. (1949). The attractions of proteins for small molecules and ions. *Annals of the New York Academy of Sciences*, **51** (4), 660–672
9 (21,975)	752 (73)	895 (0)	12 (25)	21 (448)	Davis, B.J. (1964). Disk electrophoresis. II. Method and application to human serum proteins. *Annals of the New York Academy of Sciences*, **121**, 404–427
10 (20,027)	7 (1806)	895 (0)	20 (95)	7 (910)	Iijima, S. (1991), Helical microtubules of graphitic carbon. *Nature*, **354** (6348), 56–58

C2012, number of citations in 2012; *C0*, number of citations in the publication year; *TCPY*, average citations per year.

articles. The article entitled "A short history of SHELX" (Sheldrick, 2008) had the highest *TCPY* of 5915. Similarly, six of the top 10 articles also had a *TCPY* in the top 10.

Most of the top ten articles did not have a high *C0* ranking. Six of them received no citations in the first year. It was reported that articles are not always highly cited immediately after publication (Fu, Wang, & Ho, 2012). Of all top-cited single-author articles, 48% had no citations, 18% articles had one citation, and 10% articles had two citations during the year of publication. Only 9% and 7% of the top 100 articles in terms of the *C0* were found in the top 100 articles in terms of *C2012* and *TC2012*, respectively; and 4% of the top 100 articles in terms of *C0* were found in the top 100 articles in both *C2012* and *TC2012*. The time of publication appeared to be correlated to the value of *C0* among the top 10 articles in Table 3. Those articles published after 1990 tended to have a higher *C0* value. The advancement in scientific publishing, more journals, and quicker dissemination of information may have led to the higher *C0* values. In addition, references cited in a paper were also found to have increased in recent years (Xie et al., 2008). As more papers are being published, there are more opportunities to be cited. Nevertheless, to evaluate the citation impact of an article, one should consider a longer time span than just the first few years.

The article lifespan demonstrates the influence of the article on scientific research. The citation life cycle of an article describes the history of the impact of that article. The citation lives of the top 17 single-author articles (*TC2012* > 15,000) are shown in Figs. 4–6. Articles with the highest *TC2012* can be considered the most popular articles in a research field (Fu et al., 2012). Eleven of the 17 articles were published before the 1980s, while two were published in the 1980s, three in the 1990s, and one in 2008. The article by Laemmli (1970) was top ranked in annual citations among single-author articles from 1977 to 2002 (Fig. 4) followed by the article entitled "Rapid and sensitive method for quantitation of microgram quantities of protein utilizing principle of protein-dye binding" (Bradford, 1976) from 2003 to 2007 and the article entitled "A short history of SHELX" (Sheldrick, 2008) from 2008 to 2011. Finally, the article by Bradford (1976) was again ranked tops in 2012. Becke's article published in 1993, with a *TC2012* of 38,694 and *C2012* of 4358, respectively both ranked 3rd among 1760

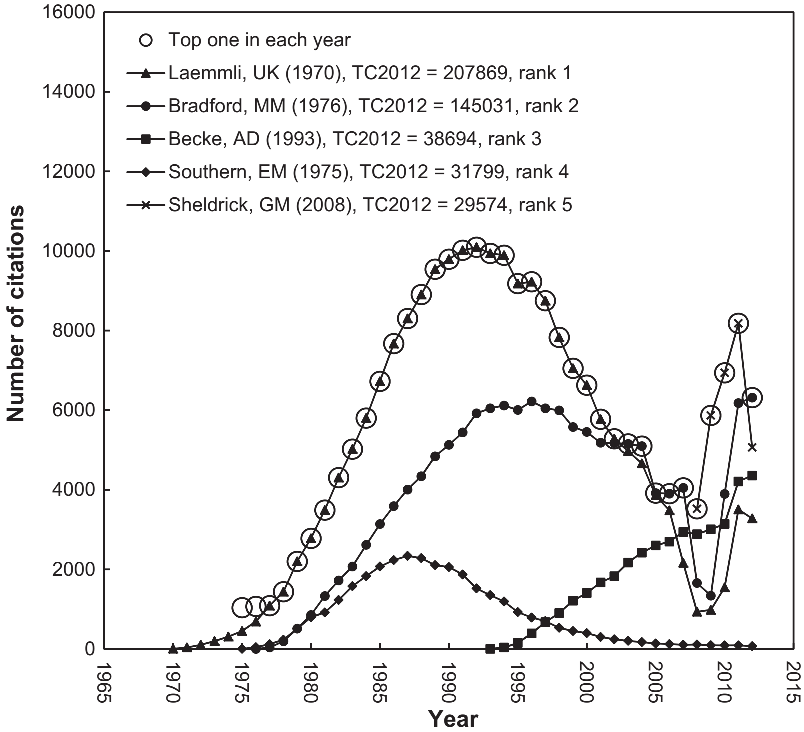

Fig. 4. Citation life cycles of the top five single-author articles (total number of citations by 2012 since publication (*TC2012*) > 15,000).

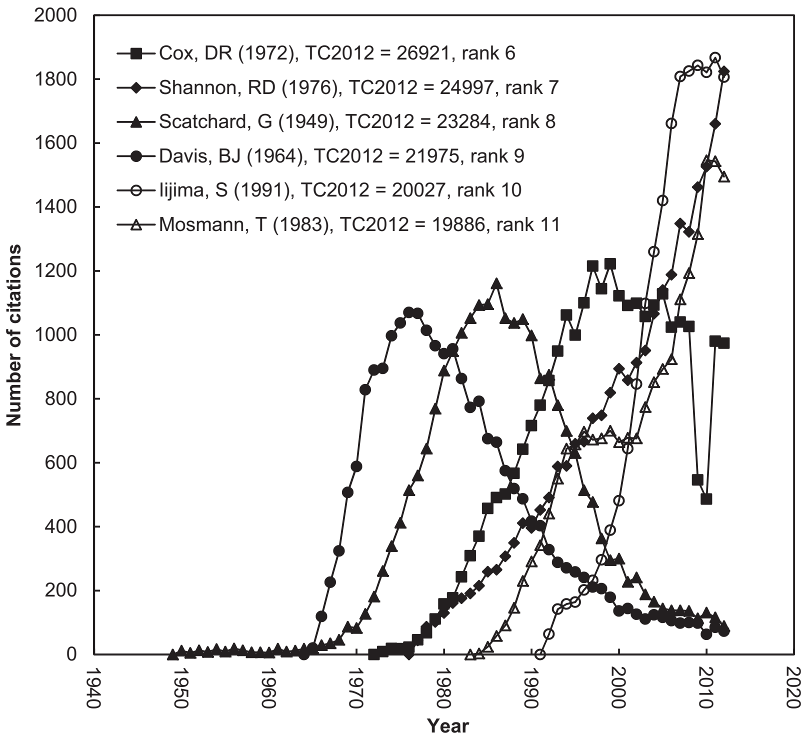

Fig. 5. Citation life cycles of the top 6–11 single-author articles (total number of citations by 2012 since publication (*TC2012*) > 15,000).

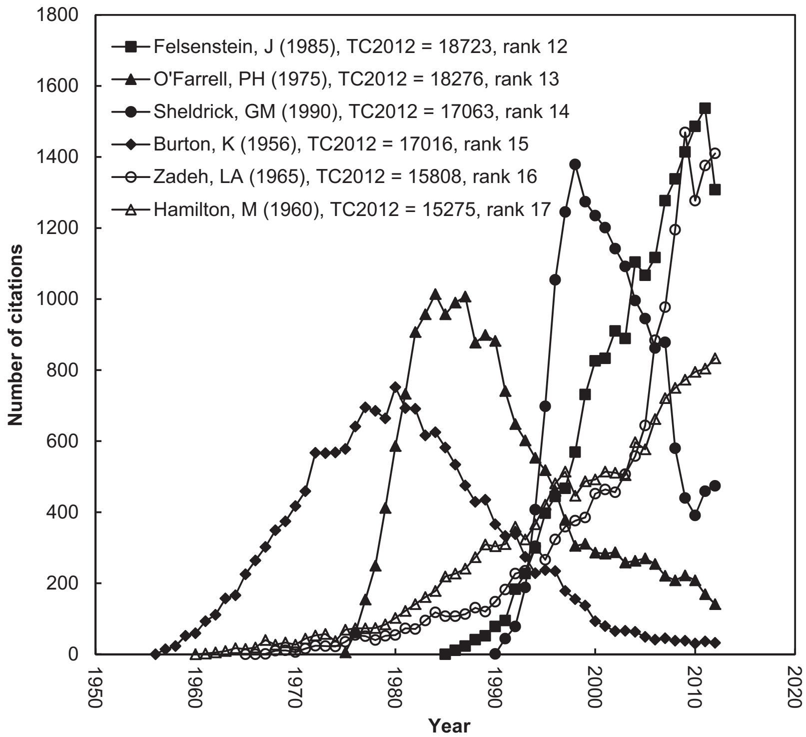

Fig. 6. Citation life cycles of the top 12–17 single-author articles (total number of citations by 2012 since publication (*TC2012*) > 15,000).

articles. A sharply increasing trend of citations was found after its publication to 2012. In general, two patterns of article life were observed. Articles published after the 1980s showed a continually increasing trend in all years since publication, while articles published before the 1980s had citation rates that initially climbed to a peak and then decreased. However, there were some exceptions. An article by Shannon (1976), entitled "Revised effective ionic radii and systematic studies of interatomic distances in halides and chalcogenides", still maintained a sharply increasing trend. An article by Sheldrick

Table 4
Overall rankings of title words and their respective rankings in the periods of 1900–1950s, 1960–1980s, and 1990–2010s.

Words in title	*TP*	1900–2010s Rank (%)	1900–1950s Rank (%)	1960–1980s Rank (%)	1990–2010s Rank (%)
Theory(ies)	133	1 (7.6)	1 (15)	2 (6.2)	22 (0.71)
Method(s)	106	2 (6.0)	3 (5.3)	1 (7.0)	3 (3.9)
Model(s)	69	3 (3.9)	22 (2.2)	3 (4.4)	1 (4.9)
Determination(s)	60	4 (3.4)	2 (6.6)	6 (2.6)	34 (1.1)
Protein(s)	56	5 (3.2)	15 (2.6)	4 (3.6)	7 (2.5)
System(s)	53	6 (3.0)	10 (2.0)	5 (3.3)	22 (0.71)
Structure(s)	50	7 (2.8)	7 (3.5)	7 (2.5)	5 (3.2)
Molecular	42	8 (2.4)	10 (3.3)	14 (1.7)	4 (3.5)
Quantum	42	8 (2.4)	15 (2.6)	14 (1.7)	2 (4.6)
Acid(s)	38	10 (2.2)	4 (4.8)	21 (0.78)	204 (0.35)
Cell(s)	36	11 (2.0)	49 (0.88)	7 (2.5)	14 (1.8)
Effect(s)	36	11 (2.0)	35 (0.88)	9 (2.3)	9 (2.1)
Solution(s)	36	11 (2.0)	6 (3.7)	18 (0.88)	34 (0.71)
Function(s)	35	14 (2.0)	20 (1.3)	11 (2.0)	22 (0.71)
Interaction(s)	34	15 (1.9)	22 (1.8)	10 (2.2)	77 (0.71)
Electron(s)	32	16 (1.8)	7 (3.5)	24 (1.4)	77 (0.71)
Properties	32	16 (1.8)	14 (2.8)	12 (1.9)	N/A
Reaction(s)	32	16 (1.8)	4 (4.8)	31 (0.69)	N/A
Human(s)	31	19 (1.8)	26 (1.5)	12 (1.9)	34 (1.1)
Estimation(s)	28	20 (1.6)	26 (1.8)	14 (1.7)	34 (1.1)
Crystal(s)	26	21 (1.5)	13 (3.1)	45 (0.59)	22 (1.1)
Field(s)	25	22 (1.4)	35 (0.88)	18 (1.6)	77 (0.71)
Population(s)	25	22 (1.4)	7 (3.5)	72 (0.49)	34 (0.71)
Problem(s)	25	22 (1.4)	26 (0.88)	26 (0.69)	14 (1.8)
Molecule(s)	23	25 (1.3)	15 (2.6)	N/A	N/A

TP, top-cited single-author articles.

Table 5
Top 20 title words in the 1900–1950s.

1900–1950s words in title	*TP*	Rank (%)
Theory(ies)	67	1 (15)
Determination(s)	30	2 (6.6)
Method(s)	24	3 (5.3)
Acid(s)	22	4 (4.8)
Reaction(s)	22	4 (4.8)
Solution(s)	17	6 (3.7)
Structure(s)	16	7 (3.5)
Electron(s)	16	7 (3.5)
Population	16	7 (3.5)
Molecular	15	10 (3.3)
Metal(s)	15	10 (3.3)
Crystal(s)	14	12 (3.1)
Properties	13	13 (2.8)
Magnetic	12	14 (2.6)
Quantum	12	14 (2.6)
Protein(s)	12	14 (2.6)
Fluid(s)	12	14 (2.6)
Molecule(s)	12	14 (2.6)
General	11	19 (2.4)
Blood	10	20 (2.2)
Model(s)	10	20 (2.2)

TP, top-cited single-author articles.

(2008), "A short history of SHELX", had the sharpest increasing trend after publication but sharply decreased in recent years. Fig. 4 shows that it took about 20 years for the leading two articles, by Laemmli and by Bradford, respectively, to reach their citations peaks. Some articles reached a peak within a shorter time span, such as the article by Davis, shown in Fig. 5, which took only about 10 years. Overall, the time it took for an article to reach the citation peak varied among articles, ranging 10–30 years. While most articles reached a citation peak in the 2nd or 3rd year, top-cited articles showed outstanding staying power with prolonged article lives.

3.5. Leading title words

It is accepted that a statistical analysis of keywords and title-words can be used to identify directions in science (Garfield, 1990). Authors might choose their title words to attract a more-general or -particular audience (Peters & van Raan, 1994). Table 4 shows the most commonly used title words in 1900–2010, as well as their rankings in separate time frames of 1900–1959, 1960–1989, and 1990–2010. Nouns in the singular and plural forms were combined. Thus the top 10 title words overall were theory(ies), method(s), model(s), determination(s), protein(s), system(s), structure(s), molecular, quantum, and

Table 6
Top 20 title words in the 1960–1980s.

1960–1980s words in title	*TP*	Rank (%)
Method(s)	71	1 (7.0)
Theory(ies)	63	2 (6.2)
Model(s)	45	3 (4.4)
Protein(s)	37	4 (3.6)
System(s)	34	5 (3.3)
Determination(s)	27	6 (2.6)
Structure(s)	25	7 (2.5)
Cell(s)	25	7 (2.5)
Effect(s)	23	9 (2.3)
Interaction(s)	22	10 (2.2)
Function(s)	20	11 (2.0)
Human(s)	19	12 (1.9)
Properties	19	12 (1.9)
Molecular	17	14 (1.7)
Quantum	17	14 (1.7)
Estimation(s)	17	14 (1.7)
State(s)	17	14 (1.7)
Field(s)	16	18 (1.6)
Equation(s)	16	18 (1.6)
Evolution	15	20 (1.5)
Simple	15	20 (1.5)

TP, top-cited single-author articles.

Table 7
Top 20 title words in 1990–2010s.

1990–2010s words in title	*TP*	Rank (%)
Model(s)	14	1 (4.9)
Quantum	13	2 (4.6)
Method(s)	11	3 (3.9)
Molecular	10	4 (3.5)
Structure(s)	9	5 (3.2)
Program	8	6 (2.8)
Functional	7	7 (2.5)
Protein(s)	7	7 (2.5)
Density	6	9 (2.1)
Phylogenetic	6	9 (2.1)
Correction(s)	6	9 (2.1)
Effect(s)	6	9 (2.1)
Polymer(s)	6	9 (2.1)
Approach	5	14 (1.8)
Density-functional	5	14 (1.8)
DNA	5	14 (1.8)
Multiple	5	14 (1.8)
Networks	5	14 (1.8)
Cell(s)	5	14 (1.8)
Problem(s)	5	14 (1.8)
Role(s)	5	14 (1.8)

TP, top-cited single-author articles.

acid(s). Previous research (Farber, 2005) indicated that the more theoretical the research, the more likely a single person will publish it. While many of the leading title words are related to theory building, the leading title words significantly changed over time. The title word theory(ies) ranked 1st overall, as well as in 1900–1959 and 2nd in 1960–1989, but its ranking dropped to 22th in 1990–2010. The title words that remained in the top 10 throughout the three time periods were method(s) and structure(s). Tables 5–7 show the top 20 title words for the three periods. Only five title words, method(s), protein(s), structure(s), molecular, and quantum remained in the top 20 in all three periods.

4. Conclusions

In total, 1760 top-cited single-author articles were published in 539 journals listed in 130 Web of Science categories from 1901 to 2010, among which 98% were published in English. *Science*, *Physical Review*, and *Journal of Chemical Physics* were the top three journals publishing top-cited single-author articles. Most of the 1760 articles were not published in high-impact journals. Top-cited single-author articles were found in a wide range of subject categories. The categories of multidisciplinary physics, multidisciplinary sciences, and biochemistry and molecular biology contained 36% of the total articles. Harvard University led all other institutions in publishing top-cited single-author articles. Articles were published by industrial institutions as well. Among leading articles, citations in the first year were generally low, and appeared to have little influence on the total citations. In general, articles published earlier seemed to show a slower rate of increase. However, a pattern of repetitive peaks was observed for articles published in different time periods. Once a peak was reached, citations trended down for a few years, then trended upwards again to a higher peak. An article by U.K. Laemmli was top ranked in annual citations in 1977–2002. Articles by M.M. Bradford and G.M. Sheldrick had the greatest impact in the last decade, while articles by A.D. Becke and R.D. Shannon demonstrated high potential to become leading articles. Method(s), protein(s), structure(s), molecular, and quantum were the leading title words that consistently remained in the top 20 in different time periods. In total, 72 Nobel Prize winners published 124 single-author articles.

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