Universality of Citation Distributions–A Validation of Radicchi et al.'s Relative Indicator $c_f = c/c_0$ at the Micro Level Using Data From Chemistry

Lutz Bornmann
ETH Zurich, Professorship for Social Psychology and Research on Higher Education, Zähringerstr. 24, CH-8092 Zurich, Switzerland. E-mail: bornmann@gess.ethz.ch.

Hans-Dieter Daniel
ETH Zurich, Professorship for Social Psychology and Research on Higher Education, University of Zurich, Evaluation Office, Mühlegasse 21, CH-8001 Zurich, Switzerland. E-mail: daniel@evaluation.uzh.ch.

In a recently published PNAS paper, Radicchi, Fortunato, and Castellano (2008) propose the relative indicator c_f as an unbiased indicator for citation performance across disciplines (fields, subject areas). To calculate c_f, the citation rate for a single paper is divided by the average number of citations for all papers in the discipline in which the single paper has been categorized. c_f values are said to lead to a universality of discipline-specific citation distributions. Using a comprehensive dataset of an evaluation study on *Angewandte Chemie International Edition* (AC-IE), we tested the advantage of using this indicator in practical application at the micro level, as compared with (1) simple citation rates, and (2) *z*-scores, which have been used in psychological testing for many years for normalization of test scores. To calculate *z*-scores, the mean number of citations of the papers within a discipline is subtracted from the citation rate of a single paper, and the difference is then divided by the citations' standard deviation for a discipline. Our results indicate that *z*-scores are better suited than c_f values to produce universality of discipline-specific citation distributions.

Introduction

In a study published recently in the *Proceedings of the National Academy of Sciences* (PNAS), Radicchi, Fortunato, and Castellano (2008) address one of the most relevant factors that may hamper a fair evaluation of the scientific performance of a single paper: variation between disciplines (fields, subject areas). As many studies have already shown, the values expected for citation rates of publications are dependent on the discipline (Bornmann & Daniel, 2008c): Publications in certain disciplines are typically cited much more or much less frequently than in others. One result of this phenomenon is that citation rates for publications published within different disciplines can not be compared directly. When evaluating research, 20 citations for a paper in computer science (average citation rate according to Essential Science Indicators, provided by Thomson Reuters, Philadelphia, PA, 1998 to 2008: 3.06) have to be valued differently than 20 citations for a paper in biology and biochemistry (average citation rate: 16.12). The findings by Radicchi et al. (2008) provide a strong validation of the relative indicator $c_f = c/c_0$, where c is the citation rate for a single paper and c_0 is the average number of citations per article for the discipline (field, subject area) to which the single paper belongs, as an unbiased indicator for citation performance across disciplines. According to Radicchi et al. (2008), if the citation rate for single papers is divided by the average number of citations per paper for the discipline, the impact of the papers can be directly compared. The proposed new indicator of research performance was quickly taken up by *Nature* (Ball, 2008).

In psychological testing it is often necessary to compare the test scores of two persons belonging to different groups. For better comparability of the two test scores—similar to what Radicchi et al. (2008) propose for evaluative bibliometrics—the individual scores are first put in relation to the scores of the whole population. To do so, however, in psychological testing it is recommended that not only the individual test score's deviation from the cohort mean be calculated. For even if person A has a better test score than person B, because person A's score is clearly higher than the mean score for that cohort than person's B's score is, for instance, it could be that person A has only the sixth highest test score in person A's group, whereas person B's score ranks fourth in person B's group. To make the deviations of two scores from

Received January 6, 2009; revised February 9, 2009; accepted February 20, 2009

 • Published online 13 April 2009 in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/asi.21076

the means better comparable, it is therefore recommended to divide the difference between test score x and population mean μ by the population standard deviation σ. This standard score is then called a z-score (Anastasi & Urbina, 1997, pp. 94–95):

$$z = \frac{x - \mu}{\sigma} \quad (1)$$

According to our search of the literature, z-scores were first proposed for use in bibliometric studies by McAllister, Narin, and Corrigan (1983). Lundberg (2007) and Newman (2008) worked with z-scores in recently published bibliometric studies.

In a comprehensive dataset on the peer review process at the journal *Angewandte Chemie International Edition* (AC-IE), we have access to nearly 2000 manuscripts that were published in different subfields of chemistry (such as "Biochemical Methods" or "Magnetic Phenomena"; Bornmann & Daniel, 2008a, 2008b). The expected values for citation rates vary greatly within the individual subfields. Using the manuscripts in our dataset we investigated whether the relative indicator c_f proposed by Radicchi et al. (2008), as compared to simple citation rates, in fact leads to a universal curve independent of the different chemical subfields and thus to comparability of papers from the different subfields. And for the collapse of the different curves into a single shape, we examined whether the use of z-scores shows an advantage over the use of c_f values.

Using our dataset on the peer review process at AC-IE, we tested Radicchi et al.'s (2008) proposal normalization of citation rates at the micro level. In most studies in evaluative bibliometrics, performance indicators such as mean citation rates or total citation counts are not calculated at the macro level (that is, not for all papers within a discipline) but instead for a selection of papers relating to a group of researchers (Bornmann, Wallon, & Ledin, 2008), an institution (Moed, 2005), or a journal (Daniel, 1993/2004). Therefore, examination of new approaches for measuring scientific performance at the micro level is an important step towards their use in daily evaluation practice.

Methods

Database for the Present Study

AC-IE is one of the prime chemistry journals in the world, with a higher annual Journal Impact Factor (JIF, provided by Thomson Reuters) than the JIFs of comparable journals (at 10.031 in the 2007 Journal Citation Reports, Science Edition). AC-IE is a journal of the German Chemical Society (Gesellschaft Deutscher Chemiker [GDCh], Frankfurt am Main, Germany) and is published by Wiley-VCH (Weinheim, Germany). For the investigation of manuscript review at AC-IE (Bornmann & Daniel, 2008a, 2008b, 2009), we used information on all 1,899 Communications that were reviewed in the year 2000. Of the 1,899 Communications, 46% ($n = 878$) were accepted for publication in AC-IE, and 54% ($n = 1{,}021$) were rejected. A search in the literature databases Science Citation Index (SCI, Thomson Reuters) and Chemical Abstracts (CA, Chemical Abstracts Services, CAS, Columbus, OH) revealed that of the 1,021 rejected manuscripts, 959 (94%) were then published in 136 other (different) journals.

Conducting of Citation Analysis

For accepted and rejected (but published elsewhere) manuscripts, we determined the number of citations for a fixed time window of three years after the publication year. "Fixed citation windows are a standard method in bibliometric analysis, in order to give equal time spans for citation to articles published in different years, or at different times in the same year" (Craig, Plume, McVeigh, Pringle, & Amin, 2007, p. 243). The citation analyses for the present study were conducted based on CA. CA is a comprehensive database of publicly disclosed research in chemistry and related sciences (see http://www.cas.org/).

AC-IE "publishes articles from the full spectrum of chemistry," according to the journal's chief editor, Peter Gölitz (2005, p. 5539). CAS categorizes chemical publications into 80 different subject areas (called sections). Every publication becomes associated with a single principal entry, which makes clearly apparent the most important aspect of the work (Neuhaus & Daniel, 2009). In contrast to the journal sets provided by Thomson Reuters, CA sections are assigned on a paper-by-paper basis (Bornmann, Mutz, Neuhaus, & Daniel, 2008). For our study, we asked the Central Information Service for the institutes of the Chemical Physical Technical (CPT) Section of the Max Planck Society (located at the Max Planck Institute for Solid State Research in Stuttgart, Germany) to generate mean citation rates c_0 and standard deviations sd for 33 of the 80 CA sections. For each of these 33 sections, we have in the sample ten or more manuscripts accepted by AC-IE or rejected (but published elsewhere); a total of 1,707 manuscripts of our dataset are categorized in the 33 sections. The c_0 and sd values for a section are based on the publications of the year 2001 and the citations of these publications in the years 2002 to 2004 (fixed three-year citation window). The manuscripts accepted and rejected by AC-IE are mainly Communications and research articles. Because CAS "does not provide a distinct document type for research articles" (Neuhaus & Daniel, 2009, p. 226), the c_0 and sd values were generated by excluding publications with non-relevant document types, such as conference proceedings and reviews.

Results

Table 1 shows the average citation rates c_0 for the 33 CA sections considered in this study. It is clear to see that the mean values for the individual CA sections are very different: Whereas a paper published in 2001 and categorized by CAS as belonging to the "General Biochemistry" section was cited on average 14.54 times, a paper assigned to the "Ceramics" section has an average of 2.58 citations. In Figure 1, mean

DOI: 10.1002/asi

TABLE 1. List of all 33 CA sections considered in this study with total number of papers N_p, total number of citations N_c, mean citation rates c_0, and standard deviation of citations *sd* for each section (sorted by c_0).

CA section	N_p	N_c	c_0	*sd*
General biochemistry	9977	145032	14.54	30.42
Biochemical genetics	17675	185972	10.52	36.60
General organic chemistry	1429	14640	10.24	13.55
Enzymes	9013	83540	9.27	16.32
Alkaloids	526	4171	7.93	8.33
Pharmacology	28478	214478	7.53	17.77
Biochemical methods	8792	61942	7.05	20.05
Amino acids, peptides, and proteins	1935	13313	6.88	8.52
Benzene, its derivatives, and condensed benzenoid compounds	2132	14358	6.73	11.90
Biomolecules and their synthetic analogs	1421	9304	6.55	8.34
Organometallic and organometalloidal compounds	4476	29222	6.53	7.81
General physical chemistry	8182	52431	6.41	18.52
Inorganic chemicals and reactions	6826	41846	6.13	9.45
Heterocyclic compounds (one hetero atom)	2218	13544	6.11	12.26
Alicyclic compounds	577	3514	6.09	9.64
Aliphatic compounds	595	3345	5.62	11.64
Surface chemistry and colloids	7781	42728	5.49	10.43
Electric phenomena	22155	118420	5.35	26.43
Physical organic chemistry	6448	34062	5.28	9.69
Magnetic phenomena	7404	38550	5.21	15.67
Optical, electron, and mass spectroscopy and other related properties	25510	129577	5.08	16.37
Physical properties of synthetic high polymers	4894	24050	4.91	8.27
Chemistry of synthetic high polymers	5244	25440	4.85	9.82
Radiation chemistry, photochemistry, and photographic and other reprographic processes	3783	18088	4.78	11.76
Carbohydrates	2822	13172	4.67	6.73
Terpenes and terpenoids	691	3230	4.67	5.46
Catalysis, reaction kinetics, and inorganic reaction mechanisms	2670	12238	4.58	9.20
Electrochemistry	3637	14672	4.03	10.96
Heterocyclic compounds (more than one hetero atom)	3337	12640	3.79	6.59
Crystallography and liquid crystals	7324	22193	3.03	9.30
Inorganic analytical chemistry	3978	11754	2.95	7.18
Ceramics	9351	24081	2.58	7.11
Industrial organic chemicals, leather, fats, and waxes	2171	4706	2.17	8.16

citation rates with confidence interval of $\pm$ 1.5 standard errors for papers assigned by CAS to different sections are shown. In comparing the mean citation rates of two sections, if their confidence intervals do not overlap, one may safely conclude that the citation rates are significantly different (at the .05 level of significance; (see here Goldberger, Maher, & Flattau, 1995, p. 625). In addition to the mean values of citations within the individual CA sections, Table 1 also shows the standard deviations *sd* as a measure of range within a citation distribution. The wide range of *sd* values (from 5.46 in "Terpenes and Terpenoids" to 36.60 in "Biochemical Genetics") indicates that within the individual CA sections the citation rates vary around the mean very differently. This is an indication that it makes sense to consider the *sd* when normalizing the citation rates for different CA sections, as is the case in the calculation of z-scores.

Using the mean and *sd* values in Table 1, we calculated c_f values and z-scores for the manuscripts that were accepted or rejected (but published elsewhere) by AC-IE and assigned to the 33 CA sections ($n = 1707$). Table 2 shows the mean citation rates, mean c_f values, and mean z-scores for the manuscripts within a CA section. As can be seen in the table, for the different sections there are between 10 ("Biochemical Genetics") and 287 ("Inorganic Chemicals and Reactions") accepted or rejected (but published elsewhere) manuscripts. Whereas the range of the mean citation rates for the manuscripts in individual CA sections is 22.16 ($min = 8.92$ for "Terpenes and Terpenoids" and $max = 31.08$ for "Electric Phenomena"), for the relative indicators the range is 8.36 and thus reduced by about a half ($min = .81$ for "General Biochemistry" and $max = 9.17$ for "Industrial Organic Chemicals, Leather, Fats, and Waxes"). For the z-scores the range is reduced even further, at 3.17 ($min = -.09$ for "General Biochemistry" and $max = 3.08$ for "Inorganic Analytical Chemistry"). The results in Table 2 indicate that, as compared to using simple citation rates, more similar impact values between the CA sections can be achieved through using the relative indicators c_f and the z-scores and that somewhat better results are achieved here using the z-scores than the c_f values.

Radicchi et al. (2008) present two figures to show a comparison of the distributions of citation rates and c_f

DOI: 10.1002/asi

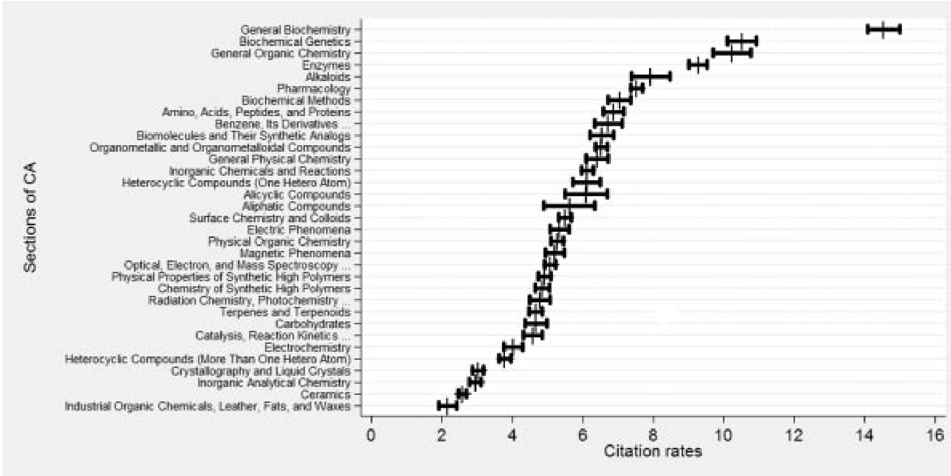

FIG. 1. Mean citation rates with confidence intervals of ± 1.5 standard errors for papers assigned by CAS to different sections. In comparing the mean citation rates of two sections, if their confidence intervals do not overlap, one may safely conclude that the citation rates are significantly different (at the .05 level of significance).

TABLE 2. Mean citations rates, mean c_f values, and mean z-scores for the manuscripts accepted or rejected (but published elsewhere) by AC-IE that were categorized in 33 CA sections ($n = 1707$, sorted alphabetically by CA section).

CA section	Number of manuscripts	Mean citation rates	Mean c_f values	Mean z-scores
Alicyclic compounds	29	14.86	2.44	.91
Aliphatic compounds	20	14.45	2.57	.76
Alkaloids	14	11.07	1.40	.38
Amino acids, peptides, and proteins	59	14.09	2.05	.85
Benzene, its derivatives, and condensed benzenoid compounds	81	16.54	2.46	.83
Biochemical genetics	10	14.70	1.40	.11
Biochemical methods	39	14.31	2.03	.36
Biomolecules and their synthetic analogs	58	15.26	2.33	1.04
Carbohydrates	88	11.42	2.45	1.00
Catalysis, reaction kinetics, and inorganic reaction mechanisms	28	14.79	3.23	1.11
Ceramics	14	21.29	8.25	2.63
Chemistry of synthetic high polymers	58	17.81	3.67	1.32
Crystallography and liquid crystals	35	9.83	3.24	.73
Electric phenomena	12	31.08	5.81	.97
Electrochemistry	12	10.00	2.48	.55
Enzymes	37	13.03	1.41	.23
General biochemistry	46	11.78	.81	−.09
General organic chemistry	95	18.20	1.78	.59
General physical chemistry	20	12.85	2.01	.35
Heterocyclic compounds (more than one hetero atom)	48	11.94	3.15	1.24
Heterocyclic compounds (one hetero atom)	50	17.24	2.82	.91
Industrial organic chemicals, leather, fats, and waxes	18	19.89	9.17	2.17
Inorganic analytical chemistry	13	25.08	8.50	3.08
Inorganic chemicals and reactions	287	16.43	2.68	1.09
Magnetic phenomena	16	26.94	5.17	1.39
Optical, electron, and mass spectroscopy and other related properties	29	14.35	2.82	.57
Organometallic and organometalloidal compounds	244	11.03	1.69	.58
Pharmacology	24	14.00	1.86	.36
Physical organic chemistry	125	14.36	2.72	.94
Physical properties of synthetic high polymers	16	14.19	2.89	1.12
Radiation chemistry, photochemistry, and photographic and other reprographic processes	31	15.03	3.15	.87
Surface chemistry and colloids	38	15.66	2.85	.98
Terpenes and terpenoids	13	8.92	1.91	.78

DOI: 10.1002/asi

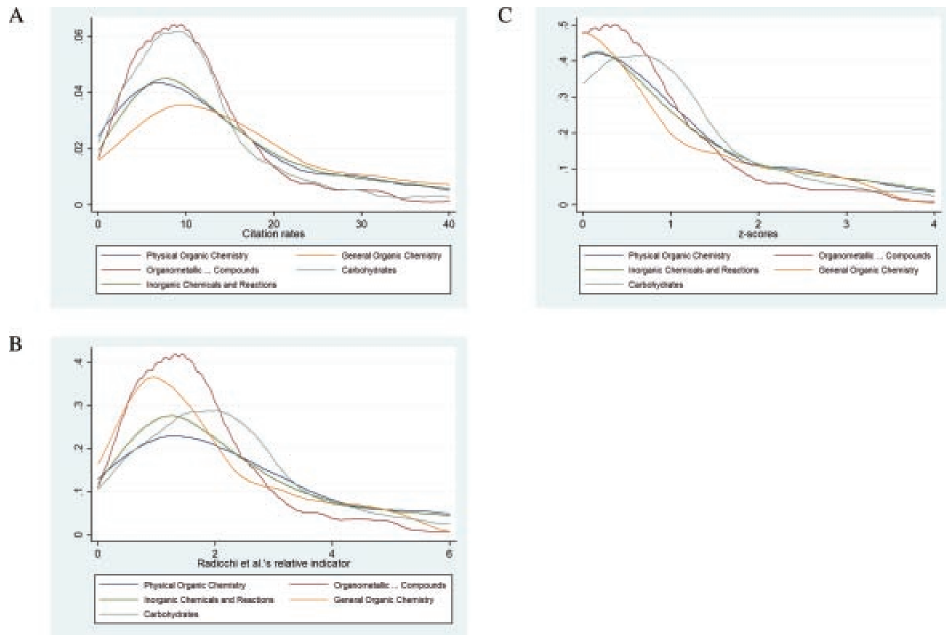

FIG. 2. Distribution of citation rates (graph A), Radicchi et al.'s relative indicator (graph B), and z-scores (graph C) for the manuscripts accepted or rejected (but published elsewhere) by AC-IE that were categorized in the CA sections "Physical Organic Chemistry" ($n = 125$ manuscripts, $c_0 = 5.28$, $sd = 9.69$), "Organometallic and Organometalloidal Compounds" ($n = 244$ manuscripts, $c_0 = 6.53$, $sd = 7.81$), "Inorganic Chemicals and Reactions" ($n = 287$ manuscripts, $c_0 = 6.13$, $sd = 9.45$), "General Organic Chemistry" ($n = 95$ manuscripts, $c_0 = 10.24$, $sd = 13.55$), and "Carbohydrates" ($n = 88$ manuscripts, $c_0 = 4.67$, $sd = 6.73$).

values for papers assigned to several different scientific disciplines. Whereas in their figures the distributions of the citation rates clearly differ between the individual disciplines, the use of c_f led to a "very good collapse of all curves for different values of c_0 into a single shape" (p. 2). We also undertook a graphing comparison (Cox, 2004) in the present study. Figure 2 shows the distributions of citation rates (graph A) and c_f values (graph B) for the manuscripts accepted or rejected (but published elsewhere) by AC-IE that were assigned to the CA sections "Physical Organic Chemistry" ($n = 125$ manuscripts, $c_0 = 5.28$, $sd = 9.69$), "Organometallic and Organometalloidal Compounds" ($n = 244$ manuscripts, $c_0 = 6.53$, $sd = 7.81$), "Inorganic Chemicals and Reactions" ($n = 287$ manuscripts, $c_0 = 6.13$, $sd = 9.45$), "General Organic Chemistry" ($n = 95$ manuscripts, $c_0 = 10.24$, $sd = 13.55$), and "Carbohydrates" ($n = 88$ manuscripts, $c_0 = 4.67$, $sd = 6.73$). These are the five CA sections in which in the dataset of our study the most accepted or rejected (but published elsewhere) manuscripts are found (altogether $n = 839$ manuscripts). As the distributions of the values in graphs A and B in Figure 2 show, in contrast to the graphs in Radicchi et al. (2008) the use of c_f does not lead to a collapse of the five curves for different values of c_0 into a single shape. The differences between the curves for the citation rates in graph A remain even after the normalization in graph B.

In addition to the distributions of the citation rates and the c_f values, Figure 2 also shows the distribution of the z-scores (graph C). Although the z-scores also do not lead to a very good collapse of all curves into a single shape, graph C shows a better approximation of a universal curve as compared to graphs A and B. In agreement with the results in Table 2, this finding indicates that z-scores are better suited than c_f values for a cross-discipline comparison of citation impact of publications.

Discussion

In a recently published PNAS paper, Radicchi et al. (2008) propose the relative indicator c_f as an unbiased indicator for citation performance across disciplines. The idea of relative scientometric indicators originates from Schubert and Braun (1986). Vinkler (1986, 1997) suggested the use of the mean number of citations per paper index referring to the journals of a whole subfield or field as a reference standard for the Relative Subfield Citedness (RW) index. Aksnes and Taxt (2004) tested the application of relative indicators in a case study of research groups at the University of Bergen (Norway). The proposed relative indicator c_f corresponds, in principle, to the RW index. The difference between the new indicator and the standard indicators used in evaluative bibliometrics lies in the fact that the standard indicators are ratios of total or mean citation rates and the new indicator is a ratio composed of a citation rate of one single paper and a mean citation rate. Until now, the use of a single paper's citation rate in RW indices is not common in scientometrics.

Using a comprehensive dataset of an evaluation study on the journal AC-IE, we tested the relative indicator c_f in practical application at the micro level and compared it with simple citation rates and z-scores, which have been used for many years in psychological testing for normalization of test scores. The results for the manuscripts accepted or rejected (but published elsewhere) by AC-IE manuscripts indicate that z-scores have an advantage over c_f values if the impact of publications in different subfields of chemistry is to be made comparable. The consideration of the *sd* in the calculation of the z-scores leads at the micro level to an improved approximation of the subfield-specific distributions to a universal curve, which was not the case when using c_f values. However, the extent to which this finding can be replicated at the macro level should be tested using extensive datasets, such as that used by Radicchi et al. (2008).

In these studies it would be very interesting, if in addition to the mean-based normalization methods (as were tested in the present study) the use of percentile rank scores would also be investigated. Percentile rank scores are the simplest way to make values from different populations comparable and are used widely as a standard for comparison in psychological testing to judge a person's test scores (intelligence test scores, for example) based on a comparison with the percentiles of a calibrated sample (see Jackson, 1996). Percentile rank scores usually involve ranking the units (in bibliometrics, the papers) in ascending order according to a criterion (in bibliometrics, the citation rates; see Rousseau, 2005, for an example of the use of percentiles describing journal impact). The frequencies with which papers having a certain citation rate are found are then accumulated successively across all papers (papers with citation rate 0, 1, 2, ...). The percentile rank score amounts to the fraction of the cumulative frequencies of the total number of all papers.

Particularly in bibliometric analysis the use of percentile rank scores for evaluative purposes is very advantageous (see also Plomp, 1990), as no assumptions have to be made as to the distribution of citations; that is, the scores are applicable also for the (usually) skewed distributions of bibliometric data (Bornmann, Mutz, & Daniel, 2007).

Acknowledgments

The entire research study, which also includes an investigation of the quality assurance of open access journals, is supported by a grant from the Max Planck Society. The authors would like to thank Dr. Christophe Weymuth (formerly at the Organic Chemistry Institute, University of Zurich, and now at BIOSYNTH AG, Switzerland) for investigation of the manuscripts rejected by *Angewandte Chemie International Edition* and published elsewhere. We also thank Dr. Werner Marx and Dr. Hermann Schier of the Central Information Service for the institutes of the Chemical Physical Technical (CPT) Section of the Max Planck Society (located at the Max Planck Institute for Solid State Research in Stuttgart, Germany) for conducting the search for citations of the accepted and rejected (but published elsewhere) manuscripts in the literature database Chemical Abstracts and for calculating the section-specific mean citation rates and standard deviations.

We thank Dr. Peter Gölitz, Editor-in-Chief of *Angewandte Chemie*, the Editorial Board of *Angewandte Chemie*, and the German Chemical Society (GDCh, Frankfurt am Main, Germany) for permission to conduct the evaluation of the peer review process of the journal, and thank the members of the editorial office for their generous support during the carrying out of the study.

References

Aksnes, D.W., & Taxt, R.E. (2004). Peer reviews and bibliometric indicators: A comparative study at a Norwegian university. Research Evaluation, 13(1), 33–41.

Anastasi, A., & Urbina, S. (1997). Psychological testing (7th ed.). Upper Saddle River, NJ: Prentice Hall International.

Ball, P. (2008, 20 October). Is physics better than biology? Retrieved December 23, 2008, from http://www.nature.com/news/2008/081020/full/news.2008.1169.html

Bornmann, L., & Daniel, H.-D. (2008a). The effectiveness of the peer review process: Inter-referee agreement and predictive validity of manuscript refereeing at Angewandte Chemie. Angewandte Chemie International Edition, 47(38), 7173–7178.

Bornmann, L., & Daniel, H.-D. (2008b). Selecting manuscripts for a high impact journal through peer review: A citation analysis of Communications that were accepted by Angewandte Chemie International Edition, or rejected but published elsewhere. Journal of the American Society for Information Science and Technology, 59(11), 1841–1852.

Bornmann, L., & Daniel, H.-D. (2008c). What do citation counts measure? A review of studies on citing behavior. Journal of Documentation, 64(1), 45–80.

Bornmann, L., & Daniel, H.-D. (2009). The luck of the referee draw: Would it make a difference if a journal editor exchanged one review for another? Learned Publishing, 22(2), 117–125.

Bornmann, L., Mutz, R., & Daniel, H.-D. (2007). The b index as a measure of scientific excellence. A promising supplement to the h index. Cybermetrics, 11(1), paper 6.

Bornmann, L., Mutz, R., Neuhaus, C., & Daniel, H.-D. (2008). Use of citation counts for research evaluation: Standards of good practice for analyzing bibliometric data and presenting and interpreting results. Ethics in Science and Environmental Politics, 8, 93–102.

Bornmann, L., Wallon, G., & Ledin, A. (2008). Does the committee peer review select the best applicants for funding? An investigation of the selection process for two European Molecular Biology Organization programmes. PLoS One, 3(10), e3480.

Cox, N.J. (2004). Speaking stata: Graphing distributions. Stata Journal, 4(1), 66–88.

Craig, I.D., Plume, A.M., McVeigh, M.E., Pringle, J., & Amin, M. (2007). Do open access articles have greater citation impact? A critical review of the literature. Journal of Informetrics, 1(3), 239–248.

Daniel, H.-D. (1993/2004). Guardians of science. Fairness and reliability of peer review. Weinheim, Germany: Wiley-VCH. Published online 16 July 2004, Wiley Interscience, DOI: 10.1002/3527602208.

Goldberger, M.L., Maher, B.A., & Flattau, P.E. (1995). Research-doctorate programs in the United States-continuity and change. Washington, DC: National Academy Press.

Gölitz, P. (2005). Who is going to read all this? Angewandte Chemie International Edition, 44(35), 5538–5541.

Jackson, C. (1996). Understanding psychological testing. Leicester, UK: British Psychological Society.

Lundberg, J. (2007). Lifting the crown-citation z-score. Journal of Informetrics, 1(2), 145–154.

McAllister, P.R., Narin, F., & Corrigan, J.G. (1983). Programmatic evaluation and comparison based on standardized citation scores. IEEE Transactions on Engineering Management, 30(4), 205–211.

Moed, H.F. (2005). Citation analysis in research evaluation. Dordrecht, The Netherlands: Springer.

Neuhaus, C., & Daniel, H.-D. (2009). A new reference standard for citation analysis in chemistry and related fields based on the sections of Chemical Abstracts. Scientometrics, 78(2), 219–229.

Newman, M.E.J. (2008). The first-mover advantage in scientific publication. Retrieved September 5, 2008, from http://arxiv.org/abs/0809.0522v1

Plomp, R. (1990). The significance of the number of highly cited papers as an indicator of scientific prolificacy. Scientometrics, 19(3–4), 185–197.

Radicchi, F., Fortunato, S., & Castellano, C. (2008). Universality of citation distributions: Toward an objective measure of scientific impact. Proceedings of the National Academy of Sciences, 105(45), 17268–17272.

Rousseau, R. (2005). Median and percentile impact factors: A set of new indicators. Scientometrics, 63(3), 431–441.

Schubert, A., & Braun, T. (1986). Relative indicators and relational charts for comparative assessment of publication output and citation impact. Scientometrics, 9(5–6), 281–291.

Vinkler, P. (1986). Evaluation of some methods for the relative assessment of scientific publications. Scientometrics, 10(3–4), 157–177.

Vinkler, P. (1997). Relations of relative scientometric impact indicators. The relative publication strategy index. Scientometrics, 40(1), 163–169.

DOI: 10.1002/asi