Information **2014**, *5*, 285-304; doi:10.3390/info5020285

OPEN ACCESS

information

ISSN 2078-2489

www.mdpi.com/journal/information

Review

An Overview on the South Korean Scientific Production in the Field of Chemistry (1993–2012)

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Received: 19 March 2014; in revised form: 23 April 2014 / Accepted: 24 April 2014 / Published: 6 May 2014

Abstract: The present review seeks to take stock of the South Korean publication activity on the field of chemistry by analyzing systematically all chemistry-related scholarly communications collected in the Web of Science (WOS) database published by at least one Korean author or Korean institute- or university-affiliated author from 1993 to 2012. The studied parameters included the growth in number of the communications, as well as the language-, document-, category-, source-, organization-, and collaboration-wise distribution of the South Korean communications. A total of 5660 communications on chemistry were found to be published by South Korean researchers during the aforementioned period of time, and South Korea was the 15th country (1.77%) in the world in terms of informational communication activity in chemistry.

Keywords: communication; information science; information flow; scientometrics; informetrics; Korea; chemistry; scientific production; research performance

1. Introduction

It is well known that chemistry—occasionally named as "*the central science*" [1] due to the fact that it is a multidisciplinary and interdisciplinary science connected with other branches of knowledge (*i.e.*, physics, engineering, materials science, geology, environmental sciences, and biology)—"*is by far today's most active science with regard to bibliometrical indicators*" [2], and it is also known that the modern scientometric science has emerged in chemistry at the end of the 19th century as a standardized format [3]. A growing number of peer-reviewed literature examining, for example, the information flow and the evolution of chemistry research [4], chemical journals [5–8], chemical

substances [9], chemical databases [10], organic chemistry [11,12], green chemistry [13], nuclear chemistry [14], chemical engineering [15], synthesis organic chemistry research [16], chemical terminology [17], national and local scholarly communications in the selected field of science [18–20], the relationship between research performance and international collaboration in chemistry [21,22], as well as particular field of studies regarding Thorium [23], Vanadium [24], grapheme [25], energy [26,27] and high-temperature superconductors [28,29] have been published over time as research literature.

Many studies have appeared in the scientific literature with their attention focused on the national trend of research productivity on the most varied subjects [26,30–43], and recent studies devoted to understanding the South Korean scientific development process could confirm an exponentially increasing presence of Korean authors in the world's scientific literature [36,40–44].

Among others, Kim [42] has presented a very interesting overview on research performance of South Korean physicists from 1994 to 1998. In Kim's study, 4665 scholarly communications published from the researchers affiliated with the physics departments or physics-associated laboratories in South Korean universities were analyzed, and his findings showed that (1) South Korean-authored communications tended to be published in Korean and Japanese journals; that (2) the most frequently used journal by South Korean physicians was a domestic Journal named the *Korean Physical Society*; and that (3) Seoul National University (SNU) was South Korea's most productive university in the field of physics [42]. These results in the physics literature also echo the findings of another study on the chemical literature conducted by Kim and Kim [45], in which the authors reported that "*major journals used by Korean chemists are Bulletin of the Korean Chemical Society (Korea)*", which is again a domestic journal.

Taking the above observations in account, the aim of the present study was to quantitatively determine the growth of the literature on chemistry in terms of scholarly communications (sometimes called as "article(s)" or "item(s)") in South Korea (officially the Republic of Korea but hereinafter known as "Korea") from 1993 to 2012.

To take stock of the situation of the chemistry sciences in Korea, the scholarly activity on "*Chemistry*" in general and the change in the communication pattern of articles was analyzed. This present study extends and updates the research of Kim [42] on the research performance of Korean physicists over four years from 1994 to 1998 and that of Kim and Kim [45] on the productivity of the Korean chemists affiliated at the Chemistry Department of Seoul National University from 1992 to 1998 by providing a wider range of data collected from the Web of Science (WOS) database on the Korean scholarly communications published from 1993 to 2012 in the field of chemistry.

2. Data Collection and Methodology

The Web of science (WOS) is the most widespread database on different scientific fields which is frequently used for searching the statistical data regarding scientific literature [46]. WOS includes over 1.2×10^4 journals worldwide, 1.5×10^5 conference proceedings and 2.75×10^5 books and book chapters. WOS citation databases are Science Citation Index Expanded (SCI-Expanded from 1998 to present), Social Sciences Citation Index (SSCI from 1993 to present), Arts and Humanities Citation Index (A&HCI from 1993 to present), Conference Proceedings Citation Index—Science (CPCI-S), Conference Proceedings Citation Index—Social Sciences and Humanities (CPCI-SSH), and the two

chemistry databases named Index Chemicus (IC) and Current Chemical Reactions (CCR-Expanded). For these reasons in this paper the WOS database was used to collect the articles related to the field of "*Chemistry*". The search was confined to the scholarly communications from 1993 to 2012 indexed by Thomson Reuthers' WOS, and was performed from 1 to 10 January 2014.

Within the WOS database, 5660 articles published by authors affiliated to Korean institutions or universities were found within the target range of years (1993–2012). The evaluation of the cumulated data from 1993 to 2012 was performed by analyzing the bibliometric parameters including the time distribution of (1) scholarly communications; (2) language; (3) document type; (4) categories; (5) source titles; (6) countries; (7) organizations and (8) collaborations. Each of these analysis steps are discussed in the next sections.

3. Results and Discussion

3.1. Geographical Distribution of Chemistry-Related Scholarly Communications

Table 1 shows the global distribution of the national chemistry-related scholarly communications from 1993 to 2012. According to the WOS database, 33.7% of the communications was published by at least one author in the USA (106,323 communications), 10.8% was published by at least one author in Germany (34,068 communications), and 7.92% was published by at least one author in China (24,988 communications). The average number of communications in the top-15 countries in these fields of study was 21,033 (6.66%).

Table 1. List of the top 15 Countries (out of a total of 194) with the greatest number of scholarly communications in the field of chemistry from 1993 to 2012. The numbers in the first column represent the rank of the countries in terms of quantitative productivity.

	Country	Records	%
1	USA	106,323	33.70
2	Germany	34,068	10.80
3	China	24,988	7.92
4	England	22,837	7.24
5	France	21,895	6.94
6	Japan	18,755	5.94
7	Canada	13,850	4.39
8	Italy	12,898	4.09
9	Spain	11,688	3.70
10	India	11,290	3.58
11	Australia	8,900	2.82
12	Russia	7,960	2.52
13	Switzerland	7,643	2.42
14	The Netherlands	6,751	2.14
15	South Korea	5,660	1.79
Total		315,506	100

Regarding the amount of these communications, Korea was the 15th most productive country in the world with an overall score of 1.8% during the range of years under discussion. This result is in good

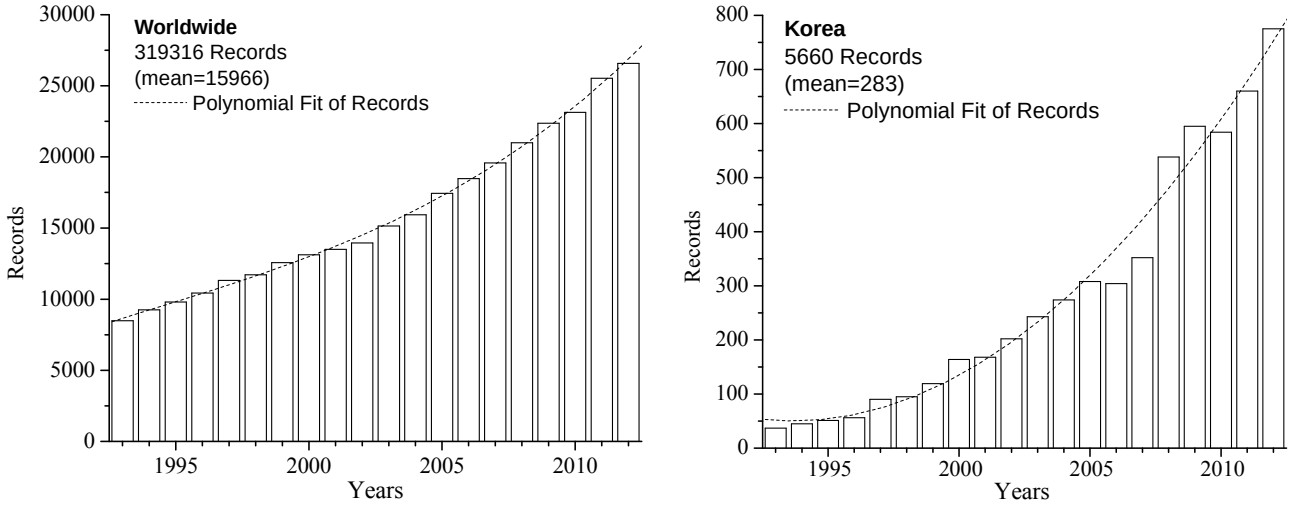
agreement with the recent observation by Park and Leydesdorff [43], who reported that—in terms of the amount of Korean S&T papers in the Science Citation Index (SCI) journals—Korea has occupied the 14th position in 2005.

For the purpose of the present study, the data sample comprised all 5660 communications indexed by WOS from 1993 to 2012 containing at least one author affiliated to Korean institutions or universities.

3.2. Comparison between the Growth of the Korean Chemistry-Related Scholarly Communications and That of the Rest of the World

Figure 1 gives an illustration of the worldwide and Korean annual growth rates in the field of chemistry studies from 1993 to 2012. 5660 Korean chemistry-related scholarly communications were published in total with an average of 283 communications per year from 1993 to 2012. 2012 was the most productive year where 775 (13.69% of total communications) communications out of these 5660 were published. As clearly visualized in Figure 1, although there was some dispersion in the scholarly communications, a polynomial fit could be used to represent the annual number of these communications.

Figure 1. Year-wise distribution of scholarly communications in the field of chemistry published (**a**) worldwide (3.19316E+05 records) and (**b**) by authors affiliated to Korean institutions or universities (5.66E+03 records) from 1993 to 2012.



(**a**) (**b**)

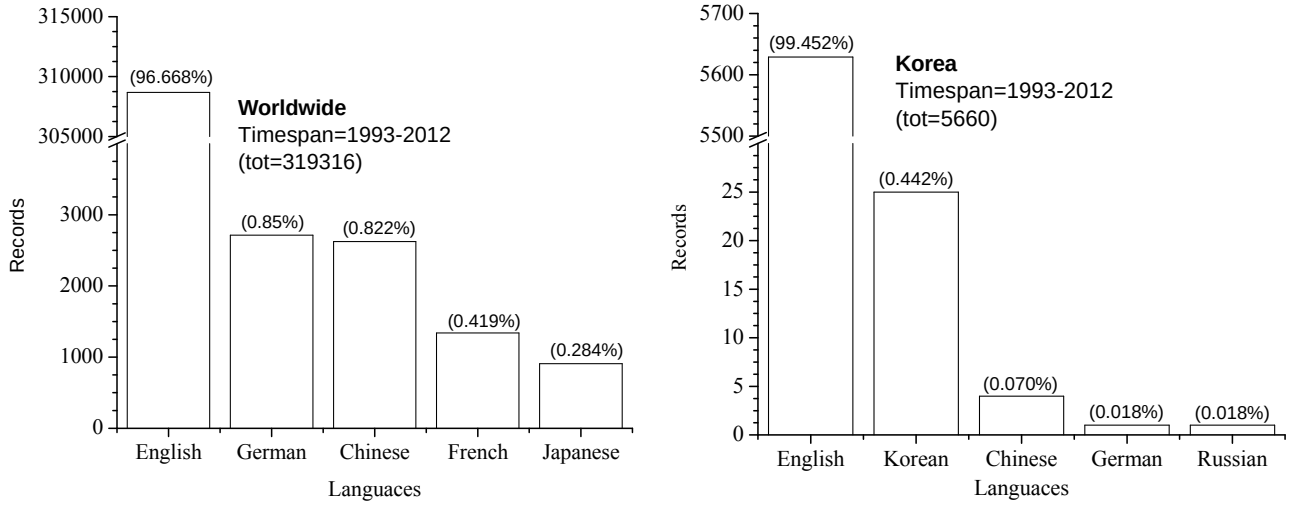
It is interesting to observe from Figure 1 that the number of papers authored or co-authored by Korean scientists grew by an average of more than 5% per year from 1993 to 2012. This phenomenal increase in the amount of research papers is an indication of growing interest in chemistry in Korea, and it is in good agreement with the previous results found recently by Fink *et al.* [44] on science and technological knowledge productions in Korea. From Figure 1, it can also be clearly visualized that the growth of the cumulative numbers of R&D literature in the field of chemistry was slow from 1993 to 2000 before accelerating during the last decade, which indicates that the research activity on this field has received a major boost during the last period (2000–2012). In particular, there was a significant increase in 2008, which can be explained by the drastic change in the WOS categories during this year.

Overall, this result is also in good accordance with that obtained by Shin on the evaluation of the effects of South Korea's "*Brain Korea 21*" (BK 21) project on Korean research productivity from 1995 to 2005 [47]. The results of the analysis obtained by Shin [47] showed that in general, the growth of chemistry-related scholarly communications by Korean institutes and universities had increased significantly following the implementation of the BK 21 project in 1999.

3.3. Language-Wise Distribution of Worldwide and Korean Chemistry-Related Scholarly Communications

Worldwide Language-wise distribution of chemistry-related scholarly communications is shown in Figure 2a. In language-wise distribution of communications in the world, English topped the list, and 29 different languages in total were used to write 319,316 scholarly communications in the field of chemistry from 1993 to 2012. On the other hand, only 5 different languages were used by Korean scientists to write the 5660 communications during the studied period.

Figure 2. Language-wise distribution of scholarly communications published in the field of chemistry (**a**) in the world (24 Language values excluded from display figure) and (**b**) by authors affiliated to Korean institutions or universities (1993–2012).



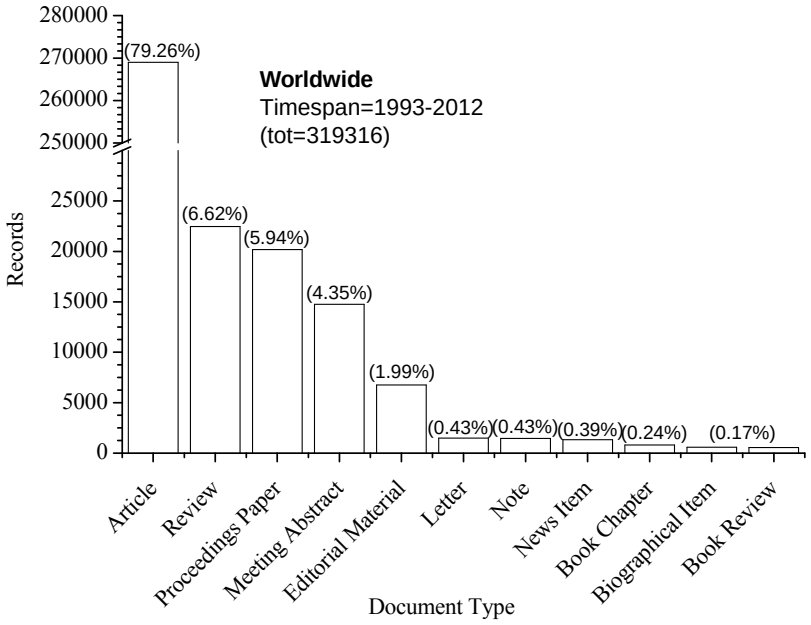
As reported in Figure 2b, English was the most frequently used language by authors affiliated with Korean institutions or universities in the field of chemistry with 5629 communications. In first approximations, this result is not in agreement with the findings of Han [48] who argued that Korean scientists and editors often had difficulty with English, as the data of this exercise reveal that out of the 5660 scholarly communications, only 25 were published in Korean language. The other languages used by Korean scientists in more than one communication was Chinese with four communications, and other minor languages included German and Russian with a percentage of about 0.018% each.

3.4. Document Type-Wise Distribution of Korean and Worldwide Chemistry-Related Scholarly Communications

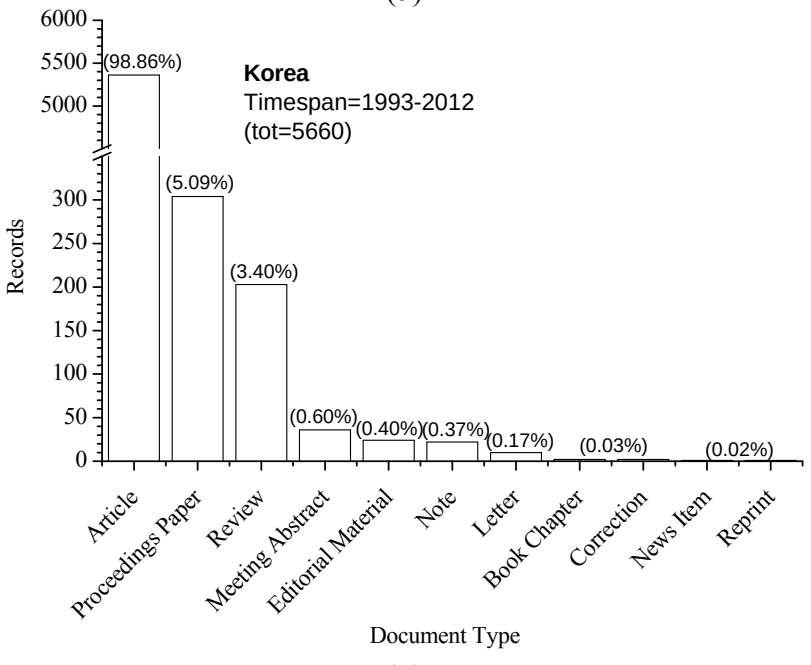
Figure 3a shows the document type-wise worldwide distribution of the communications in the field of chemistry (1993–2012). The highest number was seen in communications published as Article (79.26%), followed by Reviews (6.62%) and Proceeding Papers (5.94%).

The 5660 Korean communications were divided into 11 document types in the WOS database. Figure 3b indicates the percentage (%) of total number of chemistry-related scholarly communications in various document types (contains duplicates).

Figure 3. Comparison between (**a**) worldwide (12 Document Type values excluded from display figure) and (**b**) Korean document type distributions collected between 1993 and 2012.



(**a**)



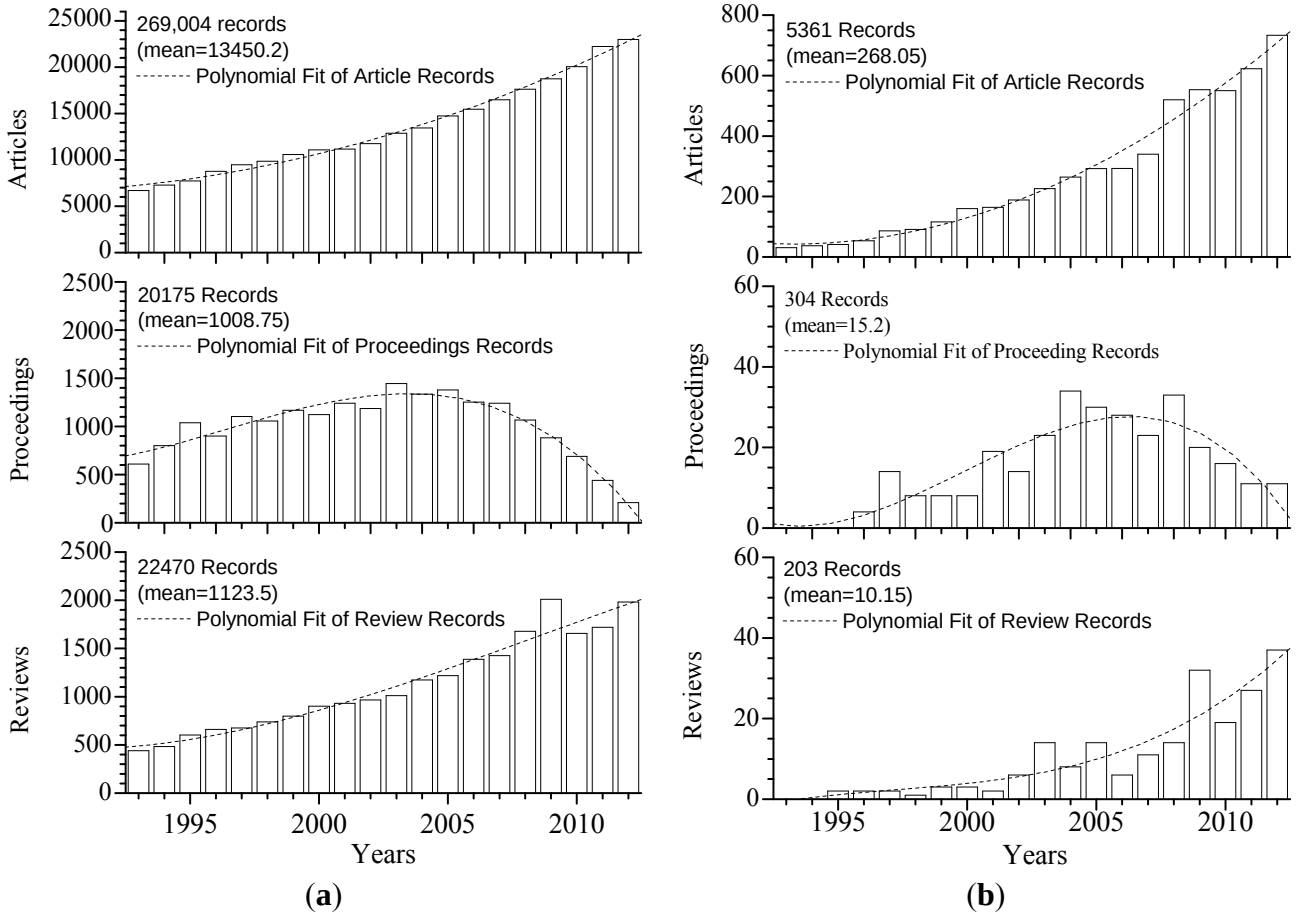
(**b**)

From Figure 3b, the first document type amounted to more than 98% of the total number of relevant chemistry-related scholarly communications. Out of 5660 communications, 5361 communications were published as Article (98.86%), followed by Proceeding Paper (5.1%) and Review (3.4%). Scientists in Korea are still publishing less Reviews and more Proceeding Papers than their peers in other countries (see Figure 3a). The country's attempt to quickly increase the number of communications listed in the Science Citation Index (SCI) by promoting everyday competition among the scientists may have successfully resulted in obtaining more scientific papers in a relatively short time (*i.e.*, Article and Proceeding Paper) [45,47].

The Worldwide and Korean scholarly communications published as Article, Proceeding Paper, and Review between 1993 and 2012 were represented by three exponential equations in Figure 4.

Overall, as illustrated in Figure 4, Article and Review document types containing at least one author from a Korean institution or university showed the greatest growth rates from 1993 to 2001. These trends were similar to the observed worldwide trends. The number of Korean Proceeding Papers followed the same behavior of worldwide scholarly communications, confirming the general character of the production of proceeding records in the world.

Figure 4. Year-wise cumulative research communications as Article, Proceedings Paper and Review in the field of chemistry (**a**) in the world and (**b**) by authors affiliated to Korean institutions or universities (1993–2012).



3.5. Category-Wise Distribution of Korean and Worldwide Chemistry-Related Scholarly Communications

The WOS categories of each of the 319,316 and 5660 scholarly communications in the world and Korea, respectively, were studied. There was a great diversity within the research topics of chemistry, including more than 100 categories identified by the WOS database from 1993 to 2012 which indicates that chemical research published in the world covers a wide spectrum of categories.

Table 2 lists the major WOS categories with the greatest number of chemistry-related scholarly communications published in the world (1993–2012). The major chemical categories in the world were Chemistry Multidisciplinary, Chemistry Organic, Chemistry Inorganic Nuclear, Chemistry Physical and Materials Science Multidisciplinary (212,497 communications, 66.55%).

Table 2. List of the top 10 WOS categories (out of a total of 158) with the greatest number of scholarly communications in the field of chemistry published by authors affiliated to Korean institutions or universities in terms of the number of communications (1993–2012). Top 10 worldwide WOS categories (out of a total of 248) are included in this table for comparison purposes. The first column represents the WOS Category's rank (1–10).

	WOS Categories (Worldwide)	**Records**	**% out of 319,316**
1	Chemistry Multidisciplinary	75,131	23.53
2	Chemistry Organic	41,094	12.87
3	Chemistry Inorganic Nuclear	38,795	12.15
4	Chemistry Physical	37,276	11.67
5	Materials Science Multidisciplinary	20,201	6.33
6	Biochemistry Molecular Biology	13,901	4.33
7	Environmental Sciences	13,188	4.13
8	Physics Atomic Molecular Chemical	12,679	3.97
9	Chemical Engineering	12,167	3.81
10	Chemistry Analytical	10,653	3.37
	WOS Categories (Korea)	**Records**	**% out of 5660**
1	Chemistry Multidisciplinary	1974	34.87
2	Chemical Engineering	840	14.84
3	Chemistry Physical	711	12.56
4	Materials Science Multidisciplinary	687	12.14
5	Chemistry Organic	522	9.22
6	Physics Applied	407	7.19
7	Chemistry Inorganic Nuclear	349	6.17
8	Physics Condensed Matter	287	5.07
9	Nanoscience Nanotechnology	282	4.98
10	Environmental Sciences	220	3.89

Table 2 also lists the top 10 WOS categories published by Korean researchers between 1993 and 2012. The five core Korean categories which are Chemistry Multidisciplinary (34.88%), Chemical Engineering (14.84%), Physical Chemistry (12.56%), Materials Science Multidisciplinary (12.14%) and Chemistry Organic (9.22%) took the majority of the total chemistry-related scholarly communications (4734 communications) with a great percentage of 83.64%. The other categories with

more than 200 communications were Physics Applied (7.2%), Chemistry Inorganic Nuclear (6.17%), Physics Condensed Matter (5.07%), Nanoscience Nanotechnology (4.99%), and Environmental Sciences (3.89%) with 407, 349, 287, 282 and 220 communications, respectively. These results are consistent with the previous studies about the scientific sub-field distribution of published papers from 1992 to 1998 covered by the Science Citation Index (SCI) CD-ROM in chemistry fields by the Chemistry Department of Seoul National University [45]. In particular, based on the titles of journals, the authors argued that the SNU chemists focused heavily on Chemistry Multidisciplinary (39.6%), Chemistry Organic (12.9%), and Physical Chemistry (10.9%) [45]. Considering these results, it can be noted that Korean chemists tend to exclusively focus more and more on the few WOS categories, meaning that about four fifths (83.64%) of all chemistry-related scholarly communications published by Korean chemists are restricted to five categories with a national pretension to Chemical Engineering, Physical Chemistry and Materials Science.

Figure 5. Year-wise cumulative scholarly communications in the top-3 Korean WOS categories (Chemistry Multidisciplinary, Chemical Engineering, and Chemistry Physical) published (**a**) in the world and (**b**) by authors affiliated to Korean institutions or universities (1993–2012).

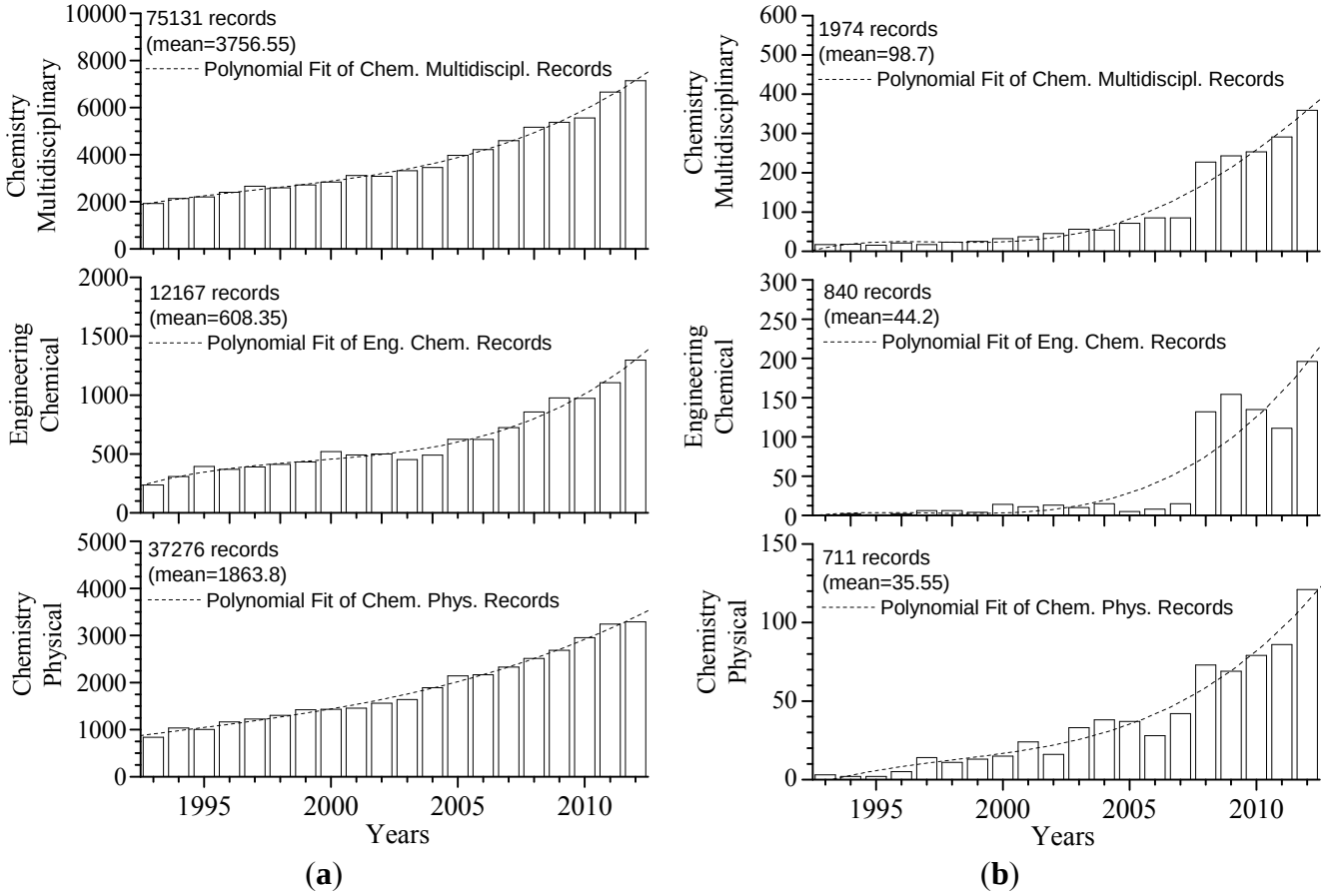


Figure 5 reveals the year-distribution of the worldwide and Korean chemistry-related scholarly communications in the Top 3 categories from 1993 to 2012. In the Chemical Engineering and Chemistry Physical fields, the communications have increased from 0 in 1993 to about 200 in 2012 and from 3 to about 120 communications in the same range of time, respectively (see Figure 5b).

Visibly in Figure 5b, the proportion of the Korean communications in the three core categories exhibited higher variation during the covered research period than the global scholarly communications in the same scientific subject. The changes in WOS categories plausibly explain the previously obtained results on the year-wise distribution of all scholarly communications published by authors affiliated to Korean institutions or universities in the field of chemistry (without any distinction regarding WOS categories) (see Figure 1b). As a result of these changes, Korean chemists' academic outputs have significantly increased in number from 2007 to 2009, and Korea's influence on the field of Chemical Engineering and Chemistry Physical has grown stronger during the last years.

3.6. Source Title-Wise Distribution of Korean and Worldwide Chemistry-Related Scholarly Communications

In the present section, the worldwide and Korean source titles on chemistry topic are taken as a tool to study the communications. There were more than 100 different source titles among the 5660 Korean chemistry-related scholarly communications. Table 3 shows the source title-wise distribution in the chemical journals listed in WOS in the world and in Korea. The table indicates the top 10 communication sources in the field of chemistry from 1993 to 2012.

Table 3. The top 10 Source Titles (out of a total of 991) in terms of the number of scholarly research communications published by authors affiliated to Korean institutions or universities from 1993 to 2012. Top 10 worldwide Source Titles (out of a total of 8952) are included in this table for comparison purposes.

	Source Title (Worldwide)	**Records**	**% out of 319,316**
1	*Abstracts of Papers of the American Chemical Society*	12,936	4.05
2	*Journal of the American Chemical Society*	6,786	2.12
3	*Inorganic Chemistry*	5,797	1.81
4	*Angewandte Chemie International Edition*	5,437	1.70
5	*Organometallics*	5,065	1.59
6	*Chemistry A European Journal*	4,201	1.31
7	*Tetrahedron Letters*	4,152	1.30
8	*Journal of Organic Chemistry*	3,790	1.19
9	*Journal of Organometallic Chemistry*	3,712	1.16
10	*Clinical Chemistry*	3,552	1.11
	Source Title (Korea)	**Records**	**% out of 5660**
1	*Journal of Industrial and Engineering Chemistry*	646	11.41
2	*Bulletin of The Korean Chemical Society*	391	6.91
3	*Angewandte Chemie International Edition*	130	2.30
4	*Journal of the American Chemical Society*	124	2.19
5	*Tetrahedron Letters*	121	2.14
6	*Chemical Communications*	91	1.61
7	*Chemistry A European Journal*	71	1.25
8	*Inorganic Chemistry*	60	1.06
9	*Journal of Physical Chemistry C*	58	1.02
10	*Journal of Chemical Physics*	53	0.97

According to Han [48], there are 662 societies of science and technology in Korea, including Chemistry and Chemical Engineering. In the chemistry area, the "Korean Chemical Society" has established two journals, which are the *Bulletin of the Korean Chemical Society* (BKCS) and the *Journal of the Korean Chemical Society* (JKCS). The official journal of the "Korean Society of Industrial and Engineering Chemistry" in Korea is the *Journal of Industrial and Engineering Chemistry* (JIEC). It is interesting to note here that 646 (11.41%) communications containing at least one author affiliated to Korean institutions or universities which were on the highest rank in number were from the *Journal of Industrial and Engineering Chemistry* (JIEC), followed by the *Bulletin of the Korean Chemical Society* (BKCS) with 391 communications (6.91%). According to Table 3, it can be observed that many Korean researchers prefer to publish their works in national journals and this fact may have implications for the future internationalization of academic results in chemistry fields obtained by Korean researchers.

These results are consistent with the previous studies conducted by Kim and Kim where the authors had said that one of the major journal used by Korean chemists at the Seoul National University (SNU) was the *Bulletin of the Korean Chemical Society* (BKCS) [45].

While Korea's Science Citation Index (SCI) communications publication in English in the above journals has been rapidly increasing, another interesting exercise is to identify the Journal-type distribution of the 25 chemistry-related scholarly communications published in Korean language by Korean chemists and recorded in WOS database.

The resulting data from this exercise has revealed that out of 25 scholarly communications, 11 communications were published in *Polymer Korea* (official journal published bimonthly by the "Polymer Society of Korea"), followed by 8 communications in the *Korean Journal of Laboratory Medicine* (official journal of the "Korean Society for Laboratory Medicine") and 2 in the *Korean Journal of Metals and Materials* (domestic academic journal of the "Korean Institute of Metals and Materials"). The other 4 communications wrote in Korean were in the *Journal of Korean Academy of Nursing* (journal published by "Korean Society of Nursing Science"), the *Korean Journal for Food Science of Animal Resources* (bimonthly journal published by "Korean Society for Food Science of Animal Resources"), the *Korean Journal of Medical History* (journal published by "Korean Society for the History of Medicine"), and the *Journal of the Korean Institute of Metals and Materials*. In fact, a characteristic of most Korean scholarly journals is that they are university-based journals and that most of them are published by academic societies without any cooperation from commercial publishers [43,48].

3.7. Organizations-Wise Distribution of Korean Chemistry-Related Scholarly Communications

The top 10 Korean organizations that produced the highest number of chemistry-related scholarly communications are shown in Table 4. These ten institutions have published 3255 communications, about 57.51% of the total amount of all Korean communications in chemistry published from 1993 to 2012.

The most productive Korean institutions and universities in the field of chemistry were the Seoul National University (SNU) with 705 communications (12.46%), Korea Advanced Institute of Science and Technology (KAIST) with 450 communications (7.95%), Yonsei University (YU) with

398 communications (7.03%), Korea University (KU) with 307 communications (5.4%) and Pohang University of Science and Technology (POSTEC) with 284 communications (5.02%). These results are in good agreement with the results recently obtained in a large-scale analysis of measuring research performance in Korean universities [33]. For more information regarding the relationship between the governance in the Korean higher education and the Korean public universities, see Byun [49].

Table 4. Top 10 Korean Organizations (out of a total of 2026) in terms of the productivity of scholarly communications from 1993 to 2012. The first column represents the rank of the Organization.

	Organizations	Records	% out of 5660
1	Seoul National University (SNU)	705	12.46
2	Korea Advanced Institute of Science and Technology (KAIST)	450	7.95
3	Yonsei University (YU)	398	7.03
4	KOREA University (KU)	307	5.42
5	Pohang University of Science and Technology (POSTEC)	284	5.02
6	SUNGKYUNKWAN University (SKKU)	245	4.33
7	Pusan National University (PNU)	236	4.17
8	HANYANG University (HU)	221	3.90
9	Korea Institute of Science and Technology (KIST)	207	3.66
10	INHA University	202	3.57

The top 10 Korean research grants ranked by the quantity of chemistry-related scholarly communications are shown in Table 5. As it can be noted, the most cited grant code on the acknowledgment section of the papers published by Korean scientists in the field of chemistry were two Korean *World Class University* (WCU) programs, called R31-2008-000-10010-0 and R31-2008-000-10059-0 with 50 and 20 communications respectively, and a Grants-in-Aid coded 20108010 with 26 communications (0.46%).

Table 5. Top 10 Korean Grants and Programs (out of a total of 2318) in terms of the quantity of scholarly communications in the field of chemistry (1993–2012). 3935 records (69.5%) do not contain data in the analyzed field.

	Grant Numbers	Note	Records	% out of 5660
1	R31-2008-000-10010-0	World Class University (WCU) Program	50	0.88
2	20108010	Grants-in-Aid	26	0.46
3	R31-2008-000-10059-0	WCU Program	20	0.35
4	R11-2005-065	Basic Science Research Program	17	0.30
5	R31-10013	WCU Program	15	0.26
6	2010-00353	Global Research Laboratory (GRL) Program	14	0.25
7	R33-2008-000-10003	WCU Program	14	0.25
8	2009-0093818	Priority Research Centers Program	11	0.19
9	20108001	Grants-in-Aid (“pi-space”)	11	0.19
10	CHE-0924620	Grant	11	0.19

In general, the Korean government invested KRW 825 billion for *World Class University* (WCU) programs over five years, and following three selection rounds (Establishment of Majors/Departments, Invitation of Scholars and Invitation of World Renowned Scholars) [50], the Korean *World Class University* (WCU) programs have funded about 140 different programs in 33 Korean universities [51]. For a comprehensive overview of the Korean government's policies for establishing *World Class University* (WCU) and their implications for Korean higher education institutions, see Byun *et al.* [51] and Deem *et al.* [52].

3.8. The Top Cited Korean Chemistry-Related Scholarly Communications from 1993 to 2012

The 20 most cited chemistry-related scholarly communications published by Korean scientists from 1993 to 2012 have attracted more than 12,539 citations in total with about 627 citations per communication on average (see Table 6).

Table 6. The most frequently cited scholarly communications in the field of chemistry published by authors affiliated to Korean institutions or universities from 1993 to 2012. The "Times Cited" in the last column indicates the number of the times where a published communication was cited by other authors (including conference proceedings).

Year	***Source Title*: Volume;Issue,Pages**	Times Cited
1993	*Science*: 262;5141,1855–1857	144
1994	*Journal of the American Chemical Society*: 116;16,7399–7400	229
1995	*Journal of the Chemical Society-Faraday Transactions*: 91;18,3245–3253	107
1996	*Applied Surface Science*: 93:2,143–149	118
1997	*Journal of the American Chemical Society*: 119;2,451–452	224
1998	*Journal of the American Chemical Society*: 120;41,10622–10628	330
1999	*Coordination Chemistry Reviews*: 188,297–341	238
2000	*Nature*: 404;6781,982–986	2527
2001	*Science*: 294;5541,348–351	487
2002	*Chemical Society Reviews*: 31;2,96–107	582
2003	*Nature*: 423;6941,705–714	3499
2004	*Angewandte Chemie-International Edition*: 43;38,5033–5036	546
2005	*Chemistry-A European Journal*: 11;12,3521–3529	508
2006	*Chemical Society Reviews*: 35;4,355–360	433
2007	*Chemical Society Reviews*: 36;2,267–279	302
2008	*Langmuir*: 24;14,7245–7250	369
2009	*Journal of Computational Chemistry*: 30;10,1545–1614	1243
2010	*Progress in Polymer Science*:35; 7,837–867	248
2011	*Advanced Energy Materials*: 1;1,34–50	135
2012	*Chemical Reviews*: 112;2,675–702	270

Out of these 12,539 citations made by researchers from all over the world, the highest number of citations per year was obtained in the year 2003, followed by the year 2000 and 2009. The lowest number of citations was obtained in the year 1995, 1996 and 2011. In particular, the highest number of citations for a single Korean communication was obtained in the year 2003 with 3499 citations on a Review published in *Nature* in the WOS categories of "Multidisciplinary Sciences" (where the authors

introduced the "*conceptual approach that requires the use of secondary building units to direct the assembly of ordered frameworks epitomizes this process*" called reticular synthesis) [53].

3.9. International Collaboration-Wise Distribution of the Korean Chemistry-Related Scholarly Communications

Approximately 65 countries were involved in the Korean chemistry-related scholarly communications' production through international collaborations. In this section the top 10 producing countries in terms of double affiliations with the Korean chemistry-related scholarly communications are discussed.

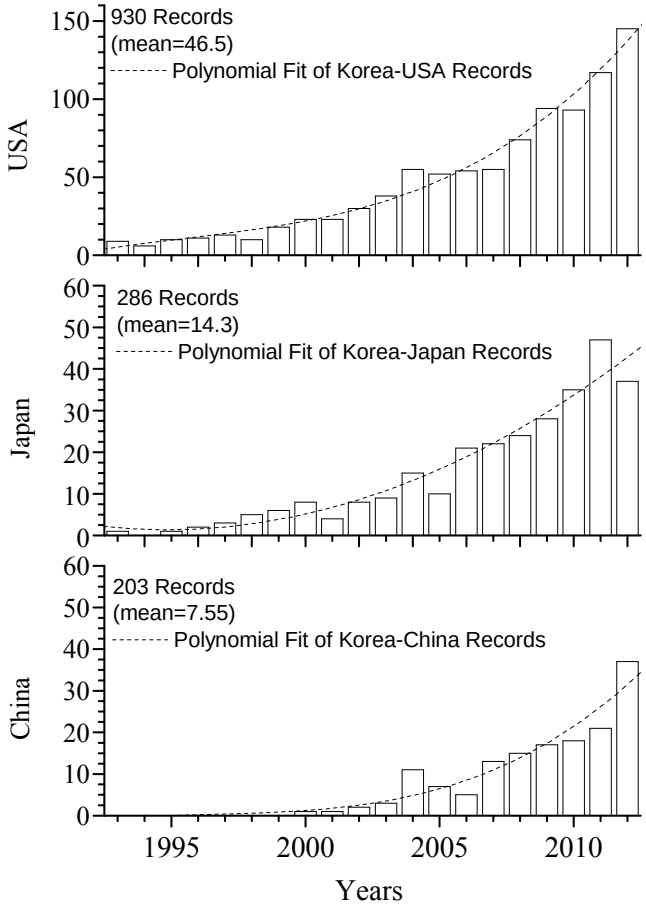
The USA had the majority of the total collaborative communications with Korean institutions and universities (930 communications) with a great percentage of 16.43 % (see Table 7). After the USA, other countries have been categorized into two groups. The first group is constituted by cooperative countries in the same geographical area of Korea: Japan (286 communications), China (151 communications), and India (116 communications). Germany (106 communications), Canada (88 communications), France (85) England (64), Australia (58) and Russia (57) are in the other group of six countries with more than 50 communications. As this categorization indicates, after the USA with 16.43% of collaborative chemistry-related scholarly communications with Korea, about 9.77% of the communications were coproduced with countries in the first Asia Pacific region and 8.09% with the countries in the second group. This result is in good agreement with the recent observation by Scheidt, *et al.* [54] and Haustein *et al.* [55], who have shown that the USA has been Korea's most important co-publication partner in all fields since 2000, such as in Medicine, Physics, Engineering, Biology and Chemistry, followed by Japan, EU and China.

In addition, an exercise was carried out to determine the international scholarly activity in the field of chemistry (1993–2012) of the top 3 countries with the highest percentage of co-affiliated scholarly communications with Korean chemists. The distribution of the co-affiliated scholarly communications from Korea with USA, Japan and China from 1993 to 2012 is given in Figure 6.

Table 7. The top-10 International Collaboration pattern (out of a total of 66 Countries) of Korean communications on chemistry (5660 records) from 1993 to 2012.

	Collaborations	**Records**	**% out of 5660**
0	South Korea	5660	100
1	USA	930	16.43
2	Japan	286	5.05
3	China	151	2.67
4	India	116	2.05
5	Germany	106	1.87
6	Canada	88	1.55
7	France	85	1.50
8	England	64	1.13
9	Australia	58	1.02
10	Russia	57	1.01

Figure 6. Year-wise cumulative cooperative scholarly communications from Korea and the top 3 Countries of Table 7 (the USA, Japan, and China) in the field of chemistry from 1993 to 2012.



In all analyzed cases, there was an increase in cooperation levels between Korea and foreign scientists from 2000 to 2004. Several possible interpretations come to mind, but the most appropriate explanation is that this phenomenon was a consequence of the grand government-initiated project in the Korean education sector (as seen above, called "*Brain Korea 21*" project) [33,47] which was executed during the first phase (1999–2005), aiming to raise Korea to become one of the top 10 countries in the world particularly in terms of number of papers listed in the Science Citation Index (SCI) as well as economic scale [51]. Looking at the results in more depth, a further possible explanation is that the number of international students in Korea has increased noticeably since the introduction of the "*Study Korea Project*" in 2004, with the aim of lead "*the globalization of Korean universities*" [56] through increasing the chance to initiate new international research collaborations between the Korean hosts and the sender institutions or universities from other countries. This fact can be used to explain the observed data on co-affiliated communications.

It is also interesting to note that 930 Korea-USA co-affiliated communications obtained in this analysis evolved in Chemistry Multidisciplinary (473 communication and 50.86% communication share), Materials Science (182 communications and 19.57% communication share) and Physics (136 communications and 14.62% communication share). In the same way, 286 Korea-Japan communications evolved in Chemistry Multidisciplinary (181 communications and 63.29% communications share), Materials Science (31 communications and 10.84% communication share),

and Physics (21 communications and 7.34% communications share), whereas 151 Korea-China communications evolved in Chemistry Multidisciplinary (81 communications and 63.29% communications share), Materials Science (28 communications and 18.54% communications share) and Chemical Engineering (26 communications and 17.22% communications share). To summarize these last results, Korean scientists seem to have the tendency to collaborate with Japanese institutions or universities in the field of Materials Science, while they are inclined to collaborate with Chinese institutions or universities in the field of Chemical Engineering.

4. Conclusions

The present systematic review employs a scientometric analysis of the Web of Science (WOS) database to explore the trends in the Korean chemistry-related scholarly communications from 1993 to 2012. Within the limits of this type of study [33,44,46], the following results have been obtained from this analysis: (1) A total number of 5660 communications related to chemistry were published by at least one author affiliated to Korean institutions or universities during the observed period of time; (2) The Koreans' interest in the field of chemistry—and more specifically in the field of Chemical Engineering Physical Chemistry and Materials Science—has strongly increased recently as shows the exponentially increasing quantity of chemistry-related scholarly communications; (3) The 20 most cited chemistry-related scholarly communications published by Korean scientists (1993–2012) have attracted more than 12,539 citations in total (627 citations per communication).

Statistical findings suggest that English (5629 communications, 99.5%) and Article (5361 communications, 98.9%) were the most commonly used Language and Document Type, respectively, by authors affiliated to Korean institutions or universities. Chemistry Multidisciplinary (34.9%), Chemical Engineering (14.8%), Physical Chemistry (12.6%), Materials Science Multidisciplinary (12.1%) and Chemistry Organic (9.2%) were the top five most common WOS categories in which a total of 4734 communications (83.6%) were listed.

The national *Journal of Industrial and Engineering Chemistry* (646 communications, 11.4%) and *Bulletin of the Korean Chemical Society* (391 communications, 6.9%) were the most commonly used scholarly titles by Korean chemists to exchange information in this field of research.

Most of the Korean chemistry-related scholarly communications were done by the Seoul National University (705 communications, 12.5%), Korea Advanced Institute of Science and Technology (450 communications, 8%) and Yonsei University (398 communications, 7%). Korean *World Class University* (WCU) programs were the most productive National Programs in Korea.

The values of international collaborative activities indicators suggest that the USA has the majority of the total collaborative communications with Korean institutions and universities (930 communications, 16.4%), followed by other cooperative countries in the same geographical area of Korea, like Japan (286 communications, 5%), China (151 communications, 2.7%) and India (116 communications, 2%).

The Korean scientific production in the field of chemistry is growing fast compared to its relatively short history. Nonetheless, despite the intense efforts of the Korean government, institutions and universities, which resulted in a growing number of Korean chemistry-related scholarly communications over the last decade, there still seems to be a sort of collective hesitation to submit the

obtained results out of Korea and to initiate new scientific collaborations with groups far from the Asia Pacific-region (like Middle East, Europe, South America, *etc.*).

Conflicts of Interest

The author declares no conflict of interest.

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