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Characteristics and trends of research articles authored by researchers affiliated with institute of chemical engineering in Taiwan

Yu-Wei Chang [a,*], Tung-Wen Cheng [b,1]

[a] Department of Library and Information Science, Fu Jen Catholic University, New Taipei City 24205, Taiwan
[b] Department of Chemical and Materials Engineering, Tamkang University, New Taipei City 25137, Taiwan

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ABSTRACT

This study used the bibliometric method to analyze the characteristics and trends of research articles authored by researchers affiliated with institute of chemical engineering in Taiwan based on bibliographic data indexed by Web of Science (WOS). Results based on 14,524 articles published in the period of 1973–2010 demonstrated an increasing trend in the number of articles. The two-authored articles were the largest share; however, the articles authored by five or more researchers have become the largest part since 2007. Because co-authorship is a common phenomenon, the co-authored articles were further divided by types of collaboration. The results indicate that inter-institutional collaboration replaced the intra-departmental collaboration and has become the dominant type of collaboration since 2005. The interdisciplinary articles also revealed a considerable upward tendency. In addition, over 60% of articles were produced by the top five institutes. All articles were published in 967 journals and covered 135 subjects. Polymer Science, Chemical Engineering, and Physical Chemistry were the main subjects in most of the articles. The increase in the number of subject categories by year confirms that the research scope in chemical engineering is expanding.

1. Introduction

Chemical industry, which is the second largest industry in the manufacturing sector in Taiwan [1], is essential to Taiwan economic development and has made a considerable contribution to Taiwan's international competition. This indicates that chemical engineers and researchers of chemical engineering are crucial for the development of the chemical industry and the field of chemical engineering. In particular, research on chemical engineering is often related to industrial requirements [2], implying that education of chemical engineering is essential for the development of chemical industries.

The education of chemical engineering in Taiwan can be traced to the period of Japanese colonization (1895–1945). In 1918, the first course in applied chemistry was offered by the School of Industrial Instruction (the earliest name of National Taipei University of Technology). In 1931, the Department of Applied Chemistry was established in Tainan Technical College (the original name of National Cheng Kung University, NCKU). In 1941, the first Department of Chemical Engineering (ChE) in Taiwan was established at Taihoku Imperial University (renamed National Taiwan University, NTU, in 1945). In addition, the first master program of chemical engineering in Taiwan was established at NCKU in 1962. The first PhD program of chemical engineering was also established by NCKU in 1969. With the continuing expansion in the number of universities over the past decades, an increasing tendency was observed in the number of researchers affiliated with institutes of chemical engineering and the quantity of research.

Analysis of the characteristics and trends of research output over a long period can contribute to the understanding of research development in a specific discipline. To achieve this objective, bibliometric methods, which were quantitative-analytical methods [3], were widely used in various disciplines, including the field of chemical engineering. For example, Peters and Van Raan [4,5] used the co-word analysis to reveal the trend in research topics in the field of chemical engineering. They also analyzed the characteristics of citing literature based on 19 leading chemical engineering researchers [6]. Yin [7] focused on the trends in the number of publications authored by chemical engineering researchers in Singapore, Malaysia, Thailand, Indonesia, and Philippines. The results obtained from bibliometric methods were objective because all of the analyzed data were collected from bibliographical databases. In addition, bibliometric methods are appropriate for analyzing a large amount of data to reveal trends over a period of years.

* Corresponding author. Tel.: +886 2 2905 3316; fax: +886 2 2901 7405.
E-mail addresses: yuweichang2007@gmail.com (Y.-W. Chang), twcheng@mail.tku.edu.tw (T.-W. Cheng).
[1] Tel.: +886 2 2621 9554; fax: +886 2 2620 9887.

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Although numerous studies conducted by Taiwanese researchers of chemical engineering research were published, information about their characteristics and trends is limited. Chen reviewed papers authored by Taiwan researchers published in the *Journal of the Chinese Institute of Chemical Engineers* in 2004 and 2005 [8]. Cheng and Chen investigated the ISI papers written by chemical engineering researchers in Taiwan and published in 2006 [9]. They discovered that approximately two thirds of articles were contributed by researchers of 12 leading institutes. The correlation between the number of authors and the number of articles fit the power-law model well. Cheng *et al.* compared the papers published in 2008 authored by researchers in the fields of chemical engineering, civil engineering, and mechanical engineering [10]. The results also confirmed that the correlation between the number of authors and the number of articles in three fields efficiently fit the power-law model. Chen classified articles published in *Journal of the Taiwan Institute of Chemical Engineers* from 2007 to 2009, and revealed that most articles belonged to the two fields of biochemical engineering and separation technology [11].

A number of related studies focused on articles published in a specific year or in a short period, and a number of studies limited the source materials to a specific journal. The limited data indicates that the results of characteristics and trends of research articles published by researchers affiliated with institutes of chemical engineering in Taiwan are insufficient. Therefore, this study used the bibliometric method to investigate the characteristics and trends of research articles authored by researchers affiliated with institutes of chemical engineering in Taiwan for a long period. The focus of this study included productivity of articles, authorship pattern, types of collaboration, productive institutes, productive journals, and distribution of articles by subject categories. The research questions addressed in this paper are as follows:

1. Is there an increasing trend in the number of articles authored by researchers affiliated with institute of chemical engineering in Taiwan?
2. What is the authorship pattern of articles published by researchers affiliated with institute of chemical engineering in Taiwan?
3. What institutions are the top five prolific institutes of chemical engineering in Taiwan?
4. What types of collaboration occurred between researchers affiliated with in institute of chemical engineering in Taiwan?
5. Which leading journals published the most articles authored by chemical engineering researchers?
6. What subject categories are covered by articles authored by researchers affiliated with institute of chemical engineering in Taiwan?

2. Method

2.1. Data collection

This study used the bibliometric method to analyze the characteristics and trends of research articles authored by researchers affiliated with institutes of chemical engineering in Taiwan. The bibliographic records analyzed for this study were retrieved and converted from Web of Science (WOS) database, which is a multidiscipline citation index database with authorial affiliations information. Taiwanese researchers in natural sciences or engineering tend to publish their papers in journals indexed by WOS because papers published in journals indexed by WOS are emphasized in research evaluation in Taiwan. Therefore, WOS was evaluated as the optimal database to obtain source materials.

A search strategy that consisted of three elements was developed to obtain bibliographic data related to research articles authored by researchers affiliated with institutes of chemical engineering in Taiwan. First, two key concepts of "Taiwan" and "Chemical Engineering" were included in address data of authors, which were subsequently changed into two search terms, "Taiwan" and "Chem Engn", to be filled in the field of address of WOS. Second, the document type was limited to *Articles*, referring to research articles. Third, the latest year of publication of articles was 2010. Based on the above search strategy, a total number of 14,806 bibliographic records were obtained from WOS. Each bibliographic record consisted of the title, name of author, authorial affiliations, source journal, year of publication, and subject category.

Disqualified articles may be included in the 14,806 articles based on the search requirements. For example, in a co-authored article, one author is from the department of physics in Taiwan and another author is from the department of chemical engineering in Japan. Therefore, authors' affiliations data in bibliographic records were examined manually. After excluding 282 disqualified articles, 14,524 articles were analyzed for this study.

2.2. Data analysis

The data converted from WOS can be analyzed by Bibcoupl.exe program, which was devised by Professor Leydesdorff and is available free of charge on the Internet [12], and the various output generated from it can subsequently be saved as Excel format files.

2.2.1. Authorship pattern

The number of authors per article and the average number of authors per article can be identified according to the name of the author. The authorship pattern of articles authored by Taiwanese researchers affiliated with institutes of chemical engineering, such as the percentages of articles with various number of authors is subsequently revealed.

2.2.2. Types of collaboration

Additional information can be identified according to the author affiliate address information, such as type of institution, disciplinary attribute of institution, country, and type of collaboration in a co-authored article. The authorial affiliation is the information provided by authors listed in an article. If the author did not provide detailed address information, some information would not be obtained. For example, if only the name of university was revealed in the author affiliated address information, the discipline that the author belonged to would not be identified.

Two criteria were used in this study to divide the co-authored articles by types of collaboration. In terms of geographical proximity between co-author, all co-authored articles were first divided into two groups, that is, international articles and domestic articles. When two or more countries were contained in address data of a co-authored article, the co-authored article was defined as an article resulted from international collaboration. The domestically co-authored articles were further distinguished into three types of collaboration, as follows: (1) intra-departmental collaboration: only one institutional affiliation was listed in address data; (2) inter-departmental collaboration: two or more departments/institutes were listed and all of them were affiliated with the same university/institution; (3) inter-institutional collaboration: at least two universities/institutions were listed in address data. In addition, this study identified the articles of interdisciplinary collaboration, in which at least two authors represented departments/institutes in various fields. Therefore, each co-authored article was coded with two types of collaboration.

2.2.3. Article distribution by subject category

Each article published in journals indexed by WOS has one or more subject categories assigned by Journal of Citation Report

(JCR), based on the subjects of source journal. If an article was assigned with n subject categories, each subject category was assumed to have $1/n$ article.

2.2.4. Standardization of journal titles

Considering the changes of journal titles, the standardization of journal titles was conducted by adding current journal title to previous journal title. The various titles of a journal were regarded as the same journal. The processes for standardization of name were also applied to the names of the institutions.

3. Results and discussion

3.1. Growth trend of articles

Fig. 1 illustrates the annual number of articles authored by researchers affiliated with institutes of chemical engineering in Taiwan. A total of 14,524 articles were published between 1973 and 2010. Only five articles were published in 1973, and the number of articles was a single or double digit number below 90 before it increased to 128 in 1987. The number of articles increased considerably since 1990, that is, from 155 articles in 1990 to 1043 articles in 2010. A considerable upward trend was observed during the period of 1990–2010. According to the findings of Yin, the number of articles published by Taiwanese chemical researchers from 1996 to 2008 was larger than that published by chemical engineering researchers in Singapore, Malaysia, Thailand, Indonesia, and Philippines [7].

Literature growth resulted from various factors, such as the increase in the number of researchers [13], funding incentives [14], scientific collaboration [15] and the progress in information technology [16,17]. Among the above possible factors contributing to the growth of research articles, the increasing number of researchers is a more direct factor leading to the rapid growth of literature. According to the statistics of the Taiwan Institute of Chemical Engineers, both the number of MS and PhD students in chemical engineering related program in Taiwan increased from 288 and 24 in 1990 to 1544 and 155 in 2010, respectively [18]. The upward trend in the number of MS plus PhD students is consistent with the increasing curve of article number. However, the difference between the number of graduate students and that of articles increased since 2000. This result may be attributed to an increasing trend of multiple authorship in natural sciences [19–21]. The trend of multiple authorship in the field of chemical engineering in Taiwan was discussed in Section 3.2.

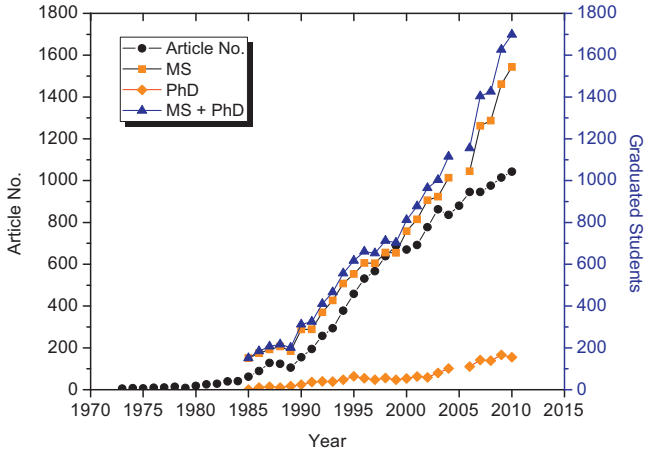

Fig. 1. The number of articles and graduate students by year.

Table 1
Authorship pattern.

No. of authors per article	No. of articles	Percentage
1	601	4.14
2	5165	35.56
3	4055	27.92
4	2048	14.10
5	1181	8.13
6	656	4.52
7	376	2.59
8	196	1.35
9	99	0.68
10	63	0.43
11	32	0.22
12	21	0.14
13	13	0.09
14	4	0.03
15	6	0.04
16	4	0.03
17	1	0.01
18	1	0.01
20	1	0.01
27	1	0.01
Total	14,524	100.00

3.2. Authorship pattern

Only 4.14% of the total of 14,524 articles had a single author; the majority (95.86%) of the articles was co-authored by at least two authors (see Table 1). The number of authors per article ranged from 1 to 27. The average number of authors per article was 3.30. More than three fourths of the articles (77.58%) were published by two to four authors. The two-authored articles accounted for the largest proportion (35.36%), followed by three-authored articles (27.92%), and four-authored articles (14.10%). However, as shown in Fig. 2, the proportions of both single-authored and two-authored articles exhibited declining trends. In particular, a sharp decline appears in the share of two-authored articles. In addition, the number of articles written by four or more authors increased considerably since 2000. In 2005 and 2006, the three-authored articles accounted for the largest proportion (29.89–30.02%). The articles authored by five or more authors became the largest part (over 32%) since 2000, and their proportion was up to 45.25% in 2010.

In accordance with prior studies on authorship in other fields [22–26], the trend toward multiple authorship in chemical engineering was observed in this study. The phenomenon of multiple authorship indicates that more collaboration occurred

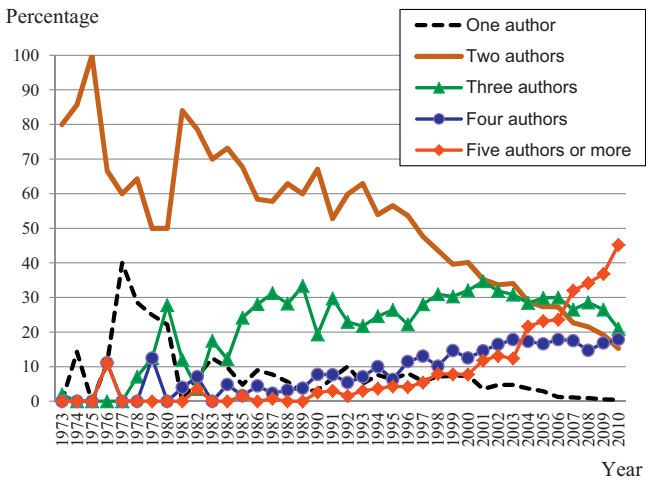

Fig. 2. Percentages of articles authored by different number of authors by year.

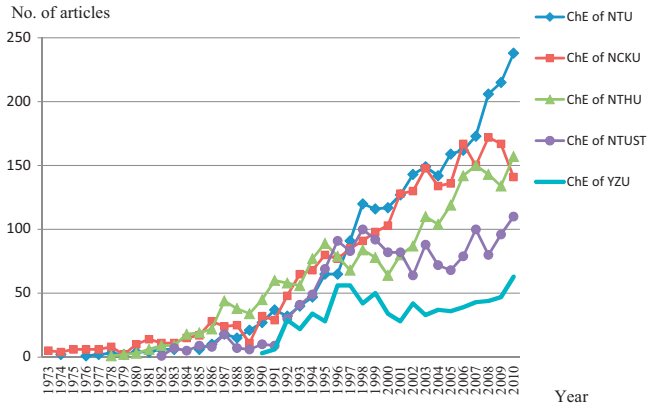

Fig. 3. Numbers of articles published by the top five prolific institutes by year.

between researchers. The research collaboration may be fostered by several factors, such as insufficient budget, improvement in research quality, growth in the interdisciplinary studies, the complex nature of scientific research, professionalization of science, and the progress in communication [23,24,27–29]. Moreover, scientific collaboration may enhance research productivity and visibility [27].

3.3. Top five prolific institutes of chemical engineering

Fig. 3 shows the top five prolific institutes of chemical engineering. The ChE of National Taiwan University (NTU) published the largest number of articles in journals indexed by the WOS (2570 articles), followed by ChE of National Cheng Kung University (NCKU) (2452 articles), ChE of National Tsing Hua University (NTHU) (2189 articles), ChE of National Taiwan University of Science and Technology (NTUST) (1556 articles), and ChE of Yuan Ze University (YZU) (772 articles). Approximately 61% of articles were produced by those top five prolific institutes of chemical engineering. All the top five institutes have an increasing trend in the productivity of research articles, especially ChE of NTU, which exhibited a considerable upward trend in recent years. The ChE of YZU is the fifth rank institute, even though it belongs to private university with a shorter history.

Generally, universities are the main producers of research output. In particular, prestigious national universities in Taiwan usually generate a larger amount of research output because of a number of factors, such as financial support from government, energetic faculties, and plenty of researchers. The top four prolific ChEs in Taiwan have a larger number of graduated MS and PhD students [18].

Table 2
Numbers and percentages of articles by types of collaboration.

Types of collaboration	No. of articles	Percentage
Intra-departmental collaboration	7547	54.21
Inter-departmental collaboration	762	5.47
Inter-institutional collaboration	4312	30.97
International collaboration	1302	9.35
Total	13,923	100.00
Interdisciplinary collaboration	5241	37.64
Non-interdisciplinary collaboration	8682	62.36
Total	13,923	100.00

3.4. Types of collaboration

Table 2 lists the number and proportion of co-authored articles that resulted from five types of collaboration, including intra-departmental collaboration, inter-departmental collaboration, inter-institutional collaboration, international collaboration, and interdisciplinary collaboration. For all 13,923 co-authored articles, the portion of articles co-written by researchers from the same institute of chemical engineering (for example, the department of chemical engineering in a university) accounted for the largest share (54.21%), followed by the articles co-authored by researchers from various institutions (for example, university or company) (30.97%), the articles co-published by researchers from various countries (9.35%), and the articles co-written by researchers from various departments/institutes in the same university/institution (5.47%). In addition, the proportion of interdisciplinary collaboration (37.64%) was smaller than that of non-interdisciplinary collaboration (62.36%).

An examination on the trend of each type of collaboration classified by geographical proximity between co-authors, as shown in Fig. 4, revealed that a considerable decreasing trend appeared in the percentages of intra-departmental collaboration, whereas each of the other three types of collaboration exhibited an increasing trend. In particular, an obvious upward trend was observed in the percentage of articles produced from inter-institutional collaboration. In addition, the inter-institutional collaboration has become the dominant type of collaboration since 2005. This indicates that more interactions exist among

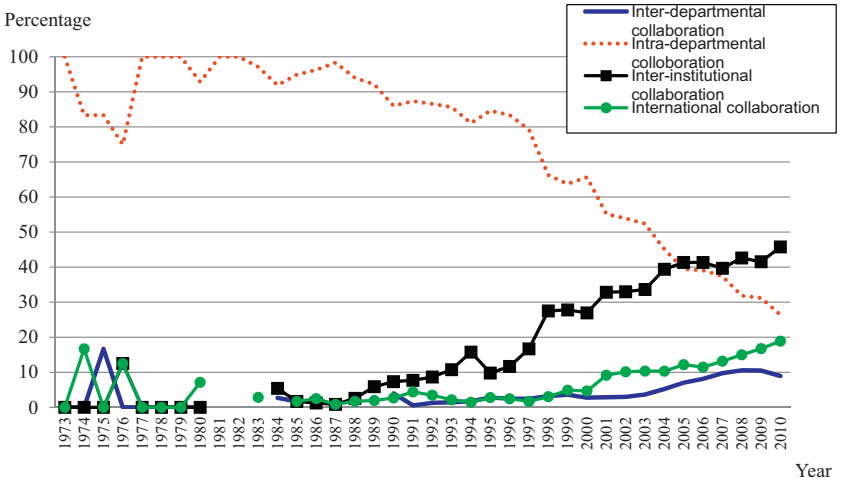

Fig. 4. Proportions of articles resulting from various types of collaboration by year.

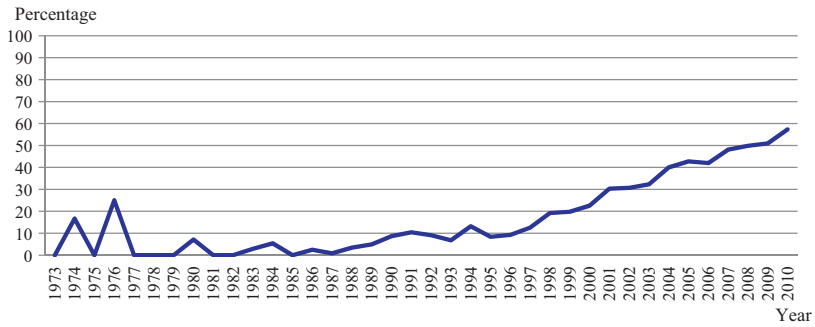

Fig. 5. Proportion of articles resulting from interdisciplinary collaboration by year.

Table 3
Articles of the top five institutes by types of collaboration.

	Intra-department	Inter-department	Inter-institution	Inter-nation	Inter-discipline
ChE of NTU	1254 (49.58%)	173 (6.84%)	816 (32.27%)	286 (11.31%)	998 (39.46%)
ChE of NCKU	1455 (60.10%)	181 (7.48%)	650 (26.85%)	135 (5.58%)	715 (29.53%)
ChE of NTHU	1108 (51.27%)	51 (2.31%)	896 (41.51%)	107 (4.91%)	854 (39.50%)
ChE of NTUST	869 (57.02%)	38 (2.49%)	497 (32.61%)	120 (7.87%)	452 (29.66%)
ChE of YZU	424 (59.38%)	34 (4.76%)	221 (30.95%)	35 (4.90%)	221 (30.95%)

institutions. Geographical distance between the institutions of collaborators is no longer the main contributing factor to domestic research collaboration in Taiwan. In addition, most of the percentages of intra-departmental collaboration from 1970s to 1980s were almost 100%, which may have been affected by a smaller number of articles and authors. Almost authors were affiliated with institutes of chemical engineering. Few of them were affiliated with institutes of chemistry or electronic engineering.

Similarly, the trend of interdisciplinary collaboration increased steadily (see Fig. 5). A crucial tendency was observed during the period of 1998–2010, which varied from 17.84% in 1998 to 57.05% in 2010. Moreover, the interdisciplinary collaboration has become dominant since 2009. This reveals that over half of co-authored papers were produced by researchers representing various fields. In addition to the changes in research interests, another possible reason for the increasing tendency in interdisciplinary collaboration is that chemical engineers must broaden their knowledge and technologies to other fields in response to the rapid change of chemistry industries [30].

3.5. Types of collaboration among the top five institutes

Table 3 lists the number of articles and percentages of articles divided by four types of collaboration among the top five institutes. All the top five institutes produced the most articles that resulted from intra-departmental collaboration with the percentage ranging from 49.58% to 60.10%, followed by articles of inter-institutional collaboration (26.85% to 41.51%). The third-ranked and fourth-ranked types were international collaboration and inter-departmental collaboration, respectively, except in the ChE of NCKU. The percentage of articles produced from intra-department collaboration in ChE of NTU was lower than that from the other institutes. Moreover, the ChE of NTU has the highest percentage of articles that resulted from international collaboration, followed by the ChE of NTUST.

International collaboration can enhance the visibility of research [27]. Although the Internet enhances the communication between countries, Hayati and Didegah [29] indicated that the main factor fostering international collaboration was international political relations. This indicates that the factors leading to an increase in international collaboration are more complex than those related to domestic collaboration. In this context, the number of articles resulting from domestic collaboration are larger than that produced by international collaboration.

The annual distributions of four types of collaboration in regard to geographical proximity between co-authors in the top five institutes are shown in Fig. 6. All of the top five institutes exhibited similar trends in the percentage of each type of collaboration. A decreasing trend was revealed in proportion of articles of the intra-departmental collaboration, whereas upward trends were observed in the proportion of articles generated from other types of collaboration. Particularly, the articles of inter-institutional collaboration accounted for the largest proportion in recent years, with approximately 50%. The percentages of inter-institutional collaboration in the top five institutes were higher than the overall percentage yielded from co-authored articles of all institutes. This indicates that the top five institutes have higher percentage of articles resulting from inter-institutional collaboration among all institutes.

An upward trend of interdisciplinary articles was observed in the top five institutes, as shown in Fig. 7. Most of the top five institutes published over 60% of interdisciplinary articles in recent years. When comparing the annual percentages of interdisciplinary articles produced from the top five institutes to that published by all institutes (Fig. 5), the top five institutes have higher percentages of interdisciplinary articles than the overall percentage. This implies that researchers representing the top five institutes tend to engage in collaborative activities.

3.6. Top 10 journals

The 14,524 articles were published in 967 journals. Table 4 lists the top 10 journals that published the most articles during 1973–2010. Approximately 29% of articles were published in the top 10 productive journals. Among them, *Journal of Applied Polymer Science* published the most articles (838 articles), followed by *Journal of the Taiwan Institute of Chemical Engineers* (703 articles), and *Industrial & Engineering Chemistry Research* (552 articles). As assigned by JCR, Chemical Engineering and Polymer Science were the main subject categories for the top 10 journals. This indicates that the disciplines of Polymer Science and Chemical Engineering are of considerable interest to the chemical engineering researchers.

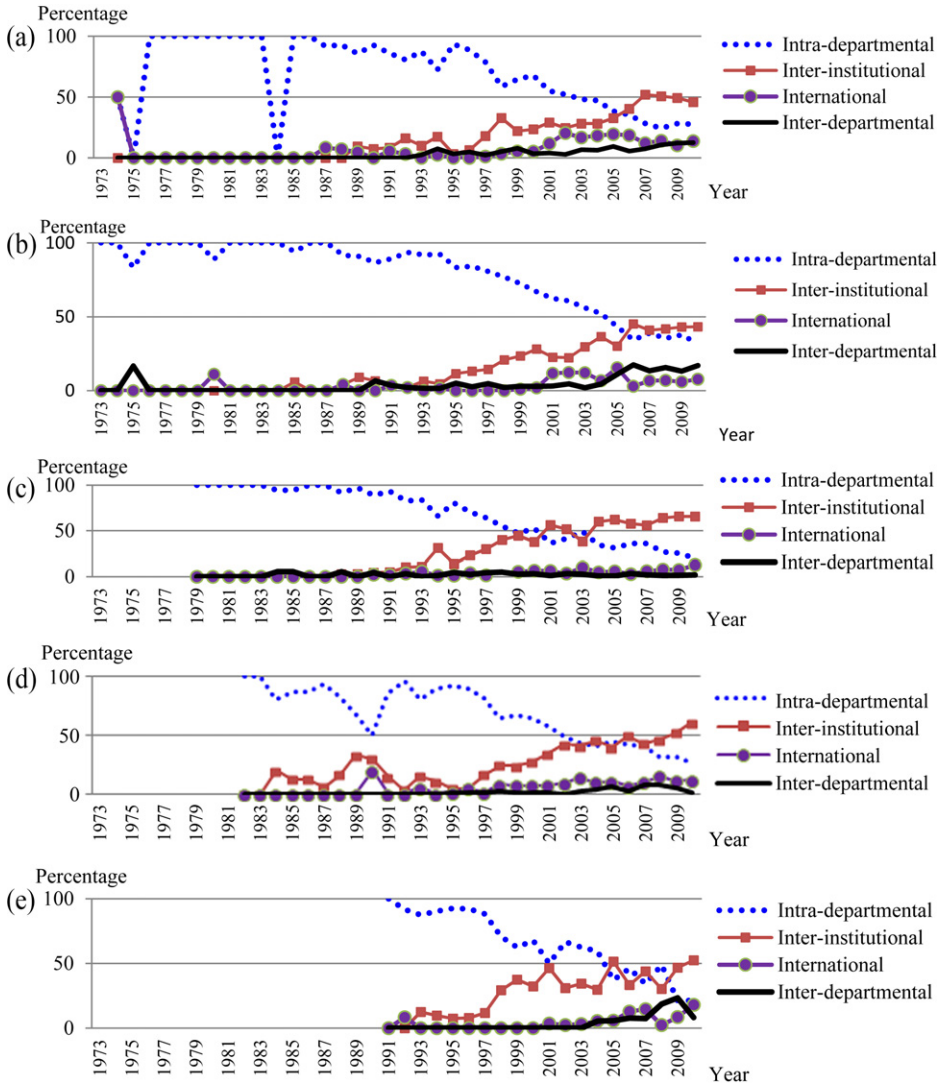

Fig. 6. Distribution of types of collaboration by year in ChE of (a) NTU; (b) NCKU; (c) NTHU; (d) NTUST; (e) YZU.

3.7. Article distribution by subject category

Based on the classification of JCR, the 967 journals published the 14,524 articles were distributed in 135 subject categories. This reveals that the researchers affiliated with institutes of chemical engineering in Taiwan have diverse research interests. According to the method mentioned in Section 2.2.3, the top 25 subject categories containing over 100 articles are listed in Table 5. Among them, Polymer Science ranked as the top one subject category, which contained 23.12% articles, followed by Chemical Engineering (19.72%) and Physical Chemistry (8.45%). The top three subject categories covered over half of articles (51.29%), indicating that

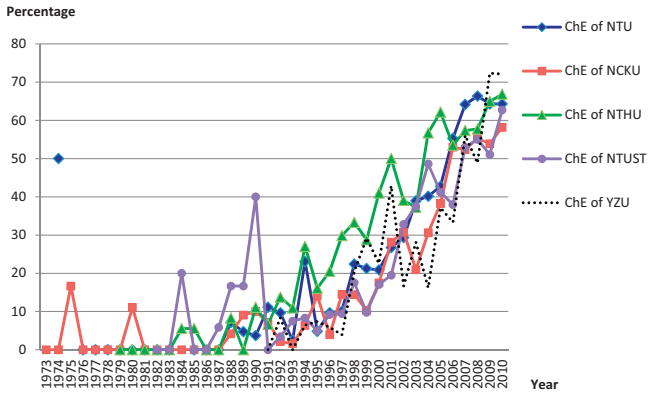

Fig. 7. Trends of interdisciplinary articles of top five institutes.

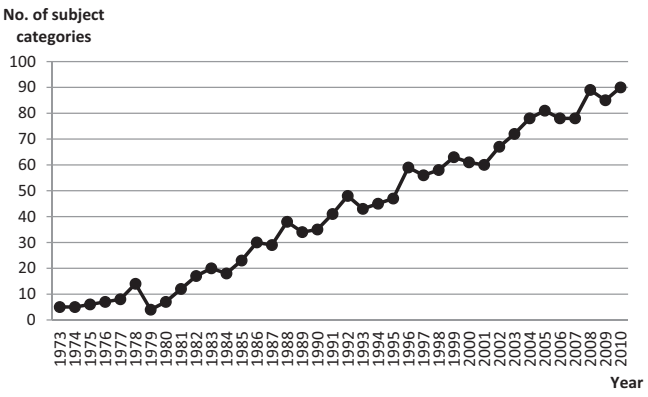

Fig. 8. Numbers of subject categories by year.

Table 4
The top 10 journals title in terms of the number of published articles.

Rank	Journal title	Subject category	No. of articles	Percentage
1	*Journal of Applied Polymer Science*	Polymer Science	838	5.77%
2	*Journal of the Taiwan Institute of Chemical Engineers*	Engineering, Chemical	703	4.84%
3	*Industrial & Engineering Chemistry Research*	Engineering, Chemical	552	3.80%
4	*Journal of Polymer Science Part A-Polymer Chemistry*	Polymer Science	529	3.64%
5	*Polymer*	Polymer Science	407	2.80%
6	*Journal of Membrane Science*	Engineering, Chemical; Polymer Science	268	1.85%
7	*Macromolecules*	Polymer Science	241	1.66%
8	*Journal of Colloid and Interface Science*	Chemistry, Physical	238	1.64%
9	*Journal of The Electrochemical Society*	Electrochemistry; Materials Science, Coatings & Films	206	1.42%
10	*Chemical Engineering Science*	Engineering, Chemical	200	1.38%

Table 5
The top 25 subject categories of articles authored by chemical engineering researchers in Taiwan.

Rank	Subject category	No. of articles	Percentage
1	Polymer Science	3358.00	23.12
2	Engineering, Chemical	2863.70	19.72
3	Chemistry, Physical	1227.92	8.45
4	Materials Science, Multidisciplinary	838.42	5.77
5	Electrochemistry	578.40	3.98
6	Chemistry, Multidisciplinary	534.78	3.68
7	Biotechnology & Applied Microbiology	508.18	3.50
8	Physics, Applied	403.60	2.78
9	Environmental Sciences	338.67	2.33
10	Chemistry, Analytical	210.65	1.45
11	Engineering, Environmental	203.83	1.40
12	Energy & Fuels	186.17	1.28
13	Crystallography	182.58	1.26
14	Materials Science, Coatings & Films	160.33	1.10
15	Physics, Atomic, Molecular & Chemical	154.08	1.06
16	Engineering, Biomedical	150.00	1.03
17	Materials Science, Biomaterials	144.33	0.99
18	Thermodynamics	137.28	0.95
19	Physics, Condensed Matter	131.37	0.90
20	Nanoscience & Nanotechnology	117.82	0.81
21	Automation & Control Systems	111.00	0.76
22	Materials Science, Ceramics	109.50	0.75
23	Engineering, Multidisciplinary	108.78	0.75
24	Biochemistry & Molecular Biology	107.42	0.74
25	Mechanics	105.35	0.73

most articles focused on a number of core subject categories. In addition to Chemistry and Chemical-related areas, researchers of chemical engineering also published their papers in various areas, such as Physics, Materials Science, Biotechnology, Environmental Sciences, Nanoscience, and Mechanics.

From the percentage of each subject category, the percentages of Polymer Science and Chemical Engineering were considerably higher than those of other subject categories. Moreover, all the percentages of subject categories ranking below sixteenth place were lower than 1%. This indicates that most subject categories covered only a small number of articles. Because publishing works in other disciplines is one of the main types of interdisciplinary information transfer [31], the articles published in diverse subject categories of journals confirm that chemical engineering is an interdisciplinary discipline [32,33].

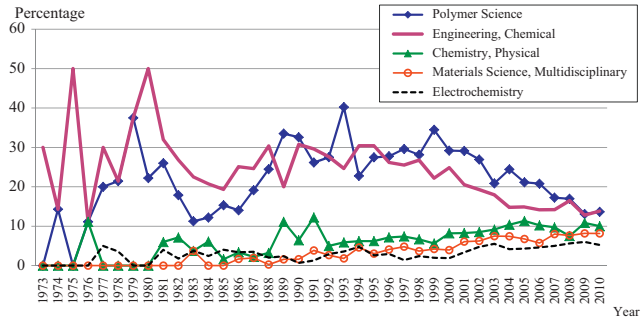

Fig. 9. The share of the top five subject categories by year.

Fig. 8 shows the annual changes in the number of subject categories. The number of subject categories increased with year, indicating that an increasing number of journals with various subject categories were selected by researchers affiliated with institute of chemical engineering in Taiwan to publish their works. Researchers usually published their articles in journals related to the research subjects, and the increase in the number of subject categories indicates that chemical engineering researchers in Taiwan have broadened their scope of interest, or that more researchers affiliated with institute of chemical engineering came from disciplines other than chemical engineering.

The annual percentages of the top five subject categories yielded from the total articles published during 1973–2010 are shown in Fig. 9. It reveals that the percentage of Polymer Science or Chemical Engineering was higher than that of other subject categories in most years. A decreasing trend, however, appeared in the percentages of Polymer Science and Chemical Engineering, especially after 2000. This indicates that journals in Polymer Science or in Chemical Engineering were no longer the dominant journals for chemical engineering researchers in Taiwan to publish their research output. A decreasing trend appeared in the differences among the share of the top five subject categories because the research scope in chemical engineering has broadened.

4. Conclusion

Findings of this paper revealed that research articles authored by researchers affiliated with institutes of chemical engineering in Taiwan increased considerably during 1973–2010. All articles were published in 967 journals, and approximately 29% of articles were published in the top 10 journals. Among them, *Journal of Applied Polymer Science* was the main journal, followed by *Journal of the Taiwan Institute of Chemical Engineers*. In addition, top prolific institutes were identified. Approximately 61% of articles were concentrated in the top five prolific departments of chemical engineering in five universities.

Over 95% of articles authored by researchers affiliated with institutes of chemical engineering in Taiwan were co-authored. Although two-authored articles accounted for the largest share, a considerable decreasing trend was identified. An increasing number of articles were written by at least three authors. The trend toward multiple authorship implies that more collaborations were formed between researchers.

The majority of articles were contributed by domestic researchers. Among domestically co-authored articles, the articles of intra-departmental collaboration accounted for the largest share, and their share was considerably larger than those

generated from other types of collaboration. However, a decreasing trend appeared in the share of articles of intra-departmental collaboration, revealing that researchers sought collaborators outside of their own institutes. The inter-institutional collaboration has become the main type of collaboration that produced the most articles since 2005.

In addition, an upward trend in interdisciplinary collaboration was identified in this study. The characteristic of interdisciplinary were also revealed in the diverse subject categories. Among the 135 subject categories, Polymer Science, Chemical Engineering, and Physical Chemistry were the main areas containing most of articles authored by researchers affiliated with institute of chemical engineering in Taiwan. The articles published in either journals of Polymer Science or journals of Chemical Engineering accounted for the largest proportion each year. The difference among the proportion of articles published in the journals of the top five subject categories decreased in recent years. This implies that the research scope in chemical engineering is expanding.

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References

[1] Wang CG. Taiwan Chemical industry: from tradition to high tech. Sci Dev 2011;457:76–9.
[2] Davidson JF. The origin of insights in chemical engineering: planned and unplanned research. Chem Eng Res Des 1996;74(A2):281–300.
[3] Hood WW, Wilson CS. The literature of bibliometrics, scientometrics, and informetrics. Scientometrics 2001;52(2):291–314.
[4] Peters HPF, Van Raan AFJ. Co-word-based science maps of chemical engineering. Part I. Representations by direct multidimensional scaling. Res Policy 1993;22:23–45.
[5] Peters HPF, Van Raan AFJ. Co-word-based science maps of chemical engineering. Part II. Representations by combined clustering and multidimensional scaling. Res Policy 1993;22:47–71.
[6] Peters HPF, Van Raan AFJ. A bibliometric profile of top-scientists: a case study in chemical engineering. Scientometrics 1994;29(1):115–36.
[7] Yin CY. Bibliometric analysis of journal articles published by Southeast Asian chemical engineering researchers. Malays J Libr Inf Sci 2009;14(3):1–13.
[8] Chen BH. Recent research progress in chemical engineering related fields in Taiwan: analysis from publications contributed from domestic authors. J Chin Inst Chem Eng 2006;41:244–5.
[9] Cheng YL, Chen BH. The 2006 summary of scientific productivity of chemical engineers in Taiwan. J Chin Inst Chem Eng 2007;38:501–4.
[10] Cheng YL, Ho MN, Lee DJ. The 2008 summary of scientific productivity of chemical engineering, civil engineering and mechanical engineering professionals in Taiwan. J Taiwan Inst Chem Eng 2010;41:96–7.
[11] Chen CYC. Letter to the editor. J Taiwan Inst Chem Eng 2010;37(6):609–16.
[12] Leydesdorff L. Bibliographic coupling of authors. Retrieved November 1, 2011, from http://www.leydesdorff.net/software/bibcoup/index.htm.
[13] Mine S, Ueda S, Miwa M. Library and information science educators in Japan: academic qualifications and research productivity. Libr Inf Sci 2006;55:71–82.
[14] Defazio D, Lockett A, Wright M. Funding incentives, collaborative dynamics and scientific productivity: evidence from the EU framework program. Res Policy 2009;38(2):293–305.
[15] He ZL, Geng XS, Campbell-Hunt C. Research collaboration and research output: a longitudinal study of 65 biomedical scientists in a New Zealand university. Res Policy 2009;38(2):306–17.
[16] Ding WW, Levin SG, Stephan PE, Winkler AE. The impact of impact of information technology on academic scientists' productivity and collaboration patterns. Manage Sci 2010;56(9):1439–61.
[17] Vasileiadou E, Vliegenthart R. Research productivity in the era of the internet revisited. Res Policy 2009;38(8):1260–8.
[18] The Taiwan Institute of Chemical Engineers. Chem Eng 2010;57(6):1.
[19] Hagen NT. Deconstructing doctoral dissertations: how many papers does it take to make a PhD? Scientometrics 2010;85(2):567–79.
[20] Mattsson P, Laget P, Nilsson A, Sundberg CJ. Intra-EU vs. extra-EU scientific co-publication patterns in EU. Scientometrics 2008;75(3):555–74.
[21] Satyanarayana K, Ratnakar KV. Authorship patterns in life sciences, preclinical basic and clinical research papers. Scientometrics 1989;17(3/4):363–71.
[22] Bird JE. Authorship patterns in marine mammal science, 1985–1993. Scientometrics 1997;39(1):99–105.
[23] Fernandez JA. The transition from an individual science to a collective one: the case of astronomy. Scientometrics 1998;42(1):61–74.
[24] Haigi Z. The relationship of authors to multiauthored pharmacology research papers. Int Forum Inf Doc 1996;21(3):10–23.
[25] Lipetz BA. Aspects of JASIS authorship through five decades. J Am Soc Inf Sci 1999;50(11):994–1003.
[26] Vimala V, Reddy VP. Authorship pattern and collaborative research in the field of zoology. Malays J Libr Inf Sci 1996;1(2):43–50.
[27] Bordons M, Gomez I, Fernandez MT, Zulueta MA, Mendez A. Local, domestic and international scientific collaboration in biomedical research. Scientometrics 1996;37(2):279–95.
[28] Hart RL. Co-authorship in the academic library literature: a survey of attitudes and behavior. J Acad Libra 2000;26(5):339–45.
[29] Hayati Z, Didegah F. International scientific collaboration among Iranian researchers during 1998–2007. Libr Hi Tech 2010;28(3):433–46.
[30] Costa R, Moggridge GD, Saraiva PM. Chemical product engineering: an emerging paradigm within chemical engineering. AlChE J 2006;52(6):1976–86.
[31] Pierce SJ. Boundary crossing in research literatures as a means of interdisciplinary information transfer. J Am Soc Inf Sci 1999;50(3):271–9.
[32] Shama G, Hellgardt K, Oppenheim C. Citation footprint analysis. Part I. UK and US chemical engineering academics. Scientometrics 2000;49(2):289–305.
[33] Peter HPF, Braam RR, Van Raan AFJ. Cognitive resemblance and citation relations in chemical engineering publications. J Am Soc Inf Sci 1995;46(1):9–21.