Mapping Knowledge Structure of Science and Technology Based on University Research Domain Analysis

대학의 연구 영역 분석을 통한 과학 기술 분야의 지식 구조 매핑에 관한 연구

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ABSTRACT

This study explores knowledge structures of science and technology disciplines using a cocitation analysis of journal subject categories with the publication data of a science & technology oriented university in Korea. References cited in the articles published by the faculty of the university were analyzed to produce MDS maps and network centralities. For the whole university research domain, six clusters were created including clusters of Biology related subjects, Medicine related subjects, Chemistry plus Engineering subjects, and multidisciplinary sciences plus other subjects of multidisciplinary nature. It was found that subjects of multidisciplinary nature and Biology related subjects function as central nodes in knowledge communication network in science and technology. Same analysis procedure was applied to two natural science disciplines and another two engineering disciplines to present knowledge structures of the departmental research domains.

초 록

이 연구에서는 한국의 과학 기술 중심 대학의 연구 영역 분석을 통해 과학 기술 분야의 지식 구조를 파악하고자 하였다. 해당 대학 교수들이 일정 기간 출판한 논문을 수집하여 분석에 이용하였고, 전체 대학과 학과의 두 수준에서 지식 구조를 파악하였다. 분석 기법으로는 논문에서 인용한 학술지의 주제 범주에 대한 동시인용 분석을 통해 주제들의 연관성을 다차원 지도상에 표현하였고, 사회연결망 분석에서 사용하는 중앙성 척도를 사용하여 관련 주제들의 위치를 파악하였다. 분석 결과 다학문적 성격을 띠는 주제와 생물학 관련 주제들이 전체 과학 기술 분야 및 화학과 물리학 영역의 지식 구조에서 중요한 역할을 하는 것으로 파악되었다.

Keywords: knowledge structure, science mapping, MDS map, closeness centrality, betweenness centrality, social network analysis
지식 구조, 과학 지도, 다차원척도 지도, 인접중앙성, 사이중앙성, 사회연결망 분석

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1. Introduction

Many studies have applied cocitation analysis techniques to map the intellectual structure of science (Moya-Anegon, et al. 2004; Moya-Anegon, et al. 2007), specific disciplines (White and McCain 1998; White 2003; Moya-Anegon, et al. 2005; Leydesdorff and Vaughan 2006), and smaller scientific fields (Bayer, Smart, and McLaughlin 1990; Liu 2005; Fernandez-Alles and Ramos-Rodriques 2009) assuming that two or more documents, authors, journals, or journal categories cited together by others possess a certain degree of subject similarity. Recently the cocitation analysis has been employed to assess the relationship between different subject fields (Sugimoto, Pratt, and Hauser 2008), to detect research fronts in certain research domains (Miguel, Moya-Anegon, and Herrero-Solana 2005; Zhao and Strotmann 2007; Shibata, et al. 2009), and to detect scientific specialties or communities (Wallace, Gingras, Duhon 2009).

Miguel, Moya-Anegon, and Herrero-Solana (2008) attempted to explore the intellectual structure and research fronts of the Faculty of Natural Sciences and Museum (FCNyM) of the National University of La Plata, Argentina on the basis of co-citation analysis of subject categories, journals, and authors of the university publications. The FCNyM encompasses several disciplines and scientific specialties in natural science. The result of their study revealed that FCNyM had a heterogeneous intellectual structure displaying a network of interdisciplinary relations in natural sciences.

The purpose of this study is to ascertain knowledge structures of science overall as well as specific disciplines using publication data of the faculty of a science & technology oriented university in Korea. Knowledge maps were drawn to display core subjects of certain research domains of the university and the interdisciplinary relationships among the subjects on the basis of a cocitation analysis of journal subject categories. To this aim, we employed multidimensional scaling (MDS) and cluster analysis methods provided by SPSS, and centrality measures of social network analysis offered by UCINET.

2. Methodology

2.1 Dataset Construction

The science & technology oriented university analyzed in this study consists of the College of Natural Sciences containing four Departments of Mathematics, Physics, Chemistry, and Life Science and the College of Engineering with six Departments of Materials Science & Engineering, Mechanical Engineering, Industrial & Management Engineering, Electronic & Electrical Engineering, Computer Science & Engineering, and Chemical Engineering. The number of faculty members of the two colleges is equal to 229.

The 2005-2007 edition of the SCI Expanded, one of the ISI's citation index databases provided online by Web of Science, was queried by combining the search terms representing the university address to collect research articles written by the faculty of the sample university. Since the SCI 2005-2007 edition includes citation data of the articles whose registration dates belong to this period, the actual publication years range from 2004 to 2008. The collected articles published in the 5-year period include 79, 770, 813, 784, and 9 articles, respectively, with the total of 2,455 articles.

After classifying the bibliographic references cited in the collected articles into publication types such as journal articles, patents, monographs, reports, conference proceedings, standards, and thesis, we generated a dataset consisting of the references to the journal articles for the analysis. Each bibliographic reference in the dataset was assigned the corresponding ISI-JCR journal categories. Since journals may have multiple ISI subject categories in JCR, more than one category could be assigned to the references published in such journals. The original dataset used for the analysis in this study includes 2,455 articles collected from the SCI database and 54,158 references cited in the 2,455 articles, which were published in 2,214 different journals. The number of subject categories assigned to the references are 175.

However, not all the articles were used in constructing matrices due to the large number of references to be handled in our analysis procedure. Thus we set a citation threshold to be applied to the articles for each research domain analysis. In the analysis of the whole university domain, articles within the top 30th NCR(National Citation Report) percentile of the total citations were used to produce a document-subject matrix. For the departmental analysis, we used articles within top 50% after being sorted in the order of citation frequency. In case of a department where the proportion of the articles with no citation exceeds 50%, all the articles were included in the analysis.

In the dataset, each article has the subject categories assigned to the cited journals. From the article-subject matrix, subject-subject cocitation matrix was constructed using SAS IML (9.1). In the cocitation matrix, the off-diagonal cells are filled with raw cocitation frequencies of row and column categories resulting in a symmetric matrix. It is problematic to determine the value of the diagonal cells in such a symmetric matrix, so various methods have been suggested to deal with this problem. They include treating the diagonal cell values as missing data, computing the diagonal values from the off-diagonal cell values, and placing the highest off-diagonal cocitation counts in cells (Eom 2009). In this study, the highest off-diagonal cell value approach was employed to fill the diagonal cells.

2.2 Analysis Methods

The subject category cocitation matrices generated earlier were converted to proximity matrices with Pearson's correlation coefficient values in cells for further analysis by SPSS. ALSCAL and CLUSTER routines in SPSS were used to generate MDS maps and to group subject categories by Ward clustering method. MDS technique is used to create visual maps from proximity matrices displaying the underlying structure within a set of objects (McCain 1990). In the subject category maps, categories heavily cocited appear grouped in a map, and subject categories with many links to others tend to be in central positions. Thus, highly related subject categories can be identified in a MDS map. The weakness of MDS mapping is that the original data could be distorted by representing objects in only two dimensions. To measure the overall 'goodness of fit' in mapping, stress measures such as Kruskal's stress and Young's S-stress and the proportion of variance explained (R Square in ALSCAL) are used. In this study, Young's S-stress and RSQ were computed to evaluate the acceptability of MDS maps.

Social network analysis has been employed in many recent studies for science mapping (Boyack, Klavans, and Borner 2005; Samoylenko, et al. 2006; Leydesdorff 2007; Leydesdorff and Rafols 2009; Klavans and Boyack 2009). Social network analysis provides a set of centrality measures such as degree, betweenness, and closeness centrality, and centrality in terms of the projection on the first eigenvector of the matrix or Bonacich power. In science mapping, centrality measures represent the relative positions of authors, journals, subject categories, or other data units in a citation-based network. In this study, we calculated closeness centrality, betweenness centrality, and power centrality to determine the relative positions of subjects or disciplines represented by ISI subject categories of referenced journals in citation-based networks. While closeness centrality provides a global indicator about the position of a node(subject) by measuring the distance of a node from all other nodes in a network, betweenness centrality is a measure of how often a node is located on the shortest path between other pairs of nodes in the network (Leydesdorff 2007). The betweenness of a node measures the extent to which a node or agent can play the part of a gatekeeper with a potential for control over others (Scott 2000). Power centrality or prestige index was offered by Bonacich (1987) as an alternative measure which uses weighted scores.

Leydesdorff (2007) mentioned that closeness may be used as a measure of multidisciplinarity and betweenness as a measure of specific interdisciplinarity at interfaces of subject categories in a knowledge network.

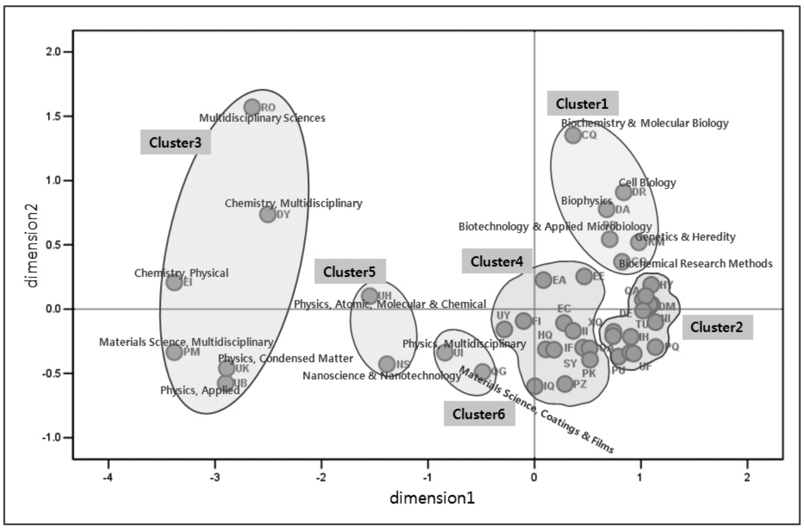
In this study, closeness and betweenness centralities were computed by Pajek and power centrality by UCINET 6.211 version.

3. Results

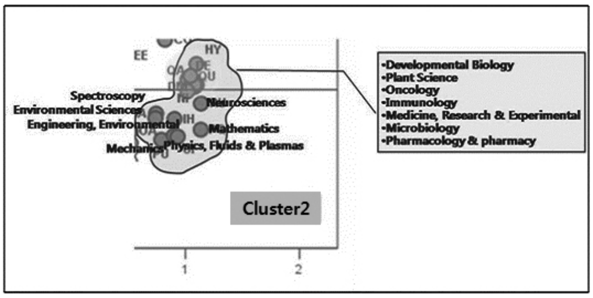
3.1 Knowledge Structure based on University Research Domain

The total of 663 highly cited articles within the range of top 30th NCR percentile were selected for the analysis. They cited 1,206 journals in references to which the total of 147 subject categories were assigned. After counting cocitation frequency of subject categories, a cocitation matrix was created for MDS mapping. For a better visibility, the knowledge structure was mapped from 44 categories within top 30% of the citation counts. Figure 1 shows a two-dimensional MDS map for the university research domain with six clusters representing the interdisciplinary relationships between the subjects grouped in the same clusters. This map also displays the relative distance between subject clusters.

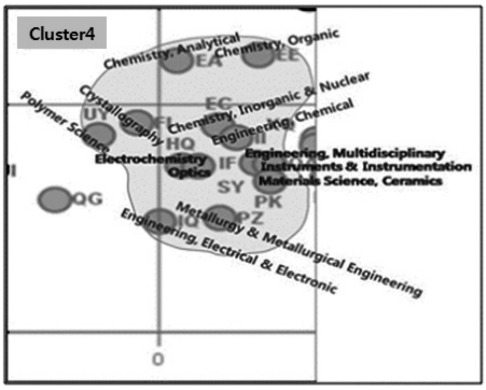
Cluster 1 on the upper right section of the MDS map contains Biology related subjects such as Biophysics, Cell Biology, Biochemistry & Molecular Biology whereas Cluster 3 positioned on the far left of the map includes subjects of multidisciplinary nature like Multidisciplinary Sciences, Chemistry-Multidisciplinary, Materials Science-Multidisciplinary, and Applied Physics. Clusters 2 and 4 contains a large number of subjects which are positioned nearby or some of which are even overlapped. Cluster 2 enlarged in Figure 2 includes various subject categories with several medicine related subjects such as Immunology, Oncology, Medicine-Research & Experimental, Pharmacology & Pharmacy, and Neurosciences. Cluster 4 also enlarged in Figure 3 includes major Chemistry subjects such as Organic Chemistry, Analytical Chemistry, and Inorganic & Nuclear Chemistry as well as a few Engineering subjects like Chemical Engineering, Electrical & Electronic Engineering, and Metallurgy & Metallurgical Engineering. Although Clusters 5 and 6, two smallest clusters, do not reveal any noticeable characteristics of the clustered subjects, Atomic, Molecular & Chemical Physics is in the same cluster as Nanoscience & Nanotechnology, and Physics-Multidisciplinary is grouped with Materials Science-Coating & Films reflecting the close relationships between the subjects.



〈Figure 1〉 MDS map of university research domain



〈Figure 2〉 Cluster 2 enlarged in university MDS map



〈Figure 3〉 Cluster 4 enlarged in university MDS map

Table 1 shows top 10 subject categories with high centrality values. Multidiscipliplinary Sciences has the highest closeness as well as betweenness centralities, reflecting its multidisciplinary nature occupying a central position in the knowledge network for the university research domain. Closeness centrality is also high for Biochemistry & Molecular Biology, Biophysics, and Chemistry-Multidisciplinary. Betweenness centrality is high for Computer Science-Interdisciplinary Applications and Chemistry-Multidisciplinary. We can see that subjects of multidisciplinary nature tend to have a high degree of closeness and betweenness centralities as expected. As for power centrality, Physical Chemistry is in the first position implying its strong impact on other subjects. The table also tells us that in general, most of the subjects with high centralities belong to natural sciences and more specifically, many Chemistry, Physics, and Biology related subjects are included in the list.

3.2 Knowledge Structure of Departmental Research Domains

In contrast to the earlier analysis based on the whole university research domain, we analyzed the

〈Table 1〉 Subject categories with high centrality values for university research domain

	closeness centrality	betweenness centrality	power centrality
1	Multidisciplinary Sciences	Multidisciplinary Sciences	Chemistry, Physical
2	Biochemistry & Molecular Biology	Computer Science, Interdisciplinary Applications	Materials Science, Multidisciplinary
3	Biophysics	Chemistry, Multidisciplinary	Multidisciplinary Sciences
4	Chemistry, Multidisciplinary	Biochemistry & Molecuar Biology	Physics, Condensed Matter
5	Biotechnology & Microbiology	Biophysics	Physics, Applied
6	Cell Biology	Cell Biology	Chemistry, Multidisciplinary
7	Chemistry, Physical	Biotechnology & Microbiology	Physics, Atomic, Molecular & Chemical
8	Chemistry, Analytical	Chemistry, Physical	Nanoscience & Nanotechnology
9	Materials Science, Multidisciplinary	Chemistry, Analytical	Physics, Multidisciplinary
10	Biochemical Research Methods	Engineering, Manufacturing	Materials Science, Coatings & Films

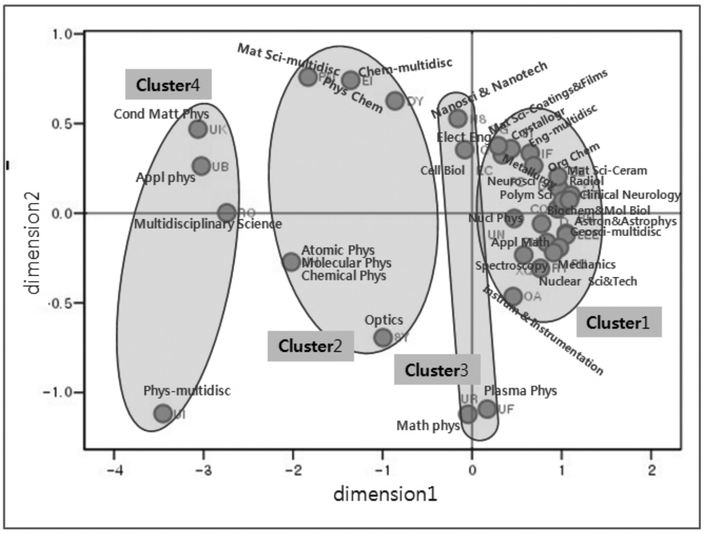
knowledge structure of individual disciplines on the basis of four departmental research domains. We selected Department of Chemistry and Department of Physics from the College of Natural Sciences, and Department of Materials Science & Engineering and Department of Industrial & Management Engineering from the College of Engineering.

3.2.1 Analysis of Physics Research Domain

Among 261 articles written by the faculty of the Department of Physics, we selected 133 articles which were cited at least once. These articles contained a total of 275 referenced journals that were classified into 73 subject categories. To make the MDS map more visible a cocitation matrix was generated from 37 subject categories within the top 50% of total citation counts.

The MDS map in Figure 4 displays the knowledge structure of Physics research domain based on the articles written by the faculty of the Department of Physics. The Young's S stress value of the MDS map is 0.056 and RSQ is 0.995.

The subjects on the map are grouped into 4 clusters: Cluster 1 includes the largest number of subjects such as Metallurgical Engineering, Materials Science, Engineering-Multidisciplinary, Organic Chemistry, Cell Biology, Polymer Science, Mechanics, Nuclear Science & Technology, Nuclear Physics, Applied Mathematics, Mathematics-interdisciplinary, etc. These subjects are positioned very close to each other, thus implying the close relationships between them based on journal cocitations. In Cluster 3 that is near to Cluster 1, Nanoscience & Nanotechnology and Electrical & Electronic Engineering are positioned nearby, whereas Plasma Physics and Mathematical Physics belonging to the same cluster are positioned far away from the other two subjects. Cluster 2, positioned at the center of the map, contains five subjects, i.e., Materials Science-Multidisciplinary, Chemistry-Multidisciplinary, Physical Chemistry, Physics-Atomic, Molecular & Chemical, and Optics. Cluster 4 contains three subjects in Physics such



〈Figure 4〉 MDS map of Physics research domain

as Applied Physics, Physics-Condensed Matter, and Physics-Multidisciplinary, with Multidisciplinary Sciences at the center of the cluster.

The MDS map in Figure 4 reveals that in Physics research domain a great number of subjects other than Physics proper are referenced, some of which show very close relationships as presented in Cluster 1, implying the interdisciplinarity of Physics domain.

In a social network analysis of Physics domain, three centrality values were computed by UCINET to see the relative position of each subject in the domain. Table 2 shows top 10 subjects with the highest centrality values. Most of the top 10 subjects in closeness and betweenness centralities are Physics subjects with Physics-Multidsiciplinary in the first position. Physics-Multidisciplinary is also the first in power centrality. We can also identify Multidisciplinary Sciences and Materials Science-Multidisciplinary in the top 10 lists of both centralities.

It is noticeable that although most of the subjects playing central or intermediary roles are Physics subjects, the subjects of multidisciplinary nature, whether they are subjects in Physics or in other disciplines, also play important roles in the knowledge communication network of Physics research domain.

3.2.2 Analysis of Chemistry Research Domain

Among 321 articles written by the faculty of Department of Chemistry, we selected 161 articles which were cited more than twice. These articles contained a total of 426 referenced journals that were classified into 83 subject categories. To make the MDS map more visible a cocitation matrix was generated from 39 subject categories within the top 50% of total citation counts.

〈Table 2〉 Subject categories with high centrality values in Physics

	closeness centrality	betweenness centrality	power centrality
1	Physics, Multidisciplinary	Physics, Multidisciplinary	Physics, Multidisciplinary
2	Physics, Atomic, Molecular & Chemical	Physics, Fluids & Plasmas	Physics, Condensed Matter
3	Physics, Condensed Matter	Physics, Mathematical	Physics, Applied
4	Multidisciplinary Sciences	Physics, Condensed Matter	Multidisciplinary Sciences
5	Physics, Applied	Physics, Atomic, Molecular & Chemical	Physics, Atomic, Molecular & Chemical
6	Optics	Multidisciplinary Sciences	Materials Science, Multidisciplinary
7	Materials Science, Multidisciplinary	Physics, Nuclear	Chemistry, Physical
8	Physics, Mathematical	Physics, Applied	Optics
9	Physics, Fluids & Plasmas	Optics	Chemistry, Multidisciplinary
10	Chemistry, Multidisciplinary	Materials Science, Multidisciplinary	Nanoscience & Nanotechnology

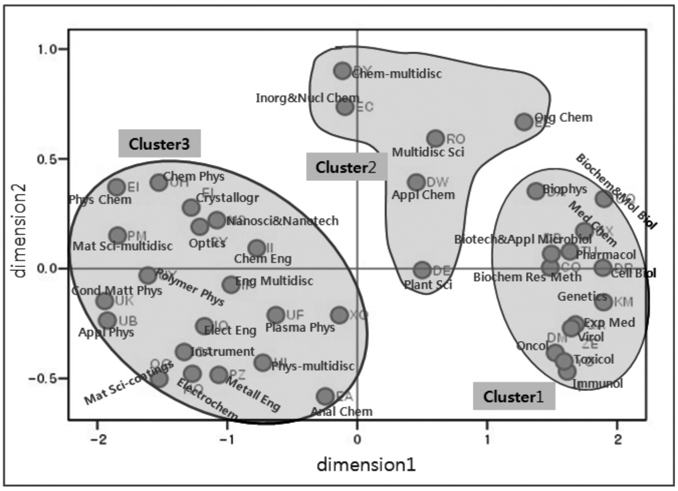
The MDS map in Figure 5 shows the knowledge structure of Chemistry research domain with the Young's S stress value of 0.063 and RSQ of 0.985.

In the MDS map of Chemistry domain, 39 subjects are widespread in the two dimensional space and grouped into 3 clusters, each of which contains more than five subjects. Cluster 2 in the upper right section includes the subjects of multidisciplinary nature like Chemistry-Multidisciplinary and Multidisciplinary Sciences in addition to a few Chemistry subjects. In Cluster 1 Biology and Medicine related subjects are grouped including Biophysics, Cell Biology, Biochemistry, Microbiology, Medical Chemistry, Genetics, Immunology, and so on. Besides, many subjects in Cluster 1 are positioned nearby representing high cocitation counts. Cluster 3 contains most of the Physics subjects and also a few Engineering subjects like Chemical Engineering, and Electrical & Electronic Engineering.

In a social network analysis, Chemistry-Multidisciplinary has the highest values in all the three centralities as shown in Table 3. Analytical Chemistry is the second in both closeness and betweenness centralities and Physical Chemistry is the second in power centrality. Organic Chemistry is the fourth and the third in closeness and betweenness, respectively. Multidisciplinary Sciences are in top four of each centrality. We can say that Chemistry-Multidisciplinary and Multidisciplinary Sciences, that are in Cluster 2 of the MDS map, are the most central and influential subjects in Chemistry research domain except for other Chemistry subjects. We can also see several Biology related subjects and Physics subjects in top 10 list of three centralities.

3.2.3 Analysis of Materials Science Research Domain

Among 444 articles written by the faculty of Department of Materials Science & Engineering, 235 articles cited more than once were analyzed. These articles contained a total of 346 referenced journals that were classified into 80 subject cate-



〈Figure 5〉 MDS map of Chemistry research domain

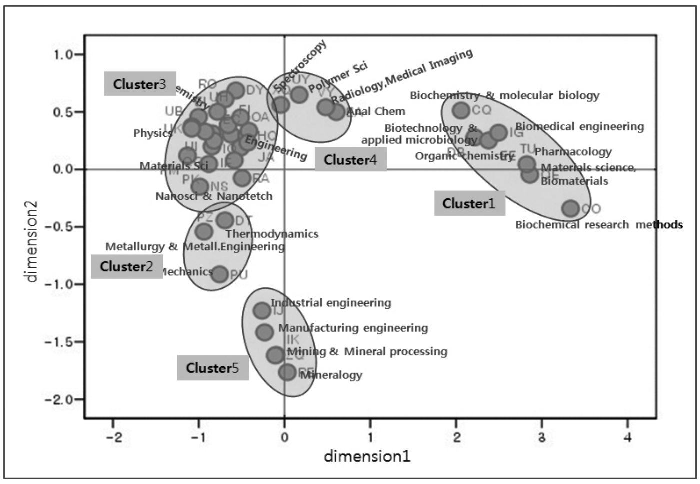
〈Table 3〉 Subject categories with high centrality values in Chemistry

	closeness centrality	betweenness centrality	power centrality
1	Chemistry, Multidisciplinary	Chemistry, Multidisciplinary	Chemistry, Multidisciplinary
2	Chemistry, Analytical	Chemistry, Analytical	Chemistry, Physical
3	Multidisciplinary Sciences	Chemistry, Organic	Multidisciplinary Sciences
4	Chemistry, Organic	Multidisciplinary Sciences	Materials Science, Multidisciplinary
5	Biochemistry & Molecular Biology	Biochemistry & Molecular Biology	Physics, Atomic, Molecular & Chemical
6	Physics, Multidisciplinary	Biochemical Research Methods	Physics, Condensed Matter
7	Spectroscopy	Cell Biology	Chemistry, Organic
8	Cell Biology	Physics, Multidisciplinary	Physics, Applied
9	Biochemical Research Methods	Spectroscopy	Biochemistry & Molecular Biology
10	Materials Science, Multidisciplinary	Biophysics	Chemistry, Analytical

gories. To make the MDS map more visible a cocitation matrix was generated from 41 subject categories within the top 50% of total citation counts.

The MDS map in Figure 6 shows the knowledge structure of Materials Science research domain with the Young's S stress value of 0.049 and RSQ of 0.993.

In Figure 6, subjects are grouped into five clusters; Cluster 2 and Cluster 5 are Engineering related clusters positioned on the lower section of the map, and Cluster 1 is Biology and Medicine related cluster containing Biochemistry & Molecular Biology, Biomedical Engineering, Biomaterials, etc. Materials Science is found in the largest cluster(Cluster 3) where many subjects are put on top of others. In Cluster 3, Materials Science are grouped with Chemistry, Physics, and Nanoscience & Nanotechnology subjects, implying the high cocitations among them.



〈Figure 6〉 MDS map of Materials Science research domain

Table 4 shows the centrality values of top 10 subjects in Materials Science research domain. Unlike other departmental research domains, Materials Science ranks top in power centrality only and ranks fourth in closeness and betweenness centralities. In closeness, Multidisciplinary Sciences is the first with Physical Chemistry and Nanoscience & Nanotechnology as the second and the third. In betweenness, Physical Chemistry is the first. As already shown in Cluster 3 of Figure 6, Chemistry and Physics subjects play important roles in Material Sciences research domain.

3.2.4 Analysis of Industrial & Management Engineering Research Domain

We analyzed 93 articles written by the faculty of Department of Industrial & Management Engineering. These articles contained a total of 233 referenced journals that were classified into 81 subject categories. To make the MDS map more visible a cocitation matrix was generated from 26 subject categories within the top 50% of total citation counts.

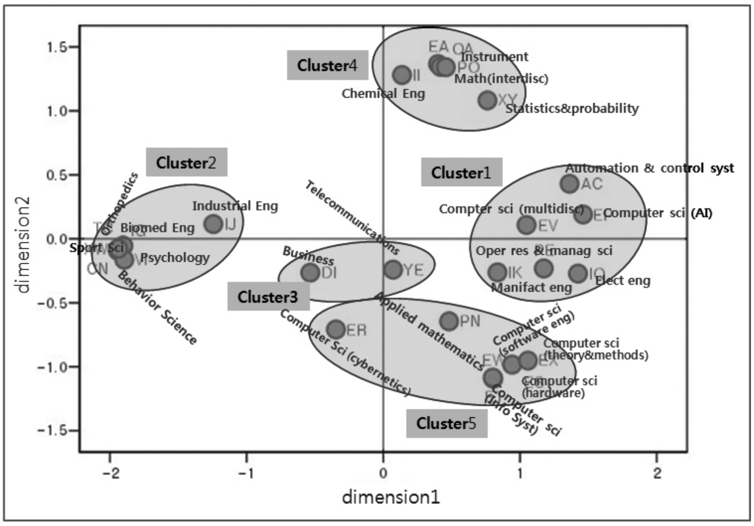
The MDS map in Figure 7 displays the knowledge structure of Industrial & Management Engineering research domain with the Young's S stress value of 0.046 and RSQ of 0.990.

The map shows that the knowledge structure of Industrial & Management Engineering mainly encompasses Computer Science subjects, Applied Mathematics, Statistics & Probability, Business, Behavior Science, and Psychology. Cluster 2 positioned on the left side of the map contains Industrial Engineering plus other subjects like Psychology, Sport Science, Behavior Science, and Biomedical Engineering that look overlapped implying the high degree of cocitations among the subjects.

The subjects with high centrality values in Industrial & Management Engineering research do-

〈Table 4〉 Subject categories with high centrality values in Materials Science

	closeness centrality	betweenness centrality	power centrality
1	Multidisciplinary Sciences	Chemistry, Physical	Materials Science, Multidisciplinary
2	Chemistry, Physical	Nanoscience & Nanotechnology	Physics, Applied
3	Nanoscience & Nanotechnology	Multidisciplinary Sciences	Physics, Condensed Matter
4	Materials Science, Multidisciplinary	Materials Science, Multidisciplinary	Chemistry, Physical
5	Physics, Applied	Physics, Applied	Nanoscience & Nanotechnology
6	Physics, Atomic, Molecular & Chemical	Physics, Atomic, Molecular & Chemical	Multidisciplinary Sciences
7	Physics, Condensed Matter	Electrochemistry	Metallurgy & Metallurgical Engineering
8	Chemistry, Multidisciplinary	Chemistry, Multidisciplinary	Chemistry, Multidisciplinary
9	Electrochemistry	Physics, Condensed Matter	Physics, Multidisciplinary
10	Physics, Multidisciplinary	Chemistry, Analytical	Physics, Atomic, Molecular & Chemical



〈Figure 7〉 MDS map of Industrial & Management Engineering research domain

main are shown in Table 5. As we expected, Industrial Engineering ranks first in both closeness and betweenness centralities. Other subjects with high closeness and betweenness centralities are Computer Science subjects and Operations Research & Management Science, and Electrical & Electronic Engineering. One unique subject in the top 10 betweenness centrality list is Psychology. In power centrality, Operations Research & Management Science ranks first with Industrial Engineering in the second place. Most of the remaining subjects in the top 10 list are Computer Science subjects.

4. Discussion and Conclusion

This study attempted to ascertain knowledge structures of science and technology using institu-

〈Table 5〉 Subject categories with high centrality values in Industrial & Management Engineering

	closeness centrality	betweenness centrality	power centrality
1	Engineering, Industrial	Engineering, Industrial	Operations Research & Management Science
2	Computer Science, Interdisciplinary Applications	Computer Science, Interdisciplinary Applications	Engineering, Industrial
3	Computer Science, Artificial Intelligence	Psychology	Computer Science, Interdisciplinary Applications
4	Operations Research & Management Science	Computer Science, Cybernetics	Computer Science, Artificial Intelligence
5	Engineering, Electrical & Electronic	Computer Science, Artificial Intelligence	Engineering, Manufacturing
6	Computer Science, Hardware & Architecture	Engineering, Electrical & Electronic	Engineering, Electrical & Electronic
7	Engineering, Manufacturing	Operations Research & Management Science	Computer Science, Theory & Methods
8	Telecommunications	Telecommunications	Automation & Control Systems
9	Computer Science, Theory & Methods	Engineering, Manufacturing	Computer Science, Software Engineering
10	Automation & Control Systems	Computer Science, Hardware & Architecture	Computer Science, Hardware & Architecture

tional research domain analysis. Publication data of a science & technology oriented university in Korea were retrieved from the SCI 2005-2007 edition and cocitation analysis method using journal subject categories as data units was applied to the journals referenced in the collected articles.

The MDS map, that was constructed on the basis of highly cited subject categories in the whole university research domain, reveals six subject clusters including clusters of Biology related subjects, Medicine related subjects, major Chemistry subjects plus a few engineering subjects, Multidisciplinary Sciences and other subjects of multidisciplinary nature. In a social network analysis aimed to ascertain subjects that are either central or influential in the university research domain, Multidisciplinary Sciences occupies the first position in all the three centralities indicating the current multidisciplinary trend of overall scientific research. It is noticeable that most of the subjects with high values of closeness and betweenness centralities are either the subjects of multidisciplinary nature or Biology related subjects such as Biochemistry & Molecular Biology, Biophysics, Biotechnology & Microbiology, and Cell Biology. We may infer that the subjects of multidisciplinary nature as well as Biology related subjects function as nodes that are either central or intermediary in the knowledge communication network of whole university research domain. High centralities of Biology was also ascertained in a study analyzing the network of academic disciplines based on co-occurrences of journals in different disciplines (Lee 2008).

The knowledge structures of two subjects in natural sciences and other two in engineering were mapped using departmental research ouputs. The

MDS map of Physics domain shows that Physics is related with many other subjects implying the interdisciplinarity of Physics. The analysis of the centralities reveals that most of the subjects with high closeness and betweenness centralities are Physics subjects with Physics-Multidisciplinary being the highest whereas the subjects of a few multidisciplinary nature such as Multidisciplinary Sciences and Materials Science-Multidisciplinary also have high centrality values.

The MDS map of Chemistry research domain includes the main cluster of Chemistry subjects plus Multidisciplinary Sciences, a cluster of Biology plus Medicine related subjects, and another cluster of Physics subjects plus a few Engineering subjects. The centrality values indicate that in addition to the other Chemistry subjects Chemistry-Multidisciplinary and other multidisciplinary subjects such as Multidisciplinary Sciences and Physics-Multidisciplinary are in central or intermediary positions.

The MDS map of Materials Science research domain includes two Engineering related clusters, one Biology and Medicine related cluster, and one large cluster containing Materials Science and other closely related subjects such as Chemistry, Physics, and Nanoscience & Nanotechnology subjects indicating high cocitations among the subjects. The centrality values reveals that Chemistry and Physics subjects in addition to Multidisciplinary Sciences play important roles in the knowledge network whereas Materials Science-Multidisciplinary ranks fourth in both closeness and betweenness centralities.

Finally, the knowledge structure in Industrial & Management Engineering domain consists of several Computer Science subjects and diverse subjects in social sciences. According to the centrality values, various subjects including Computer Science subjects, Electrical & Electronic Engineering, Telecommunication, and Manufacturing Engineering play important roles in knowledge communication network of Industrial & Management Engineering research domain.

This study presents that disciplines of multidisciplinary nature and Biology related subjects play important roles in the whole science research domain as well as in specific research domains in natural sciences such as Chemistry and Physics. We showed that it is possible to ascertain knowledge structure of science and technology overall as well as those of specific disciplines by applying cocitation analysis of journal subject categories to institutional research data. The knowledge structures reflecting institutional research domains can be useful in understanding the current research trends of a given institution and predicting future research directions as well.

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