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Abstract

The knowledge in all the references of the publications at a university on a subject constitutes the knowledge support to advance this subject. The subject structure derived from the publications and their references can be used to describe the supportive structure for advancing the studies on this subject. Using AI studies at Tongji University, by mapping cited references of all publications on AI at Tongji University to their corresponding subject categories, we use the co-occurrence of subject categories to construct a subject supportive structure for advancing AI studies. We then analyze the evolution of the supportive structure over five stages: 2004-2007, 2008-2011, 2012-2015, 2016-2019, and 2020-2023. The subject supportive structure has evolved from initial reliance on a limited set of core subjects to a more diversified, balanced, and compact unity. The subjects in the supportive structures are grouped in the clusters of Biomedical Science, Computer Science and Engineering at the beginning. Later, subject categories of the humanities and social sciences joined. In each stage, subject categories began to make new combinations to form different clusters. Based on the commonality of subject categories in the clusters, we construct the top arch structure. It shows that the clusters in subject supportive structures form four big pillars of BIOMEDICINE, ENGINEERING, COMPUTER SCIENCE, and HUMANITIES & SOCIAL SCIENCE. The subject categories are moving in these clusters as well as in these big pillars, which indicates, on the one hand, that AI studies have a special way to integrate knowledge from different subjects and lead these subjects to provide support for advancing AI studies; and on the other hand, subject knowledge has the capacity to integrate with knowledge from different subjects to form different clusters. The administration of a university needs to understand the rationale for organizing the intended development of its subject systems.

Keywords: subject supportive structure; subject knowledge; subject cluster; integration and differentiation; artificial intelligence

1. Introduction

Interdisciplinary research is widely recognized as a catalyst for creativity and innovation [1]. As knowledge domains continuously evolve and intersect, comprehensive tracking and analysis of this phenomenon becomes increasingly crucial[2].

AI is an interdisciplinary field with the power to reshape production methods, lifestyles, and ways of thinking, driving the development of new technologies, industries, and business models. It

is advancing the revolution in science, technology, and industry, bringing about fundamental changes. AI helps break down barriers between disciplines and encourages interdisciplinary cooperation. On one hand, AI supports traditional fields by fostering the integration of AI with other areas; on the other hand, AI research must incorporate knowledge from various disciplines to enhance AI's capabilities. This implies that the progress of AI depends on support from these other fields.

Many universities are attempting to harness AI's capacity to restructure their subject framework. Chaohui Wu, the president of Zhejiang University, believes that the pivot of the development of AI lies in its role in leading knowledge convergence from different subjects, and AI can obtain the growth point in the progress of convergence. In support of knowledge convergence of brain science, neurosciences, and computer science, and other fields, AI will produce a new form of intelligence, such as super intelligence or integrative intelligence[3]. Chen Jie, the president of Tongji University, also expressed the same opinion in an interview[4]. Tongji University has emerged as a trailblazer in this endeavor in China, achieving several significant milestones: in 2019, it was among China's first institutions to establish an undergraduate program in Artificial Intelligence; in 2021, it obtained approval to create an interdisciplinary doctoral program in Intelligent Science and Technology, thereby breaking traditional single-subject educational paradigms to advance AI-focused interdisciplinary research; on May 16, 2024, Tongji University launched its "AI-Empowered Disciplinary Innovation Action Plan (2024-2027)", marking a systematic institutional commitment to driving subject innovation through AI empowering to other subjects[5]. Li et al. (2025) investigated how AI studies at Tongji University integrated with the other subjects by a two-dimensional analysis of diversity and cohesion[6].

However, how different subjects interconnect to support the advancement of AI in a university has not yet been studied. In this contribution, we will investigate this by constructing a subject supportive structure for AI studies. We will, further on, use the term "supportive structure" for the more elaborate, but more precise, term "subject supportive structure".

2. Methodology: The Rationale for Constructing a Supportive Structure for Advancing the Studies of a Subject

A subject is formed by the investigations on a specific phenomenon or a series of related phenomena. These investigations produce a set of publications, among others. Usually, the set of publications represents the current state of the development of the subject, and is used to evaluate its development.

When the investigated phenomena are complex and the solutions are beyond the scope of a single subject, the information, data, techniques, tools, perspectives, concepts, and/or theories from different subjects are used to aid the investigations. When investigations yield results and the publications containing the knowledge on the phenomena are published publicly, the original investigators can communicate with colleagues who are also interested in the phenomena, so that they can make further investigations. When further investigations lead to new discoveries, new publications contain the knowledge on the phenomena published in the academic commons, inviting interactions with colleagues. In the knowledge production process, the information, data, techniques, tools, perspectives, concepts, and/or theories from other fields, which have been used to help the investigations, are integrated into the knowledge body on the phenomena to advance the subject. The publications containing the information, data, techniques, tools, perspectives, concepts, and/or theories from other fields are listed as references. This process produces citations. After expatiating the process, Liu & Rousseau (2013) and Liu & Wu (2015) drilled down from appearance to essence, and concluded that citation is the interaction between different ideas or perspectives on a phenomenon that is addressed in the citing and cited articles[7,8].

The interactions between publications and their references are different from those between publications and their citations. Scientometricians use these interactions to study different aspects of knowledge dynamics. It is regarded as methodologically rigorous to use referencing behavior to

study knowledge integration and using citation and author collaboration network to study diffusion (Liu & Rousseau, 2010 [9]Liu, Rafols & Rousseau 2012[10], Chen, Liu, Huang & Bu, 2025[11]). However, besides integration and diffusion, there is another dimension to study knowledge dynamics. We all know that the development of a subject requires financial support, human resources, administration, and so on. However, it also needs support from the knowledge aspect. Especially when the subject is an interdisciplinary subject, it needs knowledge support from other subjects. Hanney et al. (2005) argued that when a citing publication cites the cited publications (references), the citing publication supports and develops a concept or method previously described in the cited publication[12]. Support is bilateral power: the knowledge in the publication supports the knowledge in its references, and the references also support the knowledge in the publication. As the results of investigations were published, and the information, data, techniques, tools, perspectives, concepts, and/or theories from different fields or the bodies of specialized knowledge that the investigation used were taken in and was integrated into the knowledge bodies on the investigated phenomena, the publications that carry the subject knowledge are listed as references. We may say that the investigating results are discovered and the conclusions are established in a publication with the support of knowledge in its references. As the status quo of the development of a subject is represented by all the publications carrying the knowledge on the phenomena that the subject is investigating, all the references of the publications constitute the knowledge support to advance the subject. So, the set of publications that carry the results and conclusions of the investigated specific phenomena represents the status quo of the development of the field. The set of references of these publications represents the supportive power to advance the subject.

The supportive power can be described in different ways. Using a network to construct a map of science enables concrete observation, systematic analysis, and rigorous assessment of the development of a subject and its relation with other subjects. The map of science enables researchers to identify the position of various subjects within the comprehensive scientific landscape, while simultaneously revealing their interconnections and communication pathways. In this way it can serve as a powerful analytical tool, providing a clear and intuitive visualization of scientific development.

Efforts to outline a map of science using citations between publications can be traced back to the work by Garfield (1964)[13] and Price (1965)[14]. Subsequently, scholars have continued to advance the development of science mapping. In a seminal contribution, Garfield (1979) mapped the structure of DNA research by performing cluster analysis on the co-citation relationships among all DNA-related publications and their references[15]. In the early stage, mapping of science used publications as the nodes. Boyack et al. (2005) used the journals as nodes to construct a backbone of science[16]. Later, Leydesdorff & Rafols (2009) used the subject categories and research areas in the Web of Science (WoS) as nodes to construct a global map of science[17].

However, only the subject categories of publications were used as nodes in the global map, which cannot be used to describe how the subject is supported by the other subjects. In this contribution, all the publications on a specific subject of a university are used as the data source, the subject categories of these publications and of their references are used as nodes, and the co-occurrence of the subject categories in the same publication is used to link the subject categories to construct a network. The nodes are the subject categories from the publications, as well as their references. Hence, the network can be used to describe the subject supportive structure for advancing the studies of a subject in a university. We will use AI studies at Tongji University as a case study.

3. Data

Drawing on the China Artificial Intelligence Development Report 2018 published by the Center for Science and Technology Policy Research of Tsinghua University in 2019[18], the following search string was used to retrieve all the publications on AI at Tongji University: (TS=("artificial intelligence" OR "machine learning" OR "natural language processing" OR "computer vision" OR "facial recognition" OR "image recognition" OR "speech recognition" OR "semantic search" OR "semantic

web" OR "text analytics" OR "virtual assistant" OR "visual search" OR "predictive analytics" OR "intelligent system" OR "Deep Learning" OR "Robotics" OR "Autonomous Systems" OR "Human-Computer Interaction" OR "ChatGPT")) AND AD=(Tongji University). No time restriction was applied. We performed the search on October 3, 2024, and found 3,839 publications. After deduplication and data cleaning, 3,367 valid publications were retained for our study. These publications have 157,761 references.

Using the Journal Citation Reports (JCR) provided by the Web of Science, which contains subject category information for each journal (totaling 254 WoS categories), we mapped each referenced journal according to the journal's assigned WoS categories. This process resulted in 137,725 reference records being successfully mapped to relevant categories. To ensure the reliability of interdisciplinary measurement outcomes, we subsequently excluded documents that were mapped to fewer than three distinct subject categories following the reference categorization process used by Chavarro, Tang, & Rafols (2014) [19]. The result was 2,783 sample documents in 239 subject categories, which accounted for more than 94% of all subject categories (254) in the Web of Science, spanning the period 2004-2023. In this study, the total publication time is divided into five slices of four-year periods. Table 1 shows the number of publications, the number of categories in which publications were distributed, and the number of categories in which references were distributed for each period.

Table 1. The distribution of categories of AI publications in Tongji University and of their reference.

Stage	Number of publications	Number of publication's categories	Number of references' categories
2004-2007	17	21	45
2008-2011	47	35	98
2012-2015	103	42	140
2016-2019	450	102	205
2020-2023	2,166	172	237
2004-2023(total)	2,783	176	239

We construct the subject co-occurrence network with the set of references of AI publications of Tongji University in five stages as a supportive structure for the advancement of AI studies. We analyze the overall characteristics of supportive structure in each period, and then describe the structure in detail.

4. Results

4.1. The Overall Characteristics of the Supportive Structure

We use the following three indicators to analyze the overall characteristics of the supportive structures: Network Density, Degree Centralization, and Betweenness Centralization. The following are the formulae for calculating the indicators

$$d(S) = \frac{2l}{n(n-1)} \quad (1)$$

$$C_D = \frac{\sum_{i=1}^{n}(C_{RDmax}-C_{RDi})}{n-2} \quad (2)$$

$$C_B = \frac{\sum_{i=1}^{n}(C_{RBmax}-C_{RBi})}{n-1} \quad (3)$$

d(S) denotes Network Density of the supportive structure, reflecting the compactness of the network: l indicates the number of links between all nodes; n indicates the number of nodes.

C_D denotes Degree Centralization, indicating the network's overall centrality with respect to all nodes' relative degree centrality. $C_{RDi} = \frac{C_{ADi}}{n-1}$, indicating the relative degree centrality of note i, while C_{ADi} denotes the number of links directly connected to the node i. C_{RDmax} represents the largest degree centrality among all nodes in the network;

C_B denotes Betweenness Centralization, calculating whether the network is divided into different subnetworks and how much the connections between the subnetworks rely on some specific nodes. $C_{RBi} = \frac{2\sum_{j<k} g_{jk(i)}/g_{jk}}{(n-1)(n-2)}$, where g_{jk} denotes the number of all shortest paths between the node j and the node k; $g_{jk(i)}$ denotes the number of shortest paths between the node j and the node k that pass through the node i. C_{RBmax} represents the largest relative betweenness centrality among all nodes in the network; Table 2 shows the value of the three indicators in each period.

Table 2. The network density, degree centralization and betweenness centralization of the supportive structure for advancing AI studies in each period.

Stage	Number of nodes	Network Density	Degree Centralization	Betweenness Centralization
2004-2007	45	0.2808	0.5386	0.2593
2008-2011	98	0.2710	0.6705	0.1492
2012-2015	140	0.2634	0.6670	0.0949
2016-2019	205	0.3814	0.5257	0.0261
2020-2023	237	0.6138	0.3681	0.0072

The number of nodes increases over time. This means that AI studies at Tongji University are integrating more and more subject categories.

Figure 1 shows the trend of these indicators.
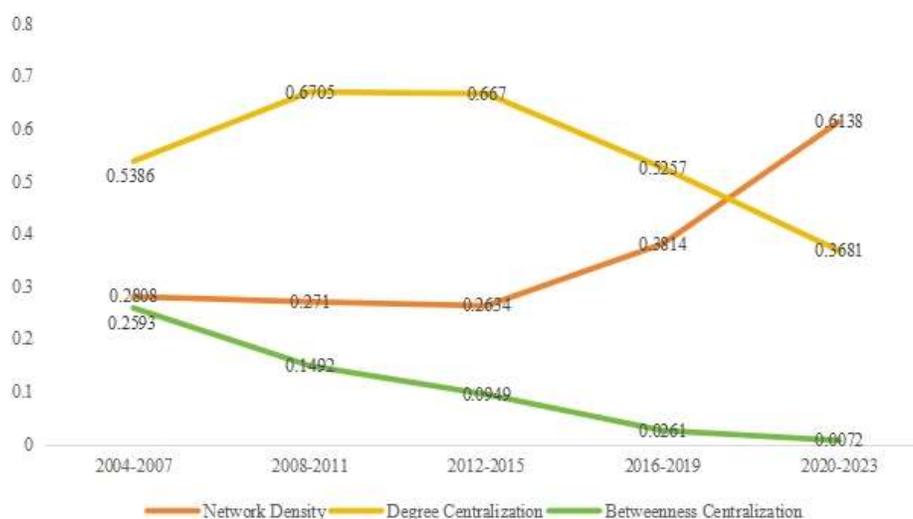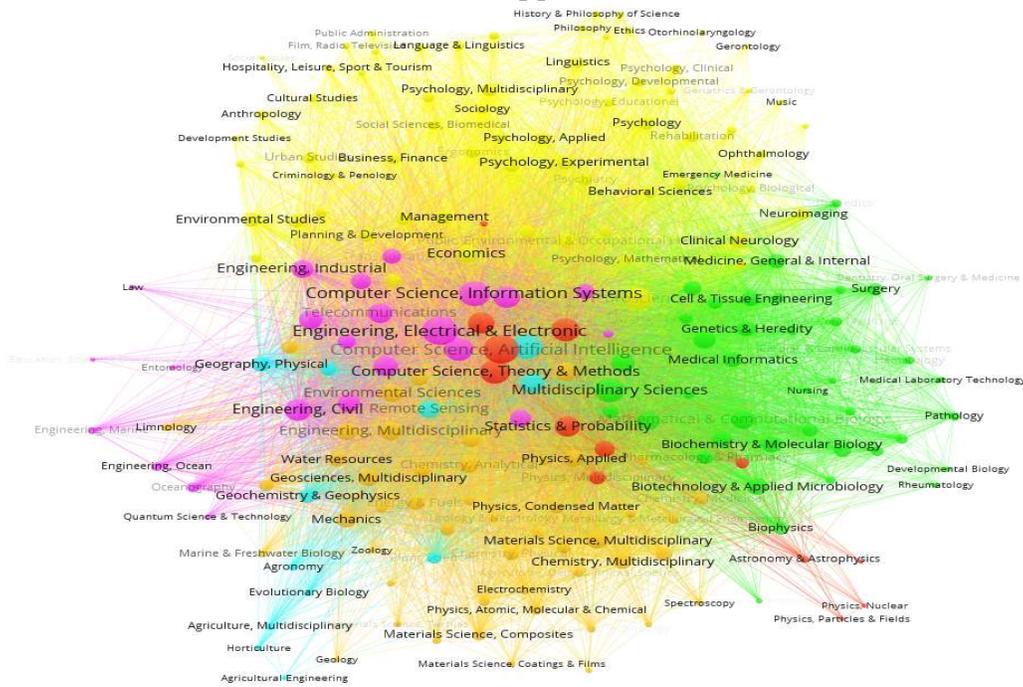

Figure 1. Trends of network density, degree centralization, betweenness centralization of the supportive structure for advancing AI studies during 2004-2023 at Tongji University.

The network density is overall relatively stable and slightly decreasing in the first three stages, but it begins to rise in the last two stages. This trend shows that the number of links between nodes

grows relatively faster with respect to the number of links in the fully meshed network, and the supportive structure becomes more and more compact in the last two stages.

Compared with the first stage, the degree centralization increased significantly in the second stage, but then decreased slightly in the third stage, and continued to decrease in the last two stages. The degree centralization at the end point is lower than at the initial point. This trend indicates that the distribution of the number of subject categories each subject category links is more even in the subject supporting structure in the end. While the structure is more compact in the last half than in the first half, this trend shows that the supportive structure is becoming decentralized.

The observed decrease in betweenness centralization between 2004 and 2023 indicates that subject categories may no longer depend on some specific subject categories to establish links with other subject categories.

The trends of these indicators suggest that the supportive structure is gradually evolving to a more balanced, compact, and decentralized structure.

4.2. The Characteristics of the Supportive Structure for Advancing AI Studies at Tongji University

The trend of network density, degree centralization and betweenness centralization reveals the overall evolutionary trend of supportive structure for advancing AI studies in Tongji University. We use VOSviewer to visualize the supportive structure of Tongji University for advancing AI studies and see how the supportive structure has evolved.

4.2.1. Visualizations of the Supportive Structure in Different Stages

Figure 2 shows the supportive structure for advancing AI studies at Tongji University at different stages.

a). 2004-2007's supportive structure

b). 2008-2011's supportive structure

c).2012-2015's supportive structure

d). 2016-2019's supportive structure

e). 2020-2023's supportive structure

Figure 2. The visualization of the supportive structure for advancing AI studies at Tongji University in different stages.
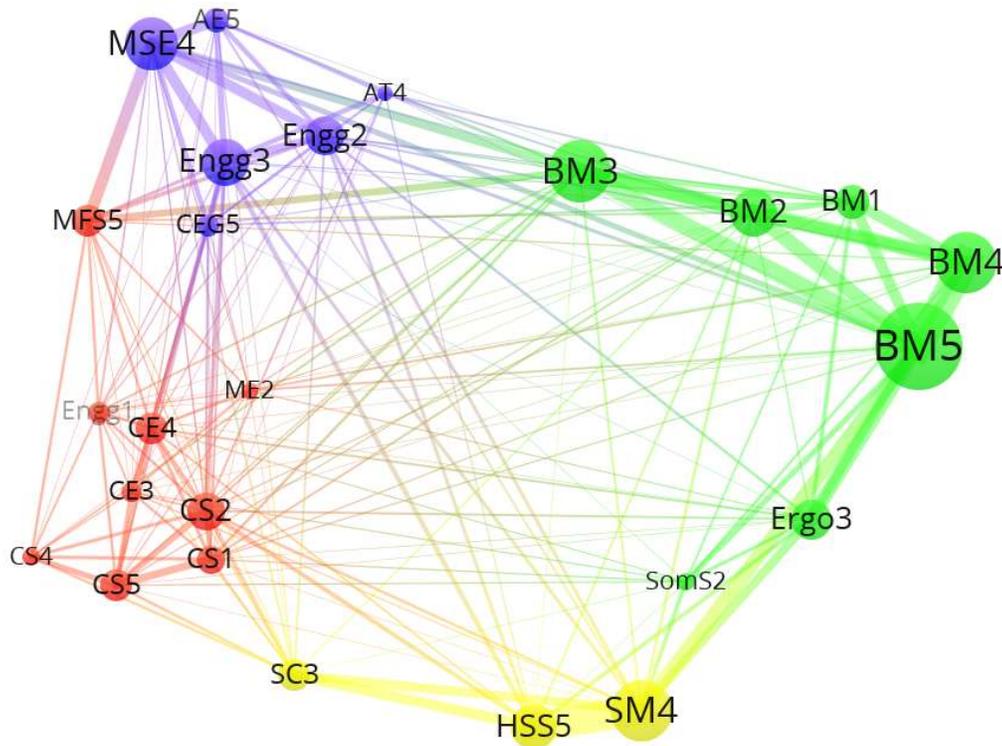

Figure 2. The top arch structure of the supportive structure for advancing AI studies at Tongji University.

The categories in supportive structures are coalesced into different clusters in different stages. Based on the categories included in each cluster, the categories' locations, and the connections

between the categories, we name each cluster in each stage. The color, name, abbreviation, and the number of categories of each cluster in the supportive structure in each stage are shown in Table 3. The number in the abbreviation represents the stage.

Table 3. The color, name, abbreviation, and the number of categories of each cluster in the supportive structure in each stage.

stage	color	name	abbr	#
2004-2007	red	Computer Science	CS1	15
	blue	Engineering	Engg1	11
	green	Biomedical Science	BM1	19
2008-2011	red	Computer Science	CS2	21
	blue	Engineering	Engg2	26
	cyan	Medical Engineering	ME2	10
	purple	Somatic Science	SomS2	11
	green	Biomedical Science	BM2	30
2012-2015	yellow	Social Computing	SC3	23
	purple	Computer Engineering	CE3	12
	blue	Engineering	Engg3	35
	cyan	Ergonomics	Ergo3	28
	green	Biomedical Science	BM3	42
2016-2019	yellow	Social Medicine	SM4	66
	red	Computer Science	CS4	13
	purple	Computer Engineering	CE4	23
	gold	Materials Science & Engineering	MSE4	48
	cyan	Agritechnology	AT4	12
	green	Biomedical Science	BM4	43
2020-2023	yellow	Humanities & Social Sciences	HSS5	57
	red	Computer Science	CS5	17
	blue	Civil Engineering & Geosciences	Engg5	18
	gold	Materials & Fundamental Science	MFS5	30
	cyan	Agriculture & Environment	AE5	30
	green	Biomedical Science	BM5	85

Next, we will describe the details of the supportive structure in each stage.

4.2.2. Characteristics of the Supportive Structure in 2004-2007

During the period 2004-2007, Tongji University published 17 publications related to AI in 21 subject categories. The references of these publications involved 45 categories.

The 45 categories were grouped into three distinct clusters. We call these the Biomedical Science cluster (BM1), the Computer Science cluster (CS1), and the Engineering cluster (Engg1). The Computer Science cluster is positioned in the middle, with the Biomedical Science cluster on one side and the Engineering cluster on the other. The Biomedical Science and Computer Science clusters are

farther apart, while the Engineering cluster and the Computer Science cluster are nearly connected through the category of "Engineering, Electrical & Electronic."

In the Computer Science cluster, "Computer Science, Information Systems", "Computer Science, Artificial Intelligence", "Computer Science, Hardware & Architecture", "Computer Science, Theory & Methods", "Telecommunication" are in the center of the structure; "Engineering, Biomedical", "Computer Science, Interdisciplinary Applications" are in the border of the Computer Science cluster and the Biomedical Science cluster, whereas "Mathematical & Computational Biology" is more close to the Engineering cluster. Outside of "Mathematical & Computational Biology" are "Robotics", "Engineering, Manufacturing" in the periphery. Some fundamental sciences, such as "Mathematics", "Mathematics, Applied", "Statistics & Probability", "Acoustics", and "Spectroscopy", are in the periphery.

The subject categories in the Biomedical Sciences cluster are connected to the categories in the Computer Science cluster only through the categories "Computer Science, Information Systems", "Computer Science, Interdisciplinary Applications", and "Engineering, Biomedical"; to the categories in the Engineering cluster only through "Engineering, Electrical & Electronic". The categories of biomedical sciences are located on the outside of the Biomedical Science cluster. On the border of the Computer Science cluster and the Biomedical Science cluster are the categories "Remote Sensing", "Geochemistry & Geophysics", "Imaging Science & Photographic Technology". "Multidisciplinary" also appears in this cluster.

In the Engineering cluster, "Engineering, Electrical & Electronic", "Computer Science, Software Engineering" are closely intertwined with the categories of the Computer Sciences cluster. "Automation & Control Systems" are at the center of the cluster. The engineering-related categories "Transportation Science & Technology", "Energy & Fuels", and "Operations Research & Management Science" are in the periphery of the cluster. The categories of fundamental science and applied science, such as "Mathematics, Interdisciplinary Applications", "Physics, Multidisciplinary", and "Physics, Applied," are also in the periphery.

Engineering is the strongest subject at Tong University. However, just a few engineering categories appeared in the supportive structure at this stage. The engineering categories are not concentrated in one cluster. Both clusters of Engineering and Computer Science encompass some fundamental science categories, fundamental applied categories, and some engineering categories. "Cell & Tissue Engineering" is in the Biomedical Science cluster. The supportive structure shows a core-periphery structure with computer science in the core, and fundamental and Engineering distributed, and biomedical science in the periphery.

4.2.3. Characteristics of the Supportive Structure in 2008-2011

During the period 2008-2011, Tongji University published 47 publications related to AI in 35 subject categories. The references of these publications involved 98 subject categories. The 8 categories in the previous stages didn't show up in this stage. Another 61 subject categories related to biomedical science, engineering, fundamental science, and social science were added to the supportive structure.

Like the previous stage, the Computer Science cluster and the Engineering cluster remained closely nested. The Biomedical Science cluster maintained some distance from both clusters. Two new clusters, **Somatic Science** (**SomS2**) and **Medical Engineering (ME2)** fill the gap.

The categories of "Computer Science, Artificial Intelligence" and "Computer Science, Interdisciplinary Applications" occupied the core positions of the structure. However, "Computer Science, Interdisciplinary Applications" is grouped with some typical categories of biomedical science. We name this cluster the **Biomedical Science** cluster **(BM2)**. This cluster also contains "Crystallography", "Telecommunications", "Chemistry, Multidisciplinary", and "Social Sciences, Mathematical Methods", "Behavioral Sciences"; "Computer Science, Artificial Intelligence" is grouped with the other four categories of computer science. Except for some categories of fundamental science and engineering, this cluster also attracts some newly appearing categories

related to social science and geoscience. We name this cluster the **Computer Science** cluster (**CS2**). Most of the engineering categories are concentrated in one cluster. "Engineering, Civil", which is the most important subject of Tongji University, was added to the supportive structure at this stage. The cluster contains some categories related to biomedical science, social science. Most categories related to Engineering are in this cluster. We name this cluster the **Engineering** cluster **(Engg2)**.

The Somatic Science cluster encompasses two types of subject categories. One type is the computer science and engineering categories, such as "Engineering, Electrical & Electronic", "Robotics", and "Engineering, Biomedical"; one type is related to the body structure or physiological processes, such as "Neurosciences," "Sports Science", "Orthopedics", and " Peripheral Vascular Disease". We refer to this cluster as the **Somatic Science** cluster. The categories in the **Medical Engineering** cluster scatter in the clusters of Biomedical Science, Computer Science, and on the border of the cluster of Engineering and the two clusters. There are three types of categories in this cluster: biomedical science, engineering, and fundamental science. The type of categories of biomedical science is in the middle of the Biomedical Science cluster. The other two types of categories are in the Computer Science cluster and the border of the Engineering cluster. Notably, categories of fundamental science, such as "Statistics & Probability", "Optics", and "Chemistry, Analytical", move to the center of the structure. The compositions and locations of the two clusters demonstrate that they establish a channel between the Computer Science cluster, the Biomedical Science cluster, and the Engineering cluster.

Many categories related to social science appear in this stage; however, they are scattered over the clusters of Computer Science, Engineering, and Biomedical Science.

4.2.4. Characteristics of the Supportive Structure in 2012-2015

In 2012-2015, Tongji University published 103 AI-related publications in 42 subject categories; its references belong to 140 subject categories. Seven categories that disappeared in the previous stage show up again at this stage. Twelve categories disappeared at this stage. 49 categories related to biomedical science, engineering, geoscience, fundamental science, and humanities and social sciences are added to the supportive structure.

The 140 subject categories are clustered into five clusters: **Engineering (Engg3)**, **Biomedical Sciences (BM3)**, **Social Computing (SC3)**, **Ergonomics (Ergo3)**, and **Computer Engineering (CE3)**. The boundaries between the clusters are rather blurred, and the clusters are spatially interlocking. Most of the social science subject categories are gathered in one cluster.

"Computer Science, Cybernetics" shows up in this stage, while the Computer Sciences cluster is now split. Some computer science categories are in the center of the structure, e.g., "Computer Science, Artificial Intelligence", "Computer Science, Cybernetics", "Computer Science, Information Systems", "Computer Science, Interdisciplinary Applications", and "Computer Science, Theory & Methods". The others are in the periphery, e.g., "Computer Science, Software Engineering", "Computer Science, Hardware & Architecture". However, they are clustered into different clusters. Around the categories of "Computer Science, Artificial Intelligence", "Computer Science, Cybernetics", "Computer Science, Information Systems", are various subject categories related to social sciences, such as "Economics", "Social Sciences, Mathematical Methods", "History & Philosophy of Science", "Information Science & Library Science", "Management", "Psychology, Educational", "Language & Linguistics", "Agricultural Economics & Policy", and some mathematical categories, such as "Mathematics, Interdisciplinary Applications", "Psychology, Mathematical", "Social Sciences, Mathematical Methods", "Statistics & Probability". We name this cluster the **Social Computing cluster.** Though "Computer Science, Theory & Methods" is at the center of the structure, "Computer Science, Software Engineering", "Computer Science, Hardware & Architecture" are in the periphery, clustered in one cluster. The three computer science categories, together with some subject categories from engineering, form the **Computer Engineering cluster**. Most categories in this cluster are in the periphery of the structure. However, "Computer Science, Theory & Methods", "Automation & Control Systems", "Engineering, Multidisciplinary", and "Instruments &

Instrumentation" scatter in the center of the structure, connecting this cluster with the other clusters. The Social Computing cluster is inserted between the Computer Engineering cluster.

The category of "Ergonomics" appeared in the supportive structure in this stage. It is in the very periphery of the structure. Around it are the categories of "Psychology", "Psychology, Applied", and "Psychology, Multidisciplinary". Inside the structure, we can see more psychological subject categories such as "Psychology, Biological", "Psychiatry" and " Physiology". Further inside the structure, many subjects in biomedical engineering are associated with this cluster. we can see "Engineering, Biomedical", "Neurosciences", "Cardiac & Cardiovascular Systems", and "Rehabilitation", "Public, Environmental & Occupational Health", and "Medical Laboratory Technology", "Transportation Science & Technology", "Architecture", "Engineering, Industrial". Ergonomics, also known as human factors engineering, is the application of psychological and physiological principles to the engineering and design of products, processes, and systems. Primary goals are to reduce human error, increase productivity and system availability, and enhance safety, health, and comfort with a specific focus on the interaction between the human and equipment and environment. The contained subject categories related to this topic, so we name this cluster the **Ergonomics cluster (Ergo3)**

The clusters of **Engineering** and **Biomedical Science** are still clustered independently and separately positioned on opposite sides. "Computer Science, Interdisciplinary Applications" is coalesced with the cluster of Engineering, and is situated in the center of the structure. The components of this cluster comprise some subject categories related to the fundamental science for Engineering such as "Remote Sensing", "Optics", "Acoustics", and "Mechanics", as well as some subject categories related practical engineering fields, including "Engineering, Electrical & Electronic", "Engineering, Civil", "Engineering Geological", "Engineering, Environmental", "Engineering, Chemical", "Engineering, Manufacturing", and "Engineering, Mechanical" and so on. In the Biomedical Sciences cluster, some multidisciplinary & applied categories, such as "Multidisciplinary Sciences", "Mathematics, Applied", "Materials Science, Multidisciplinary", and "Physics, Multidisciplinary" are in the border of the Biomedical Science cluster with other clusters. In the center of the cluster are "Mathematical & Computational Biology", "Biochemical Research Methods", and "Biotechnology & Applied Microbiology". Typical biomedical subject categories are in the periphery. In this stage, all the categories in the biomedical science cluster are connected to the categories in the other clusters.

4.2.5. Characteristics of the Supportive Structure in 2016-2019

In 2016-2019, 450 publications related to AI were published at Tongji University, which covered 102 subject categories, and cited a total of 205 categories. Compared with the previous stage, only three categories disappear, but 68 categories in social sciences, life sciences, environmental sciences, and material sciences surge in the supportive structure for advancing AI studies, changing the supportive structure. The supportive structure is like a radiating structure with the key supportive subject categories in each cluster interwoven and aggregated in the center of the structure, and less linked categories radiating in the periphery.

"Computer Science, Software Engineering", "Computer Science, Hardware & Architecture" move to the center of the structure, but they are split into two clusters. Categories related to the computer sciences make a new combination: Firstly, "Computer Science, Software Engineering", together with "Computer Science, Artificial Intelligence" and "Computer Science, Theory & Methods" are in the center of structure, with some categories related to fundamental sciences, such as "Logic", "Physics, Particle & Field", "Physics, Nuclear", "Physics, Multidisciplinary", "Mathematics", "Mathematics, Applied", "Statistics & Probability" in the periphery, to form **the Computer Sciences cluster (CS4)** again. Secondly, the categories of "Computer Science, Hardware & Architecture" attract "Computer Science, Cybernetics", "Computer Science, Information Systems", moving out from the Social Computing cluster and joining **the Computer Engineering cluster (CE4)**. "Engineering, Electrical & Electronic", "Automation & Control Systems", and some categories related

to engineering, such as "Engineering, Civil" and "Engineering, Mechanical", are included in this cluster. Thirdly, the categories related to humanities and social sciences are hence split with the computer sciences and combined with some subject categories related to biomedicine, to form a new cluster of Social Medicine (SM4).

The Social Medicine cluster is augmented with 30 new categories related to biomedicine and humanities & social sciences, and the 36 categories from the cluster of Social Computing, Ergonomics, and Engineering in the previous stage. The categories related to biomedicine are located on the border of the clusters of Social Medicine and Biomedical Science, while most categories related to social sciences are in the periphery. The categories in the Social Medicine cluster have established extensive connections in the whole structure. The category of "neuroscience" has the largest number of connections, followed by the categories of "economics" and "management".

The new subject categories, which deal with the agricultural sciences, environmental sciences, and material sciences, change the combination of categories and form two new, but overlapping clusters. One cluster contains 48 categories, including some categories of applied fundamental sciences such as "Physics, Applied", "Chemistry, Applied", "Mathematics, Interdisciplinary Applications"; and some multidisciplinary categories in the field of chemistry, geosciences, engineering, and materials; and the related engineering categories in these fields such as "Engineering, Chemical", "Engineering, Environmental", "Engineering, Geological"; and notably, all the 8 material sciences categories. The applied fundamental sciences categories and the multidisciplinary categories and related Engineering are at the center of the structure. The 8 materials sciences categories are in the periphery. Among these 8 materials sciences categories, 6 categories just showed up in this stage, i.e., "Materials Science, Paper & Wood", "Materials Science, Textiles", "Materials Science, Ceramics", "Materials Science, Coatings & Films", "Materials Science, Composites". The other two categories, i.e., "Materials Science, Multidisciplinary" and "Materials Science, Characterization & Testing", appeared in 2008-2011. We call this cluster **the Materials Science and Engineering cluster** (MSE4). The other cluster contained 12 categories. This cluster incorporate several categories related to agricultural sciences such as "Agriculture, multidisciplinary", "Agronomy", "Horticulture", "Agricultural Engineering", "Plant science", " Evolutionary Biology", and "Ecology", as well as some categories related to fundamental sciences of geosciences such as "Geochemistry & Geophysics" and "Geography, Physical", and some technology categories that can be used in agriculture and geoscience such as "Imaging Science & Photographic Technology" and "Remote Sensing", "Computer Science, Interdisciplinary Applications". The categories of agricultural sciences are in the periphery. The technology categories are in the center of the structure. The categories in this cluster scatter among the clusters of Computer Sciences, Computer Engineering, and Materials Science and Engineering. The agricultural sciences have a close relation with geoscience because agricultural products are grown in soil (earth), which is the subject investigated by geosciences. We name this cluster the **Agrotechnique cluster (AT4).**

The **Biomedical Sciences** cluster contains 43 categories. The categories in this cluster changed. However, the structure of the cluster remains almost the same. "Multidisciplinary sciences" is still in the nucleus of this cluster with the other clusters, and "Biochemical research methods," "Mathematical & Computational Biology," and "Engineering, Biomedical" are the most important categories.

4.2.6. Characteristics of the Supportive Structure in 2020-2023

AI-related studies at Tongji University exploded during the period 2020-2023. Tongji University published 2,166 AI-related articles, spanning 172 subject categories. These publications reference 237 subject categories. All the categories in the previous stages are included in the supportive structure. About 32 subject categories from biomedicine, engineering, and humanities & social sciences are added in the supportive structure. The structure in this stage is quite like that in the previous stage. The six clusters resemble a radiating structure. However, the position, connections of subject

categories differentiate from the previous stage, leading to new characteristics of the supportive structure.

The obvious difference between this stage and the previous stage is that the Social Medicine cluster in the previous stage was split. The categories related to biomedicine in the Social Medicine cluster move out and join with some new categories related to biomedicine to form the **Biomedical Science cluste**r (**BM5**). The other categories in the Social Medicine cluster, together with newly appearing categories related to social science, form an independent cluster of **the Humanities and Social Sciences cluster (HSS5)**. Because of the split of the Social Biomedical cluster, the two clusters have a clear boundary. BMs has 85 categories, and HSS5 has 57 categories.

The other 95 categories are grouped into four clusters and are intertwined with each other. Two clusters even overlap.

Except for the category of "Computer Science, Cybernetics", all the other six categories related to the computer sciences are gathered in the cluster located in the center of the supportive structure. Together with some fundamental and applied categories, such as "Logic", "Mathematics", "Mathematics, Applied", "Operations Research & Management Science", "Statistics & Probability", and some Engineering categories such as "Telecommunication", "Engineering, Electrical & Electronic", "Automation & Control Systems", "Engineering, Industrial", "Manufacturing" and "Robotics" to form **the Computer Science cluster (CS5).** Except for the category of "Logic", which is in the periphery of the structure, all the other categories are located in the center of the structure. "Computer Science, Cybernetics" is grouped with the categories related to the humanities and social sciences. In this way, the subject categories related to computer sciences moved out from the Computer Engineering cluster, and hence the Computer Engineering cluster was split.

The Engineering categories from the Computer Engineering cluster, the Material Science & Engineering Cluster, and the **Agrotechnique cluster** make a complex combination. These clusters are centered on different specific subject categories.

Centered with "Engineering, Civil", "Construction & Building Technology", some categories related Geosciences and Geological Engineering such as "Geology", "Geosciences, Multidisciplinary", "Engineering, Geological", "Geochemistry & Geophysics", "Engineering, Ocean", "Engineering, Marine", "Engineering, Multidisciplinary", "Mining & Mineral Processing", "Transportation Science & Technology", "Engineering, Petroleum" and some categories that related to fundamental sciences or technique tools such as "Chemistry, Analytical", "Acoustics", "Instruments & Instrumentation", "Imaging Science & Photographic Technology", "Remote Sensing", form a cluster. The categories of fundamental sciences and technical tools are in the middle of the structure, and the categories of Engineering and Geosciences are in the periphery. However, the size of the categories in the periphery are not small. Strangely, the category of "Literature" is also included in this cluster. We name this cluster the **Civil Engineering & Geosciences** cluster (**CEG**).

The categories of materials science are divided into three clusters at this stage. "Materials Science, Biomaterials" is included in the Biomedical Science cluster. Two categories, "Materials Sciences, Paper & wood" and "Materials Science, Textiles," are included in one cluster. Five categories, "Materials Science, Coatings & Films", "Materials Science, Composites", "Materials Science, Ceramics", "Materials Science, Characterization & Testing", "Materials Science, Multidisciplinary" are grouped in one cluster.

The cluster has five categories of materials science, attracting many categories of fundamental sciences of physics, chemistry, and mathematics. Except for the categories of Biophysics, Geochemistry & Geophysics, all the other 10 categories related to physics are grouped in this cluster. However, except for some multidisciplinary and applied categories, the categories of materials science and fundamental science are all relatively small and located in the periphery. The category of "Mathematics, Interdisciplinary Application" is at the center of the supportive structure. The multidisciplinary and applied subjects, such as "Materials Science, Multidisciplinary", "Physics, Multidisciplinary", "Physics, applied", "Chemistry, Multidisciplinary", " Chemistry, Physical", " Engineering, Mechanical", "Mechanics", are between the periphery and the center. The cluster is

centered with multidisciplinary and applied categories, gluing the materials science and fundamental science together. We name this cluster the **Materials & Fundamental Science cluster (MFS)**. In Liu et al. (2025)'s map, the categories of materials science and the fundamental science of physics and chemistry constitute a cluster [20].

The categories of "Materials Sciences, Paper & wood" and "Materials Science, Textiles" reasonably combine with the categories of agricultural sciences since paper, wood, and textiles are all produced from agricultural products. This cluster contains many categories related to environmental science and Engineering, such as "Environmental Sciences", "Green & Sustainable Science & Technology", "Energy & Fuels", "Engineering, Chemical", and "Engineering, Environmental". These categories are in the center of the structure, while agriculture-related categories are in the periphery. We name this cluster the **Agriculture & Environment cluster (AE)**.

5. Discussion

5.1. The Evolution of the Clusters, the Big Pillars of the Supportive Structure, and the Deep Reasons for Their Evolution

The supportive structure for advancing AI studies at Tongji University was initially composed of the categories related to engineering, computer science, biomedical science, and fundamental science. These categories were grouped into three clusters based on the category co-cited by one publication. The categories of fundamental science are scattered across all three clusters. The clusters were named the Engineering cluster, the Computer Science cluster, and the Biomedical Science cluster. However, the categories in three clusters are not clearly assigned by the categories' subject property. The categories of engineering and computer science were mixed in the Engineering cluster and the Computer Science cluster, e.g., the category of "Computer Science, Software Engineering" was assigned into the Engineering cluster, some categories of Engineering, such as "Engineering, Manufacturing" and "Engineering, Biomedical", were assigned into the Computer Science cluster. The Engineering cluster and the Computer Science cluster are embedded in the supportive structure, whereas the Biomedical Science cluster is situated at a distance from two clusters. In this way, the biomedical science, engineering, and computer science were three subject clusters for advancing AI studies at Tongji University initially.

Then, new categories were added and integrated into the supportive structure. The supportive structure, hence, evolved through the differentiation and integration of these categories.

The Biomedical Science cluster was first split up in the second stage. There were always some biomedical science categories that stayed independent as a Biomedical Science cluster in the five stages. But the others moved out and combined with other types of subject categories to form new clusters. In the second stage, some biomedical science categories combined with categories of engineering to form a Medical Engineering cluster, some combined with categories of computer science to form a Somatic Science cluster. The two clusters established a channel and filled the gap between the Biomedical Science cluster and the two clusters of Engineering and Computer Science. In the third stage, some psychology, physiology, and ergonomics categories merged and formed the Ergonomics cluster. In the fourth stage, some combined with the social sciences categories to form the Social Medicine cluster. In the fifth stage, all biomedical science categories are departed from the other clusters and form an independent cluster.

The Computer Science cluster was split into two clusters in the third stage. Two computer science categories about Hardware & Architecture and Software Engineering, moved to the periphery of the supportive structure, but linked to the "Computer Science, Theory and Methods" and some categories of engineering such as "Engineering Multidisciplinary" in the center of the structure, to form a Computer Engineering cluster; The "Computer Science, Cybernetics", "Computer Science, Artificial Intelligence" and "Computer Science, Information Systems", was combined with the categories of social science, inserted in the Computer Engineering cluster to form the Social Computing cluster. In the fourth stage, the categories of computer science were

differentiated again. The Computer Engineering cluster continued, with different categories of computer science and more engineering categories. The Social Computing cluster was split. Some categories of fundamental science were grouped with the categories of computer science to form the Computer Science cluster. In the fifth stage, 6 among 7 categories of computer science were brought together and formed the Computer Science cluster.

The categories of engineering initially appeared in clusters mixed with the categories of computer science. The strongest subject of Tongji University, Civil Engineering, didn't appear in the supportive structure at the first stage. "Engineering, Civil" was added to the supportive structure in the second stage. As the differentiation of the Biomedical Science cluster, the categories of Engineering began to combine with some of them to form the Medical Engineering cluster. In the third stage, some engineering categories combined with the categories of computer science to form the Computer Engineering cluster; some stayed in the Engineering cluster. Besides these two clusters, some engineering categories were combined with the categories of physiology, psychology, and biomedical sciences to form the Ergonomics cluster. In the fourth stage, more categories of material science, environmental engineering, and agricultural engineering appeared, splitting the Engineering cluster into the Agrotechnique cluster, the Materials Science and Engineering cluster and the Computer Engineering cluster. In the fifth stage, the engineering categories are combined in a new way and are adjusted to three clusters. the Materials Science and Engineering cluster was adjusted to the Materials & Fundamental Science cluster, the Agrotechnique cluster was adjusted to the Agriculture & Environment cluster. The Civil Engineering was split with computer science and combined with categories of Geoscience to form the Civil Engineering & Geosciences cluster (CEG)

A few categories of social sciences appeared in the supportive structure in the second stage. They are scattered over the clusters of Computer Science, Engineering, and Biomedical Science. In the third stage, more categories of social science were involved, and formed the Social Computing cluster, inserted into the middle of the Computer Engineering cluster. In the fourth stage, the categories of social science left the categories of computer science and combined with categories of medical science, to form the Social Medicine cluster. In the fifth stage, most of the categories of humanities and social sciences gathered to form an independent cluster.

From the evolution of the clusters, we may conclude that AI studies at Tongji University indeed lead to the differentiation and integration of subject categories, the categories of biomedical science, computer science, and social science gathered to form the respective independent clusters in the final. But the categories of Engineering differentiate into different clusters, centered together with civil Engineering, materials science, and agricultural engineering.

Liu (2018) used the commonality of journals between categories to connect the categories to construct the structure of science[21] . Liu et al. (2025) further analyzed the evolution of the map of science constructed with the same method [20]. Based on the commonality of categories in these clusters, we drew a map to reflect the relationship between these clusters in Figure 2. The clusters are grouped into four clusters. This map builds an arch to connect all the clusters produced in the process of differentiation and integration of the categories. We define this structure as the top arch structure of the supportive structure. In such, we have supportive structures and their top arch structure. The cluster of categories in the supportive structure is the element of the top arch structure. The cluster of categories in the supportive structure is defined as the pillar of the supportive structure. The cluster of these clusters in the top arch structure is defined as the big pillar of the top arch structure. The names of the big pillars and their components are shown in Table 4.

Table 4. The components of the big pillars in the top arch structure of the supportive structure and their clusters.

Pillars	2004-2007	2008-2011	2012-2015	2016-2019	2020-2023
BIOMEDICINE	BM1	BM2, SomS2	BM3, Ergo3	BM4	BM5

ENGINEERING		Engg2	Engg3	AT4, MSE4	CEG5, AE5
COMPUTER SCIENCE	CS1, Engg1	CS2, ME2	CE3	CS4, CE4	CS5, MFS5
HUMANITIES & SOCIAL SCIENCES			SC3	SM4	HSS5

Except for MFS5 (Materials & Fundamental Science cluster), the components of each big pillar are reasonable. The position of MFS5 is located near the ENGINEERING big pillar, but is grouped into the COMPUTER SCIENCE big pillar. The deep reason is that the categories of fundamental science were grouped into this cluster in the final stage, whereas most of them were grouped with computer science at the first three stages.

Tongji University was founded as a medical university by a German doctor in 1907. Before 1949, it developed into a comprehensive university. But the subject of medical science, together with the other subjects, moved out from Tongji University in 1953 when the Chinese government adjusted the subject layout of universities all over the country. Only the subject of civil engineering remained at Tongji University, and civil engineering topics from other universities moved to Tongji University. Tongji became a university of civil engineering. After 1978, Tongji University made a great effort to become a comprehensive university again. For this aim, Tongji went through two strategic transfers: from a university that only had the subject of civil engineering to a multidisciplinary engineering university; from a multidisciplinary engineering university to a comprehensive university. In the second transformation, recovering the subject of medical science is very crucial. This is not only a way to develop a subject, but also for the historical memory of its initial establishment. Recovering the subject of medical science became the university's ambition at the beginning of the 21st century. In 2007, a biomedical scientist was appointed as the president of Tongji University, who began to lay out the subjects of biomedical science at Tongji University. The integration of AI and biomedical science should be the most important measure for this subject layout. The subjects of Humanities and Social Sciences also developed after 1978. However, the subjects of Humanities and Social Sciences are still very weak till now. The history of the university may explain the reason why the supportive structures for advancing AI studies at Tongji University are evolving at the differentiation and integration of the subjects of computer science, biomedical science, Engineering, and social science.

5.2. Singular Category in a Cluster, Knowledge Integration, Category's Capacity for Multiple Integration, and Administrative Strategy for Constructing a Subject Cluster

Liu, Li & Wei (2019) found that sometimes a category is grouped in a cluster to which it clearly does not belong. The category is usually positioned on the border of a cluster and plays an important bridging role between the clusters. They defined such a category as a singular category[22]. We can see much more singular categories in the supportive structure, e.g., "Business", "Economics", "Management" were in the Computer Science cluster, "Sociology", "Social Sciences, Mathematical Methods" were in the Biomedical Science cluster at the second stage, "Law" was grouped in the Computer Engineering cluster, "Social Work" was assigned to the Materials and Fundamental Science cluster and "Literature" was assigned into the Civil Engineering and Geoscience cluster in the fifth stage. These singular categories often occurred when the categories first appeared in the supportive structure and were usually located on the periphery of the cluster, or, sometimes, right in the middle of the cluster.

Many categories were grouped into two different clusters in different stages. Among 239 categories, 28 subject categories appeared in only one stage, and 28 subject categories appeared exclusively in the Biomedical Science cluster. The other 183 categories were assigned to different clusters in different stages. Even though we assigned the categories to the big pillars through their respective clusters, there are still 123 categories assigned to different big pillars. These phenomena show that the knowledge in one subject category can be integrated with the knowledge from different

categories to form a different cluster. This means that a category has the capacity to integrate with different categories to form different clusters.

We know that knowledge can be used to solve a problem wherever it is needed, no matter what subjects the knowledge comes from. This is the deep reason and logic that can explain why categories are grouped into different clusters. Take, e.g., Imaging Science & Photographic Technology (ISPT), Remote Sensing (RS), Geochemistry & Geophysics (GcGp) to explain the logic of knowledge integration into different clusters.

Table 5. Examples of categories that are grouped into different clusters at different stages.

categories	2004-2007	2008-2011	2012-2015	2016-2019	2020-2023
ISPT	BM1	CS2	Engg3	AT4	CEG5
RS	BM1	CS2	Engg3	AT4	CEG5
GcGp	BM1	0	BM3	AT4	CEG5

In the first stage, the three categories were in the Biomedical Science cluster, but close to the Computer Science cluster. In the second stage, RS and ISPT were grouped in the Computer Science cluster; in the third stage, they were grouped in the Engineering cluster; GcGp did not show up in the second stage, but returned to the Biomedical Science cluster in the third stage. It was located on the opposite periphery of the supportive structure with the Biomedical Science cluster, far away from the center of the Biomedical Science cluster. In the fourth stage, the three categories were all grouped into the Agrotechnology cluster. In the fifth stage, they were all grouped into the Civil Engineering and Geoscience cluster. Remote Sensing is defined as the technology that acquires the image or data about the surveyed object by photographs or other means (E.L.Pruit, 1960) [23]. This explains why the two categories of RS and ISPT were always in each other's neighborhood in the supportive structure. RS and Geochemistry and Geophysics are three core methods to study Geoscience. However, they are also used for collecting information for medical imaging and diagnosis, disease surveillance and prevention, telemedicine, and data transmission, and for Precision Agriculture. All the data collected by these methods are processed by computer methods. So, the categories of ISPT, RS, and GcPp have the capacity to be clustered with different categories to form different clusters.

Why different categories form a cluster also has the logic of knowledge integration inside. We take the Medical Engineering in the second stage as an example. The categories in the Medical Engineering cluster are scattered in the Biomedical Science cluster, the Engineering cluster, and the Computer Science cluster. "Automation & Control Systems", "Statistics & Probability", and "Instruments & Instrumentation" were in the middle of the structure and in the nexus of the three clusters. "Optics" and "Engineering, Aerospace", "Materials Science, Characterization & Testing" are closely aligned with the cluster of Computer Sciences and Engineering, whereas "Respiratory System", "Medical Laboratory Technology", "Medicine, General & Internal", and "Chemistry, Analytical" are more closely associated with the Biomedical Sciences cluster. It is well-known that in the biomedical field, diagnosing lesions in the respiratory system and other human organs requires medical laboratory technology for testing, which may involve, for example, the assaying of cellular tissues, and requires advanced instruments for assaying and analyzing, and the analytical process involves the characterization and testing of materials and probabilistic statistical analysis. Additionally, the operation of advanced instruments involves the application of optical and automation technology. Consequently, this process promotes the integration of AI with computer science, engineering, and biomedicine to form the Medical Engineering cluster.

The Double First-Class Initiative is a strategic approach of the Chinese government. By selecting 42 top Universities and 95 subjects in other universities (MoE, 2017) [24], the Chinese government expects that these universities and subjects will reach the world-class level through systematic governance of universities and advancing subjects. The selected universities and subjects are heavily funded by the Chinese government. Only the strongest subjects and universities can be selected. In order to be selected, some universities try to find ways to advance their strongest subject and neglect

the relatively weak subjects. Some universities try to construct subject clusters that support each other. The latter is certainly better than the former. However, till now, no university has noticed that a subject has the capacity for multiple integration and differentiation, and hence, the subject clusters are not fixed. Measures should be taken to optimize their subject structure by understanding the logic of knowledge integration and differentiation of subjects in the governance of a university and its subjects.

6. Conclusions

When a publication cites other publications (references), it seeks support for the concept or method it wants to develop. The status quo of the development of a subject is represented by all the publications carrying the knowledge on the phenomena that the subject is investigating. In this sense, we think that the knowledge in all the references of the publications on a subject constitutes the knowledge to advance the subject. The subject structure derived from publications and their references can be used to describe the supportive structure for advancing the studies of the subject. We use the subject categories of all publications on AI and of their references at Tongji University and co-citations to construct the university's supportive structure for advancing AI studies. We analyze the characteristics and the evolution of the supportive structures in five stages. Based on the clusters in each stage and the commonality of subject categories between the clusters, we construct a top-arch structure for the supportive structure for advancing AI studies at Tongji University.

The trends of network density, betweenness centralization, and degree centralization of the supportive structure in five stages suggest that at the beginning, "Computer Science, Information Systems", "Computer Science, Interdisciplinary Applications", "Engineering, Biomedical", and "Engineering, Electrical & Electronic" play an important role in connecting the categories in different clusters. In the final stage, almost all the involved subjects are connected. The supportive structure is gradually evolving to a balanced, compact, and decentralized structure.

We find that AI studies at Tongji University, developed in support of the differentiation and integration of subject categories, hence breaking the barrier of subjects. Initially, the supportive structure for advancing AI studies was constituted by the Computer Science cluster, the Biomedical Science cluster, and the Engineering cluster. The Biomedical Science cluster and the Computer Science cluster are farther apart. while the Engineering cluster and the Computer Science cluster are almost embedded in the supportive structure. Engineering is the strongest subject at Tongji University; however, just a few engineering categories support AI studies at the beginning. Later, as more and more subject categories joined and provided support for AI studies, the clusters began to split and make a new combination. In the second stage, the Biomedical Science cluster was split, and two new clusters of Medical Engineering and Somatic Science were formed, establishing a channel between the Biomedical Science cluster and the two clusters of Engineering and Computer Science. The humanities and social sciences provided the support for AI in the second stage; however, they were scattered over the clusters of Computer Science, Engineering, and Biomedical Science. In the third stage, the Computer Science cluster was differentiated, some combining with subjects of social science to form the Social Computing cluster, some combining with the subject categories of Engineering to form the Computer Engineering cluster. Some subjects from the clusters of Biomedical Science, Medical Engineering, Somatic Science, and Engineering made a further differentiation and integration to form the Ergonomics cluster. In the fourth stage, the Engineering cluster was split and formed three centers with civil engineering, materials science, and agriculture. The subjects of the social sciences departed from computer science and combined with the biomedical sciences to form the Social Medicine cluster. in the final stage, the subject categories of Computer Science, Humanities and Social Science, and Biomedical Science gather as an independent cluster, whereas the subject categories of Engineering remain three clusters centered together with civil Engineering, materials science, and agricultural engineering.

By the construction of the top arch structure, we may see that during the evolution of the clusters in different stages, the clusters form four big pillars of BIOMEDICINE, ENGINEERING, COMPUTER SCIENCE, and HUMANITIES & SOCIAL SCIENCE to support the AI studies at Tongji University.

Subject categories are moving in these clusters as well as in these big pillars, while singular categories appear in clusters where they seem out of place. Nevertheless, we can observe that the logic of the knowledge integration that happened between different subjects. The phenomena we observed indicate, on the one hand, that AI studies have a special way to integrate knowledge from different subject categories and make these subject categories provide support for advancing AI studies; on the other hand, subject knowledge has the capacity to integrate with knowledge from different subjects to form new and dynamic clusters. These phenomena reveal that knowledge is generated not only through the differentiation and integration of subject categories, but that the drive and support force for knowledge production also has its special rationale that warrants further study. Only after understanding the rationale of this, the administration of a university may find a way to guide and support purposeful academic development.

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