Profiling the most highly cited scholars from China: Who they are. To what extent they are interdisciplinary

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Abstract

Since the beginning of the 21st century, an increasing number of Chinese researchers have joined the ranks of the world's top scientists. Some international organizations have observed this phenomenon and ranked the world's top Chinese researchers. However, investigation of highly cited interdisciplinary research (IDR) scholars is insufficient, although IDR tends to have a greater social impact. Looking at the top 2% of the world's Chinese scholars, this study analyzes the structural attributes of IDR by those top scholars in detail using network analysis, cluster analysis, block modeling, and quadratic assignment procedure analysis. The results show that the proportion of highly cited scholars in technical categories is higher than in social categories. The fields of artificial intelligence and image processing, oncology and carcinogenesis, plus neurology and neurosurgery serve as bridges across disciplines, with materials, energy, and artificial intelligence and image processing having higher eigenvector centrality. The field of social sciences has the widest range of IDR activities, but cooperation within this field is low. Forty-two of the world's first-class universities are in China, and of the world's top 2% scholars who come from China, 46.3% work for these institutions. The research themes of highly cited academics from World First-Class universities in China are most similar to the themes of scholars from universities in China with first-class academic disciplines. There are differences between non-university and university scholars in terms of research topics. It is suggested that the government can promote a triple-helix effect (public institute, industrial enterprise, and research school) so that organizations of different natures can produce synergistic effects.

Keywords

Interdisciplinary research; Scholarly communication; Researchers; Scientists; Highly cited scholars; Network analysis; Cluster analysis; Block modeling; Quadratic assignment procedure; China.

1. Introduction

The world has entered the era of Industry 4.0 with its complexity of society and knowledge in which the solutions to complex problems may be unclear, requiring an interdisciplinary approach (**Zeng** *et al.*, 2017). Interdisciplinarity combines approaches from different disciplines to solve specific problems (**Glänzel**; **Debackere**, 2021). The integration of science, technology, and society has promoted diversification in scientific research. Interdisciplinary collaboration often leads to collective creativity (**Moirano** *et al.*, 2020) and is of great significance to sustainable development in the scientific community (**Yarime** *et al.*, 2012). With the development of interdisciplinary research (IDR) and its expansion of the scope of scientific research, IDR tends to be more efficient and has a greater social impact (**Chen** *et al.*, 2015). Therefore, by studying the interdisciplinary status of highly cited scholars in a region, researchers can grasp the region's overall scientific research and development trends and motivations in various fields.

> Interdisciplinary collaboration often leads to collective creativity and is of great significance to sustainable development in the scientific community

Since the beginning of the 21st century, China and other countries have not only become more open to trade but have also made rapid progress in science and technology (**Zhang** *et al.*, 2021; **Zheng** *et al.*, 2012). At present, China has joined the United States in influencing the development of the world's political and economic sciences. The structure of research has changed dramatically over the last 20 years. Globalization of markets and developments in technology and communication are rapid. New and more complex social problems urgently need interdisciplinary professionals to solve them (**Zeng** *et al.*, 2017). In this international context, China has been undergoing rapid academic development, and the number of globally renowned Chinese researchers is increasing. Several international organizations have ranked the influence of Chinese researchers on the global academic community. For example, since 2015 *Elsevier* (2021) has annually published a report titled *Highly Cited Chinese Researchers*. However, there is insufficient investigation of scientific development in China in terms of interdisciplinarity. Thus, analysis and in-depth understanding of the profiles of highly cited scholars in China is necessary.

This study uses networks, clusters, quadratic assignment procedure (QAP) analyses, and block modeling to analyze the top 2% of the world's scholars. This study is aimed at grasping the distribution of China's top researchers, the relationships between disciplines, and differences between categories of organizations. In doing so, specific suggestions are proposed for the development of science in China, which will also be valuable for the development of science in other countries and regions.

2. Literature review

Since 1990, China's academic fields have been steadily expanding, but there is disagreement about the dominance of Chinese academics (**Wagner** *et al.*, 2022). In recent years, there has been much discussion about whether China's academic development is of high quality. **Wagner** *et al.* (2022) examined the top 1% of highly cited publications and discovered that the top 1% of China's cited articles surpassed those of all other countries after 2019. Despite this abundance, the extent of China's scientific output remains debatable. **Yang** and **Liu** (2021) contended that China is an autocratic state, that increasing the number of researchers will not necessarily improve research quality, and that democracy and academic freedom will lead to higher citation rates and other forms of academic creativity. Analysis of highly cited publications has been used on numerous occasions to assess a country's scientific impact. By studying highly cited scholars, we can evaluate the structure of scientific talent in a country from the perspective of scholarly knowledge structures.

In 2020, the *State Council of China* designated interdisciplinary fields as accessible degrees. To support IDR projects, the *National Natural Science Foundation of China* established the *Department of IDR* (**Zhang**; **Leydesdorff**, 2021; *National Natural Science Foundation of China*, 2020). This represents a shift in the structure of talent development in China, with interdisciplinary development becoming a national priority. The divisions in the IDR domain pose a complex problem (**MacLeod**, 2018), with such studies typically being thorough in two or more areas (**Cunningham** *et al.*, 2022). Interdisciplinary studies have a greater impact and visibility than single-field studies. **Chen** *et al.* (2015) discovered that publications with a high number of citations are more interdisciplinary than papers with a low number of citations, and this phenomenon occurred in 90% of scientific fields.

IDR frequently encounters new challenges and risks (**Bridle**, 2018; **Yegros-Yegros** *et al.*, 2015). It may receive less support and attention than general studies (**Bridle**, 2018). IDR typically necessitates a combination of different skills, and researchers early in their careers frequently face additional challenges and risks because of the difficulty in gaining recognition. However, highly cited scholars are known to the general public and have greater influence than average researchers. The distribution of research funding is unequal (**Benz**; **Rossier**, 2022). These highly cited scholars frequently have an advantage in terms of study time, performance evaluation, funding sources, and other issues in IDR. Consequently, IDR by highly cited scholars frequently represents the actual interdisciplinary development of their subjects and fields. Early researchers focused on the development of interdisciplinary knowledge in various fields (as well as the networks among authors) when studying interdisciplinary phenomena (**Liu** *et al.*, 2011; **Yang** *et al.*, 2010; **Aboelela** *et al.*, 2007). With its growing influence, IDR has received increasing attention. In recent years, there has been increased interest in research on the psychology of interdisciplinary scholars, on how to cultivate them, and on how to solve problems they encounter early in their careers (**Bridle**, 2018; **Paton** *et al.*, 2019; **Katoh** *et al.*, 2021). Although some scholars have discovered that highly cited papers have higher interdisciplinary characteristics (**Chen** *et al.*, 2015), there have been few studies on highly cited scholars. In particular, China has developed national policies and systems to foster interdisciplinary talent and promote IDR (**Sun**; **Cao**, 2020). Therefore, there is an urgent need to investigate the interdisciplinary status of influential scholars in China.

> By studying the interdisciplinary status of highly cited scholars in a region, researchers can grasp the region's overall scientific research and development trends and motivations in various fields

3. Research questions

RQ1. In which fields are China's highly cited researchers distributed?

RQ2. What is China's interdisciplinary knowledge network? In other words, to what extent are highly cited Chinese researchers interdisciplinary?

RQ3. Are there differences in the number of highly cited scholars and the relationships between disciplines in different types of organizations?

4. Research methodology

4.1. Data

This study used data from the top 2% of the world's highly cited researchers (**Baas** *et al.*, 2020). The data of highly cited Chinese researchers were extracted; of the 5,272 highly cited Chinese scholars, 4,084 worked at a university. Out of 708 organizations, 424 were universities. A total of 18 fields and 145 subfields were identified.

4.2. Network analysis

Network analysis is a method that can quantify the structural characteristics of nodes and links in a network, and then analyze and mine the relationships among people, organizations, and topics that constitute the network (**Park** *et al.*, 2019a; **Zhu**; **Park**, 2020). Network analysis is widely used in scientific research. Specifically, **Zhu** and **Zhang** (2020) explained the relationship between words using network path calculation, network density, centrality, cluster analysis, and other indicators. **Wang** *et al.* (2021) analyzed network density, centrality, and other indicators of cooperative and citation networks, finding that doctoral thesis supervisors in physics had limited influence on doctoral positions. **Yoon** and **Park** (2020) used semantic networks to analyze knowledge works in North Korea and found that national scientific and technological development promoted high-tech research, with energy, agriculture, and mining production studies as hot spots.

In this study, network analysis methods were used to analyze the domains of highly cited Chinese researchers in detail. We adopted two network analysis methods: one-mode network analysis and two-mode analysis. In a modular network, nodes represent research domains, and links represent the connections between domains. If a researcher has two areas of study, the two areas are considered related. In the two-mode network, nodes represent the classification of the research field and research organization, and links represent the relationship between the research organization and the research field. If a researcher has two areas of study, both areas are related to the research organization to which the researcher belongs.

In this study, centrality, link analysis, and density indices were used to analyze a network, which can evaluate the influence of nodes in the network and the structural attributes of the network. The centrality index usually includes degree, betweenness centrality, closeness centrality, and eigenvector centrality (**Yoon** *et al.*, 2017; **Zhu**; **Park**, 2021). Degree refers to the total number of nodes directly connected to a node; betweenness centrality is the intermediary role of a node, while closeness centrality is the distance of the node to other nodes, and eigenvector centrality measures the indirect influence of nodes (**Zhu**; **Park**, 2021). A connection analysis index helps in studying the relationship structure of the network, and not only reflects the influence of nodes but also analyzes the connection attributes between nodes (**Park**; **Thelwall**, 2008). A density index can evaluate the structural characteristics of the entire network (**Zhu** *et al.*, 2021). This study used *UCINET 6* and *NodeXL* software to build the matrix and conduct network analysis, QAP analysis, and visualization.

5. Cluster analysis

Cluster analysis classifies objects into different groups (**Abdullah** *et al.*, 2021; **Mansano** *et al.*, 2021; **De-Luca**, 2021). **Singh** *et al.* (2020) described the knowledge structure of enterprise universities through cluster analysis. **Lamirel** *et al.* (2020) used cluster analysis to determine a 40-year structure of Chinese scientific knowledge. In this study, the Clauset-Newman-Moore algorithm was used for classification, which finds the group that leads to the greatest growth (**Clauset** *et al.*, 2004; **Park** *et al.*, 2019b). Thus, two groups were found, and the maximum modularity value, which represents the similarity between the two groups, was obtained by combining them. Each node was associated with a group, and the group with the highest modular structure was generated after multiple calculations. This process divided a network into groups.

5.1. QAP analysis

The quadratic assignment procedure (QAP) is an algorithm used to test the correlation between networks, comparing the structural similarity between matrices (**Seok** *et al.*, 2021; **Uddin** *et al.*, 2019). It is an analysis method often used by network researchers (**Park** *et al.*, 2016). **Ju** and **Sohn** (2015) used the QAP method to compare patent networks of different offices. **Barnett** *et al.* (2014) used QAP analysis to reveal significant correlations between coauthored networks and university URL citation networks. In this study, we compared the research domain matrices of five different attribute organizations. First, Pearson correlation coefficients between the nodes of the corresponding research domains in each matrix were measured. The rows and columns in the study domain matrix were then randomly arranged, and the correlations of these nodes were calculated. Subsequently, several iterations were carried out to obtain a result. Generally, a significance level below 0.05 indicates a strong correlation. In this study, a significance level below 0.001 was used to ensure more rigorous results.

6. Block modeling

The block model is used to examine the connection structure of different types of research organizations. Block modeling can divide participants into different modules according to certain criteria based on their attributes (**Choe**; **Lee**, 2017). Previously, **Park** and **Thelwall** (2006) had used regions as standards to divide blocks and analyze network science communication. **Choi** *et al.* (2015) analyzed international cooperation in scientific research by dividing countries based on regions and languages.

Universities in China have many engineering majors, but science and technology universities have several humanities and social science majors. Government support and regional support in China vary greatly depending on the level and/or type of university. For example, according to the 2016–2019 report by the *National Office for Philosophy and Social Science*, there were more than 500 non-Double First-Class universities with fewer foundation projects than the 137 World First-Class universities and First-Class Academic Discipline Construction universities (*National Office for Philosophy and Social Science*, 2021). While universities in other countries might not do this, the allocation of research resources among Chinese universities varies so much that it would be more appropriate to divide them by grade rather than organizational attributes.

In this study, we created five blocks. Block modeling can divide scholars' units into discrete clusters based on each unique block defined by the researcher. Establishing World First-Class universities and inculcating First-Class Academic Discipline Construction universities is part of the national education policies promulgated by the Chinese government in 2017. The aim is to promote the development of Chinese universities. The proportion of national research funds allocated to various types of universities differed. Universities that are not Double First-Class often lack support from the state. Therefore, in this study, we divided organizations into the following five blocks: World First-Class universities, First-Class Academic Discipline Construction universities, non-university organizations, non-Double First-Class universities, and universities not from Mainland China.

7. Research results

RQ1. In which fields are China's highly cited researchers distributed?

A profile analysis of researchers was conducted in terms of affiliated universities and academic disciplines. Figure 1 shows that enabling and strategic technologies are the most popular field among highly cited Chinese researchers, followed by engineering, chemistry, and information and communication technologies. Social sciences, historical studies, and a few other fields, however, accounted for only a small proportion of highly cited Chinese researchers.

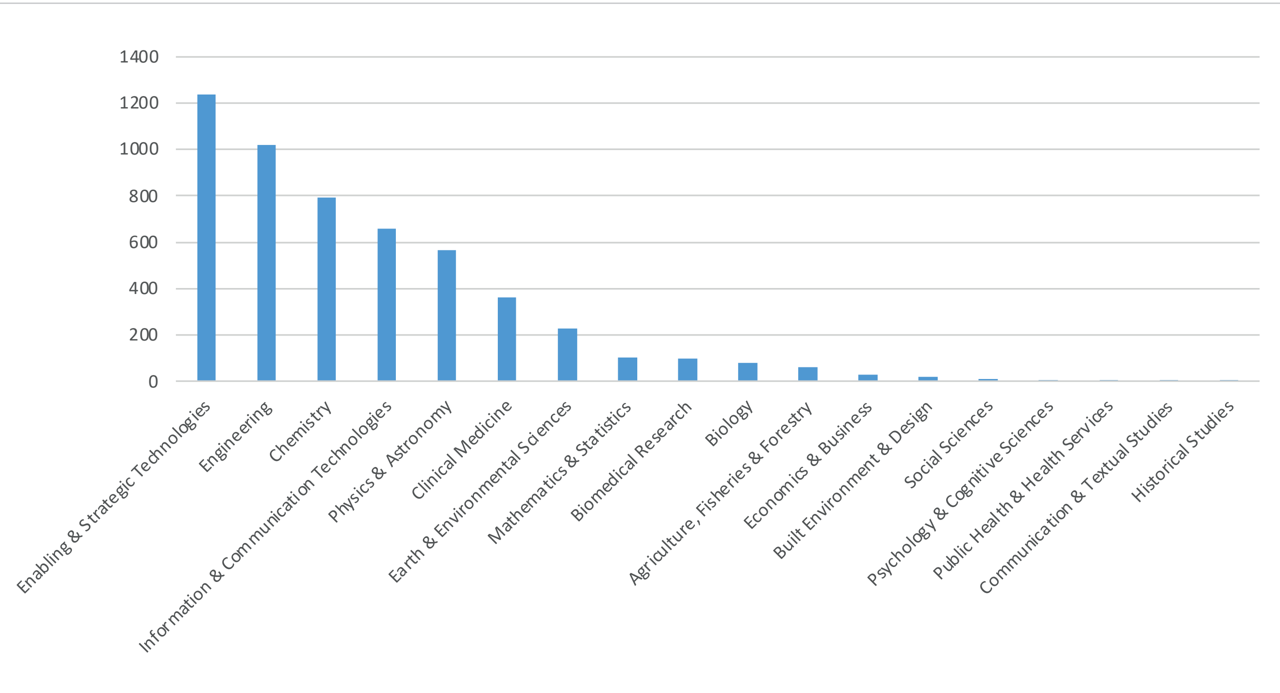

Figure 1. Fields of highly cited Chinese researchers

RQ2. What is the interdisciplinary knowledge network of China? In other words, to what extent are highly cited Chinese researchers interdisciplinary?

To answer the second question, after sorting, 145 subfields were obtained. If a researcher in two fields was observed, the two fields were considered interconnected. In other words, nodes are subfields, and links are the number of researchers shared among different sets of two fields.

In Table 1, we calculated the centrality of each node. A centrality index between 0 and 100 was obtained by standardizing the results.

Table 1. Centrality of nodes (Top 20)

Rank	Subfields	Degree	Betweenness centrality	Closeness centrality	Eigenvector centrality
1	Artificial Intelligence & Image Processing	100.00	100.00	98.89	91.33
2	Materials	97.92	52.14	100.00	100.00
3	Networking & Telecommunications	89.58	47.53	96.41	86.87
4	Energy	85.42	72.25	98.54	91.80
5	Oncology & Carcinogenesis	81.25	88.08	97.11	68.50
6	Mechanical Engineering & Transport	75.00	26.36	90.90	78.27
7	Environmental Sciences	72.92	51.88	90.28	69.62
8	Analytical Chemistry	68.75	17.84	93.09	79.55
9	Applied Physics	66.67	32.35	92.47	79.36
10	Neurology & Neurosurgery	64.58	74.27	94.06	62.71
11	Biochemistry & Molecular Biology	64.58	42.52	87.10	48.50
12	Industrial Engineering & Automation	60.42	42.14	91.82	62.28
13	Plant Biology & Botany	56.25	48.52	90.60	50.05
14	Nanoscience & Nanotechnology	54.17	21.77	88.53	65.34
15	Optoelectronics & Photonics	52.08	7.20	84.64	62.89
16	Polymers	52.08	7.56	82.32	61.65
17	Chemical Engineering	50.00	4.61	87.10	64.23
18	Chemical Physics	50.00	6.94	84.91	62.99
19	Pharmacology & Pharmacy	50.00	19.12	86.80	56.14
20	Organic Chemistry	47.92	6.28	83.07	57.23

On examining betweenness centrality, the field with the highest betweenness was artificial intelligence and image processing, followed by oncology and carcinogenesis, then neurology and neurosurgery. For eigenvector centrality, the field with the highest value was materials, followed by energy, then artificial intelligence and image processing. Artificial intelligence and image processing had the most links and the largest intermediary status. Materials had the shortest route to other fields, and fields directly related to materials had a higher average status.

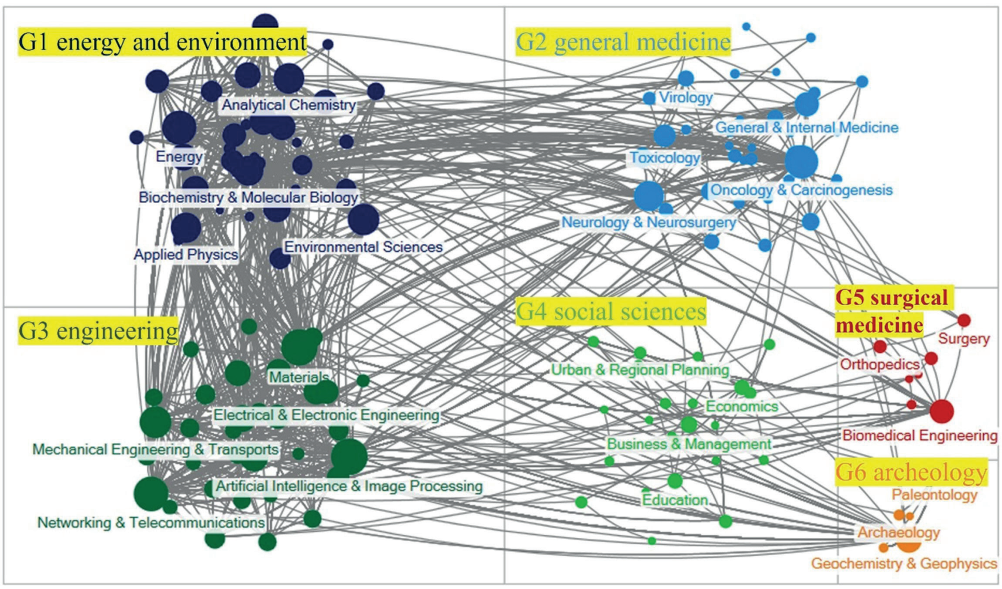

Figure 2. Subfield networks of highly cited Chinese researchers

After clustering the interdisciplinary network, six categories were generated. The largest category, as shown in Figure 2, was energy and environment, followed by general medicine, then engineering. Surgical medicine was separate from general medicine. Archeology was separate from social sciences. These findings suggest that IDR in archeology and surgery is relatively active. Cluster analysis found that the average geodesic distance was the highest in social sciences, followed by general medicine plus energy and environment. These three fields have a wider range of IDR.

> The field with the highest betweenness was artificial intelligence and image processing, followed by oncology and carcinogenesis, then neurology and neurosurgery

We used link and density analyses to examine the six groups further. Table 2 shows the link and density analysis indicators of the internal structures of the six groups. Figure 3 is a link-relationship network diagram of the various groups.

Table 2. Link analysis and density analysis indicators for the internal structures of the six groups

Group	Cluster name	Nodes	Links	Diameter	Average geodesic distance	Graph density
G1	Energy and environment	38	1,577	4	1.93	0.25
G2	General medicine	35	123	6	2.54	0.12
G3	Engineering	35	1,719	3	1.67	0.31
G4	Social sciences	25	33	8	3.76	0.08
G5	Surgical medicine	7	7	4	1.92	0.33
G6	Archeology	5	61	3	1.36	0.50

According to the results of the network analysis, engineering had the highest number of internal links (1,719), followed by energy and environment (1,577). Interestingly, we found that groups with many nodes do not necessarily have many links. For example, the general medicine group had 35 nodes but only 123 links. In addition, the surgical medicine group had seven nodes and seven links. At five nodes, archeology is the smallest group, but its 61 links is more than social sciences at 33. The largest diameter and highest average geodesic distance within a group were for social sciences, which also had the greatest span. The highest graph density within a group was for archeology (0.50), indicating close cooperation between the various fields within the group. The social sciences group had the lowest density (0.08), and thus, cooperation among the various fields within the group was relatively low.

As shown in Figure 3, G1 and G3 had the closest relationship at 1,280 links. Next, G1 and G2 had 166 links. G1, G2, and G3 had links with other groups, whereas G4 and G5 had no links with G6. The interspecialty of archeology focuses on engineering, energy and environment, and general medicine. Although research in the field of archeology has the appearance of interdisciplinarity, it may be difficult to conduct cross-disciplinary research with social sciences and surgery.

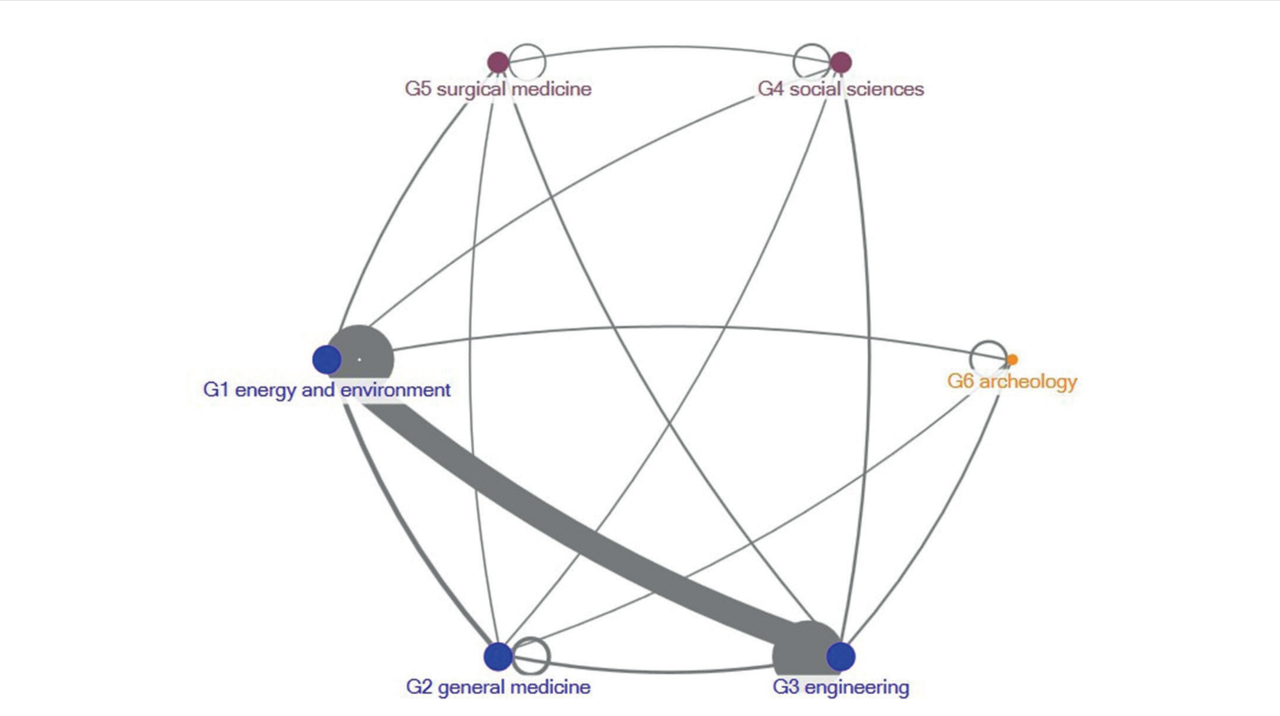

Figure 3. Network of link relationships among the groups

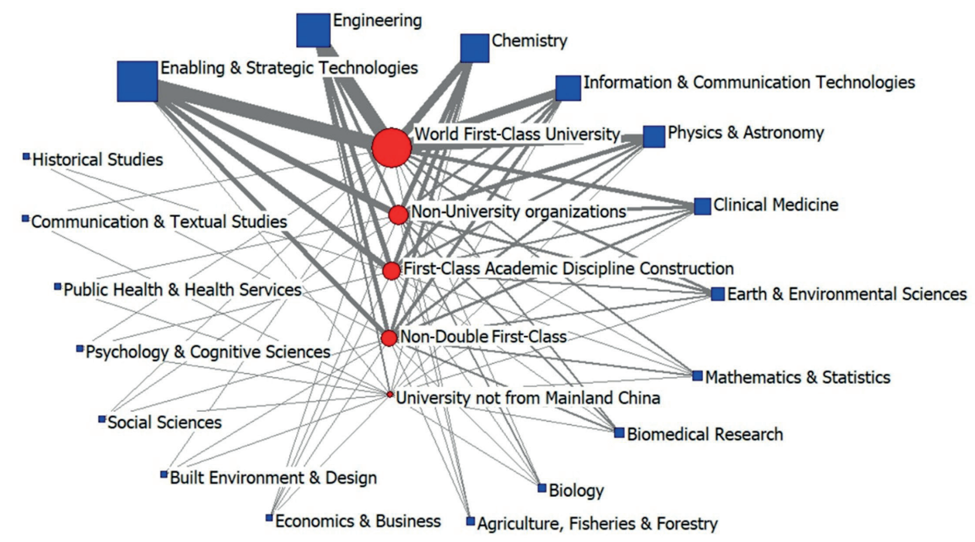

Figure 4. Network of organizational types and research fields

RQ3. Are there differences in the number of highly cited scholars and the relationships between disciplines in different types of organizations?

According to the results of the analysis, there are 80 disciplines and research institutes in 42 World First-Class universities, 74 in First-Class Academic Discipline Construction universities, 240 in non-Double First-Class universities, 30 in non-Mainland-China universities, and 284 in non-school organizations. We counted all authors' organizational attributes and research fields and created matrices for them. Network diagrams of organizational properties and research fields are in Figure 4.

The red nodes in Figure 4 represent organizations with five properties, and the size indicates the number of scholars from organizations in that category (the more scholars, the larger the node). Similarly, the size of a blue node indicates the number of scholars in the field. We found 2,442 scholars from World First-Class universities, accounting for 46.3% of the total, which is far higher than other categories. The second largest group was non-university organizations with 1,052 scholars (20.0%). The third largest category was First-Class Discipline Construction universities with 862 scholars (16.4%). The fourth largest category was non-Double First-Class universities with 828 scholars (15.7%). Finally, non-Mainland-China universities accounted for 88 scholars (1.7%).

The thicker the link in the figure, the more scholars such organizations have in the field, and the higher the strength of the relationship between the organization and the field. We found that enabling and strategic technologies performed best in the World First-Class University category, followed by engineering and then chemistry. The top three in the First-Class Discipline Construction University category were the same as in World First-Class universities. Enabling and strategic technologies continued to perform the best among non-school organizations, followed by chemistry, physics, and astronomy. Among non-Double First-Class universities, engineering and strategic technologies ranked highest followed by engineering then information and communication technologies. Among non-Mainland China universities, engineering ranked highest followed by enabling and strategic technologies then information and communication technologies.

To further analyze whether there is a statistical difference in the network of talent distribution for different fields in five types of organizations, we constructed a two-mode relational network matrix of those categories. The one-mode relational matrices of the domains were derived according to their connections. We conducted QAP analysis on the domain relation matrix of the five categories and obtained the results in Table 3.

Table 3. QAP correlations for five categories

	University not from Mainland China	**Non-university organization**	**Non-Double First-Class University**	**First-Class Academic Discipline Construction University**
World First-Class University	0.944318*	0.844537*	0.956538*	0.980226*
University not from Mainland China		0.730437*	0.909001*	0.911998*
Non-university organization			0.850232*	0.860228*
Non-Double First-Class University				0.940389*

*Significant at p<0.001

The analysis results show that the domain network between World First-Class universities and First-Class Academic Discipline Construction universities was the most similar, reaching 98.0%, followed by networks between World First-Class universities and non-Double First-Class universities. Performance differed most between non-Mainland-China universities and non-university organizations. Third was the relationship network between World First-Class universities and non-university organizations. In addition, the relationship network similarity between non-university organizations and all other categories was less than 90%, which is worse than for other categories. This shows that senior scholars from World First-Class universities and World First-Class Academic Discipline Construction universities are similar in their fields. Non-university organizations and university organizations had relatively different field relations.

> Social sciences, historical studies, and a few other fields accounted for only a small proportion of highly cited Chinese researchers

8. Discussion and conclusion

In this study, network analysis methods were used to investigate Chinese researchers ranked in the top 2% of the world's most highly cited researchers. It was found that enabling and strategic technologies, engineering, chemistry, plus information and communication technologies accounted for a large proportion of highly cited Chinese researchers, while the social sciences, historical studies, and a few other fields accounted for only a small proportion. This discrepancy among fields may have been exacerbated by the Chinese government's increased emphasis on science and engineering. According to **Xu** *et al.* (2015), funding for the social sciences in China is significantly lower than funding for the natural sciences, and the proportion of funding for the top 1% of social science articles from China that have been cited was not high and significantly lower than funding in other countries with a high article output. In terms of funding, the benefits from highly cited social science scholars in China are unclear. Changes in funding policies may improve social science research. The subfields of artificial intelligence and image processing, oncology and carcinogenesis, and neurology and neurosurgery had higher betweenness centrality. These fields serve as bridges across disciplines. Artificial intelligence and image processing techniques are increasingly used as tools to connect disparate disciplines. Artificial intelligence, according to **Liu** *et al.* (2020), caused knowledge spillover and promoted technological innovation in China. In the medical research field in China, the biology-psychology-society medical model was developed to replace the biomedical model of single-treatment research (**Song** *et al.*, 2010). Additionally, the subfields of materials, energy, and artificial intelligence and image processing had higher eigenvector centrality, compared to other subfields. A deeper analysis of hidden interdisciplinary fields was also conducted. Subdomain interdisciplinary networks were clustered into six groups. It is interesting to note that while the social sciences did not have a high number of highly cited Chinese researchers, it had the widest range of IDR activities. The frequency and breadth of social scientists' involvement in important research is increasing as data and computing power grow and as diverse teams are increasingly needed to solve complex problems (**Buyalskaya** *et al.*, 2021). The numbers of highly cited Chinese researchers and interdisciplinary indicators were higher for general medicine as well as energy and environment. The importance of IDR is universally acknowledged (**Yang** *et al.*, 2010), and expanding the extent and depth of IDR is conducive to the development of science. In addition, among highly cited scholars in China, the social sciences had the largest interdisciplinary range, but cooperation within the social sciences group was low. The closest cooperation occurred between subfields within archeology. Other interdisciplinary disciplines for archeology were engineering, energy and environment, and medicine.

China is one of four ancient civilizations with numerous sites and cultural relics. Owing to technical and preservation issues, archeology-related research has a long cycle and necessitates collaboration among scholars from various disciplines (**Wu** *et al.*, 2019; **Gu** *et al.*, 2013). For example, the study of metallurgy must be combined with engineering technology, and the study of remains cannot be separated from medical knowledge. Furthermore, professional knowledge of energy and radiation, chemistry, environmental science, geography, climatology, history, etc., is required in most archeological studies (**Li** *et al.*, 2020; **Yu** *et al.*, 2012; **Jiang** *et al.*, 2017; **Li** *et al.*, 2010; **Deng** *et al.*, 2013; **Chen**; **Gideon**, 2014).

There were great differences in the number of organizations in various categories. Although there are 42 World First-Class universities, they accounted for almost half of the top 2% scholars from China. The distribution of top scholars from China follows Pareto's law. Double First-Class universities accounted for 62.7% of high-level scholars, and there were significant differences in the distributions of scholars. Double First-Class universities are usually well-funded and enjoy high national and regional status, whereas many general universities in central and western China often lag World First-Class universities in terms of salary, treatment, and scientific research funding. The annual research expenditure of some World First-Class universities is ten times that of ordinary universities. For China, most universities are state-owned, which is usually an indicator of state-allocated funding, and they have little market competition. The majority of research funding comes from governments (**Jung**; **Seo**, 2022). However, these huge differences restrict the development of general colleges and universities. Human resources, research,

> The frequency and breadth of social scientists' involvement in important research is increasing as data and computing power grow and as diverse teams are increasingly needed to solve complex problems

material collections, data preservation, etc., can all be covered by research funding. If the government would provide relatively large subsidies to highly cited scholars from ordinary universities, it could be beneficial for retention of those scholars. Hence, knowledge spillover to general universities from highly cited scholars would be generated, and the sustainable development of general universities in scientific research will be promoted.

> Materials, energy, and artificial intelligence and image processing had higher eigenvector centrality, compared to other subfields

In addition, from the results of block model analysis, each block had its own characteristics. Studies of highly cited scholars from World First-Class universities and universities with first-class disciplines were the most similar. However, in terms of research topics, there were some differences between university scholars and non-university scholars, such as those in government agencies and enterprise research institutions. It is suggested that the government can promote a triple-helix effect in government enterprises and schools so that organizations of different natures can produce synergistic effects (**Choi** *et al.*, 2021). In university-industry-government collaborations, cooperation between two organizations can affect cooperation from the third (**Leydesdorff**; **Park**, 2014; **Park**; **Stek**, 2022). To achieve better cooperation, three-fold cooperation must be studied and macro-controlled. Because system dynamics constantly change, the endogeneity of change and innovation generates momentum, and as the system develops, selection and control become necessary components (**Leydesdorff**; **Smith**, 2022). Interdisciplinary development before 2020 can be viewed as endogenous change and innovation, whereas after 2021, under state regulation, interdisciplinary development has produced choice and control. In the next stage, research based on the triple-helix effect will be used to better regulate China's interdisciplinary system.

This study analyzed the interdisciplinary characteristics of highly cited Chinese scholars, discovered disequilibrium in fields and organizations to which they belong, and offered reasonable suggestions. China began interdisciplinary development at the national level in 2020, and our research can serve as a foundation for the development of China's future interdisciplinary references. Furthermore, this study can be used as a reference for interdisciplinary policies in other countries. Recently, many scholars have explored gender differences in research topics and their influence. In future research, classification by gender will be considered, and information of more value will be extracted from analyzing gender differences.

> It is suggested that the government can promote a triple-helix effect in government enterprises and schools so that organizations of different natures can produce synergistic effects. In university-industry-government collaborations, cooperation between two organizations can affect cooperation from the third

9. Declarations

The authors have no financial or non-financial conflicts of interest to disclose.

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