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Diversity of individual research disciplines in scientific funding

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Abstract Given the development in modern science and technology, scientists need interdisciplinary knowledge and collaborations. In the National Natural Science Foundation of China (NSFC), more than 59 % of individuals change their disciplinary application codes to pursue interdisciplinary applications for scientific funding. An algorithm that classifies interdisciplinary applications and calculates the diversity of individual research disciplines (DIRD) is proposed based on three-level disciplinary application codes. Using a sample of 37,330 unique individuals at the NSFC from 2000 to 2013, this research analyzed the DIRD of all sponsored individuals and found that DIRDs differ significantly among scientific departments, research areas, and universities. Sponsored individuals prefer not to engage in cross-research-fields or interdisciplinary applications. In addition, top-class universities in China exhibit stronger ability to carry out interdisciplinary research than do other universities. This thorough investigation of interdisciplinary applications in a scientific foundation provides new insights in managing scientific funding.

Keywords Disciplinary diversity · NSFC · Scientific funding · Interdisciplinary research · Research discipline

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Introduction

Interdisciplinary research plays an important role in modern science and technology as the complexity and extent of project implementation increases (Metzger and Zare 1999). Researchers themselves need interdisciplinary knowledge or seek a variety of knowledge from other individuals through interdisciplinary collaborations to extend the scope of their research (Carayol and Thi 2005). Interdisciplinary studies need financial support from different disciplines (van Rijnsoever and Hessels 2011), and many scientific foundations, including the National Natural Science Foundation of China (NSFC), encourage interdisciplinary collaborations to accelerate innovation borne out of research (Benner and Sandström 2000). Individuals may select different research disciplines when they apply for scientific funding. This study investigates the diversity of individual research disciplines (DIRD) through analyzing NSFC-sponsored projects from 2000 to 2013 at the individual level. The aim is further understanding of interdisciplinary research across different research areas and universities.

In interdisciplinary scientific research (IDR), dataset of scientific funding is more challenging to retrieve and analyze compared to the easily accessible bibliometric data. Notwithstanding this difficulty, evaluating scientific funding should be conducted because it becomes increasingly important to enhance decision making in fund distribution (Auranen and Nieminen 2010). Peer review of funding has been previously studied in an attempt to understand the evaluation procedure (Roebber and Schultz 2011); number of academic publications is also used as an important indicator to evaluate scientific funding (Yang et al. 2013). Inequality in fund distribution has been an attractive research topic in recent years. Research shows that scientific funding has become increasingly preoccupied with social and economic inequality across universities and scientific disciplines (Xie 2014). In medical science, for instance, the alignment of research funding of a disease-specific research and the burden of this disease is assessed (Vanderelst and Speybroeck 2013). In the present study, disciplinary application codes (DACs) in research proposals for scientific funding is used to investigate the individual interdisciplinary applications.

Previous research on measuring IDR usually takes advantage of bibliometric dataset to develop the measures of diversity, entropy, and betweenness centrality (Wagner et al. 2011). Scientific funding is a good source of data in studying interdisciplinarity in spite of the existing defect of discipline classification schemes (Huutoniemi et al. 2010). In the evaluation of research proposal, interdisciplinary accountability should be considered in peer review and evaluation; toward this end, Huutoniemi (2012) studied beneficiaries of accountability, goal accountability, process accountability, and design of accountability. In the evaluation of scientific funding, DIRD is calculated as one of the important performance metrics and is investigated using DACs. Interdisciplinarity can refer to different capabilities or to a diversity of societal stakeholder involvements, as well as to cognitive distances among papers, journals, and fields (Heimeriks 2012). Rather than the investigation of interdisciplinarity at the journal-to-journal citation level (Leydesdorff et al. 2013), this study investigates the three-level DACs in scientific funding to analyze individual interdisciplinarity from the levels of scientific department, research area, research field, and research direction.

Individual interdisciplinarity is indicated by the DIRD, which measures the difference in the usage of DACs. China is rising globally as a major contributor to science and technology (Xie et al. 2014). Since its establishment in 1986, the NSFC, as the main financial support for natural scientific research, has invested more than 100 billon into more than 300,000 projects to support about 1 million researchers. To facilitate the selection of project applications and review experts, NSFC established a multi-level and comprehensive discipline classification code system on the basis of discipline classification schemes. Individuals are thus required to select the suitable DAC, which represents the specializations in their own disciplines, when they apply for scientific funding. The DIRD embodies not only the interdisciplinary nature of modern scientific development but also the connections among different disciplines (Sandström 2009). Therefore, this investigation of DIRD can help in understanding the intrinsic law and the evaluation of IDR supported by scientific funding.

In summary, on the basis of dataset of NSFC-sponsored projects, this study gives a two-fold contribution. First, the method for calculating DIRD is proposed for investigations on individual interdisciplinarity. The algorithm takes into account the overlapping multiple levels of DACs and considers the identification of individuals to avoid name ambiguities. Another proposal is the five-class categorization of interdisciplinary applications, consisting of cross-scientific-departments, cross-research-areas, cross-research-fields, cross-research directions, and unchanged disciplines. Second, on the basis of the DIRD values of 37,330 unique individuals, the disciplinary diversity of research discipline and universities are investigated. Results show that more than 59 % of individuals change their DACs in the application for scientific funding. Highly significant differences in DIRDs were noted among different scientific departments, research areas, and universities. In addition, individuals in all scientific departments prefer not to engage in cross-research-field interdisciplinary applications. Furthermore, top-class universities in China exhibit stronger ability to engage in interdisciplinary applications and carry out interdisciplinary research than other universities.

The rest of this paper is organized as follows. Section "Dataset and methods" presents our methods including dataset collection and the proposed algorithm. In section "Results", we empirically analyze and visualize the results. Finally, section "Conclusions" summarizes our work and addresses possible extensions in the future.

Dataset and methods

In order to understand the DIRD in NSFC and analyze individual interdisciplinarity from the levels of scientific department, research area, research field, and research direction, we will address research questions in detail. In the following, the dataset and the methods including the algorithm to calculate DIRD and data analysis will be introduced as well.

Dataset

This paper retrievals the raw dataset of all the sponsored projects from 2000 to 2013, taken from the ISIS system (Information System of National Natural Science Foundation of China). The total 224,087 records of sponsored projects are stored into the MySql database for the convenience of analysis. Each record includes the title, principal investigator, approval year, institution, amount of sponsored money, Approval number, and discipline codes, etc. In this dataset, the total 37,330 unique individuals in terms of their name and affiliations are indentified for the analysis.

The first science funding system originated in Germany, in the middle ages of Europe. The US science funding system was established late. Since then, Australia, Canada, Britain and other countries also established a science fund system. In 1986, NSFC was established. Over the years various science funding systems in China have made great progress. Till now, almost all the Chinese government sections at the national, province and city level manage a variety of funding programs for scientists of universities and research institutes. However, there still lacks a unified coordination mechanism to plan, distribute and evaluate such a large number of funding programs (Cao et al. 2013). In the NSFC that is the main financial support for natural scientific research, DACs is divided into three levels, and is composed of English characters and Arabic numerals. The English character is the code of scientific department. The three levels of Arabic numerals denote research areas, research fields and research directions, respectively. According to this defined three-level DACs system in NSFC, DACs are required to be selected by the applicants of NSFC for their NSFC applications.

In the NSFC, there are eight scientific departments: mathematical and physical science (A), Chemical sciences (B), Life sciences (C), Earth sciences (D), Engineering and materials science (E), Information science (F), Management science (G) and Medical sciences (H). For each project, applicants need to provide a DAC, which is used to select the suitable reviewers during the peer review and classify them in the evaluation. The DAC is a three-level code to indicate the detailed discipline an application belongs to. As shown in Table 1, the total 86 number of first-level DACs indicates the research area such as Mathematics, Physics, Mechanics, Astronautics, etc. The total 981 number of second-level DACs indicates the research field such as Algebra, Functional analysis, Geometry, etc. The total 1679 number of third-level DACs indicates the detailed research direction such as Analytic number theory, Algebraic number theory, Number theory application, etc.

NFSC adjusts parts of DACs every year. These adjustments can be divided into three types. The first type refers to unchanged corresponding relations between disciplines and DACs—the NFSC merely changes the names of several disciplines but the disciplines and the corresponding DACs stay the same. The second type of adjustments refers to changed corresponding relations. The last type is manifested in the increase or decrease of DACs. The complex justification for the changes in the amount of DACs can be attributed to the emergence of new disciplines, the generation of inter-disciplines, or the imperfection of the disciplinary code system. The above adjustments—except for the first type—greatly influence our research findings because DACs are used in this study to investigate the diversity of individual disciplines. Thus, we need to consider the problem whether DACs are identical across years in our sample data.

Table 1 The three-level disciplinary application codes (DAC) of NSFC

Dept code	Scientific dept	First DAC	Second DAC	Third DAC	Total
A	Mathematical and physical science	5	45	254	304
B	Chemical sciences	7	76	283	366
C	Life sciences	20	153	389	562
D	Earth sciences	6	75	52	133
E	Engineering and materials science	9	113	295	417
F	Information science	5	45	354	404
G	Management science	3	48	52	103
H	Medical sciences	31	426	0	457
	Total	86	981	1679	2746

We collected the standards of 2008–2013 DACs from the NSFC official website and conducted a detailed comparison among them in the database. We found that the most adjustments in 2009 belong to the first type, but DACs underwent a considerable change in 2010. Only seven scientific departments (A–G) were covered in 2009, whereas the number increased to eight in 2010 (A–H). In addition, all three types exist in 2010. DAC changes after 2010 all belonged to the first type. We compared DACs between our sample data and code standards in each year, and we found that all the code levels and code names in the dataset are perfectly aligned with the code standard in 2013. Thus, we can confirm that the dataset in this paper exhibits good consistency. However, ambiguity exists among DACs in the dataset because it cannot be completely solved and the discipline classification scheme has not been perfected with the development of interdisciplinary trend in science and technology (Huutoniemi 2012).

In order to check the DIRD across the top-class universities, a dataset to indicate 985 and 211 universities has also been used to distinguish the sponsored projects. Project 211 is the Chinese government's new endeavor aimed at strengthening about 100 institutions of higher education and key disciplinary areas as a national priority for the 21st century (Choi 2010). Project 985 is a constructive project for founding world-class universities in the twenty first century conducted by the government of the People's Republic of China (Zhang et al. 2013). The universities involved into Project 211 and Project 985 belong to top-class universities, which will obtain more sponsored money than other universities from the central government. Now the total 39 universities have been selected into Project 985 and the total 112 universities have been sponsored by Project 211. A 985 university is also the 211 university, vice versa not. 985 universities usually rank higher than 211 universities in terms of scientific funding, and are regarded as global-class universities in China (Zhang et al. 2013).

In the dataset, the total 37,330 unique individuals are sponsored by NSFC. In Fig. 1, the number of sponsored individuals of 985 and Non-985 Universities are plotted. It is shown the sponsored individuals of 86 985-universities in Life sciences (C), Earth sciences (D) and Medical sciences (H) are much less than other non-985 universities. In

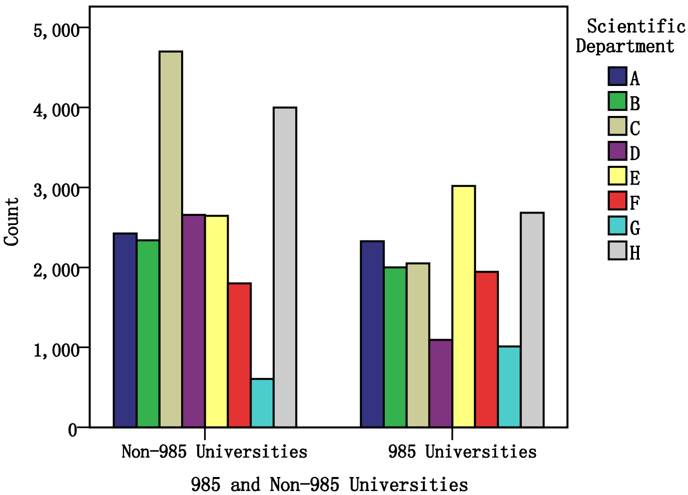

Fig. 1 The number of sponsored individuals of 985 and Non-985 universities

Engineering and materials science (E) and Management Science (G), the sponsored individuals of 86 985-universities are much more than other non-985 universities. The total 16146 individuals from 985-Universities are sponsored by NSFC, and the total 21,913 individuals from 211-Universities are sponsored by NSFC. In Fig. 2, the number of sponsored individuals of 211 and Non-211 Universities are plotted as well. In contrast, the same as the comparison between 985 and Non-985 universities, in Medical science (H), Life sciences (C), Earth sciences (D), individuals of 112 211-universities are much less than other non-211 universities. In other scientific departments, 211-universities dominate in term of the sponsored individuals.

Research questions

In the NSFC applications, each application is required to select a main DAC and a second DAC. Usually, the review is processed using the main DAC. Only in the situation wherein it is hard to find reviewers according to the main DAC, the second DAC will be used for the selection of expert reviewers. Finally, the NSFC classifies the sponsored applications into their corresponding disciplines according to their main DACs. Therefore, in our dataset the DAC of each application is its main DAC. It is very important for applicants to select the suitable DAC for their applications of scientific funding, because the DACs represent the specialities in their own scientific disciplines, and the selection of DACs also relates to the selection of expert reviewers who play the most important role in the decisions of sponsorship. Furthermore, DACs in some senses can implicitly discover the intrinsic social network behind the applications partly because of the single-blind review policy in the NSFC. If an individual submit the application to the different scientific department from his/her previous applications, it will become more difficult to survive in the review process. It is because the write style of proposal might be different, the standard of review might be different as well, and moreover the expert reviewers will be also different from who he/she has already been familiar and has experiences with.

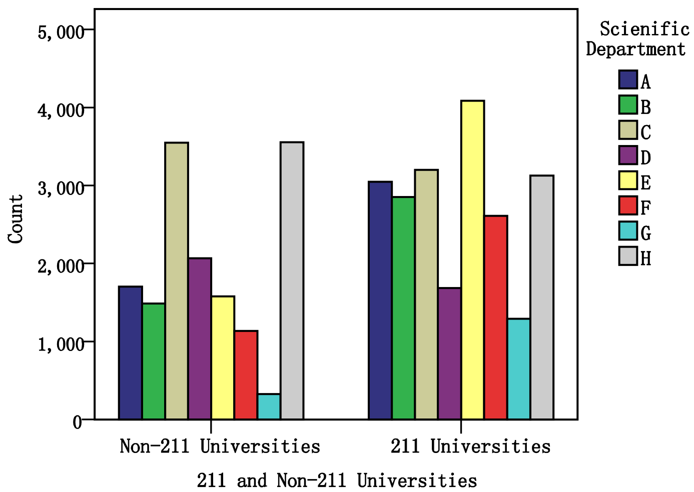

Fig. 2 The number of sponsored individuals of 211 and non-211 universities

However, according to our statistical analysis, there are still more than 59 % individuals to change the DACs in their applications of NSFC over the years. Therefore, interdisciplinary applications are ubiquitous. Individuals usually apply across research directions, or across research fields, or across research areas, or across scientific departments. In the Tables 2, 3, an example of cross-research-directions and cross-scientific-departments is given, respectively. In the first example, the usage of F030401 different from the F030402 and F030403 is cross-research-directions, and is cross-research-areas compared to F020503 and F010401. In the second example, the usage of C110301 different from H0109 and H0223 is cross-scientific-departments. The successfulness of sponsorship of the second example is harder than the first example because its application of cross-scientific-departments.

Therefore, the analyses of DAC of NSFC in this paper will be driven by the following two research questions:

Q1: Is there difference of DIRD between different eight scientific departments and among the different research areas?

Q2: Is there difference of DIRD between top-class universities of 211, 985 universities and other non-211 and non-985 universities?

Methods

In order to calculate the DIRD for measuring individual interdisciplinarity, the formulation of DIRD calculation is proposed in the following. Let N_p denote the set of grants the individual p has been sponsored, and let D_i denote the interdisciplinary diversity of the grant i with his/her other grants in N_p. DIRD of the individual p is the sum of the interdisciplinary diversity of all his/her grants. We have the following formula

Table 2 An example of cross-research-directions and cross-research-areas

Name	Sponsored money	Year	DAC	DAC name	Affiliation
Pengfei Li	900,000	2000	F010401	Heterogeneous network	SJTU
Pengfei Li	150,000	2001	F030403	Image analysis and understanding	SJTU
Pengfei Li	200,000	2003	F020503	Electronics and information system	SJTU
Pengfei Li	800,000	2005	F030402	Multimedia and virtual reality	SJTU
Pengfei Li	280,000	2008	F030401	Pattern recognition	SJTU

Table 3 An example of cross-scientific-departments

Name	Sponsored money	Year	DAC	DAC name	Affiliation
Baojun Wu	180,000	2001	H0109	Pulmonary circulation and pulmonary vascular diseases	PKU
Baojun Wu	50,000	2009	H0223	Other scientific problems of circulation system disease	PKU
Baojun Wu	2,900,000	2012	C110301	The regulation of biological and adaptation	PKU
Baojun Wu	700,000	2014	H0109	Pulmonary circulation and pulmonary vascular diseases	PKU

$$\mathrm{DIRD}_p = \sum_{i=1}^{n} D_i, \quad i \in N_p \tag{1}$$

where n is the total number of grants the individual p has been sponsored. Then, the calculation of each D_i is implemented by comparing the DAC of the grant i with the DACs of all the other grants of him. Let W_{ij} denote the interdisciplinary score between the grant i and the grant j, we have

$$D_i = \frac{\sum_{j=1}^{n-1} W_{ij}}{n-1}, \quad j \neq i \text{ and } i,j \in N_p \tag{2}$$

Therefore, by the combination of formula (1) and (2), we have the formula of the DIRD of the individual p

$$\mathrm{DIRD}_p = \sum_{i=1}^{n} \sum_{j=1}^{n-1} \frac{\sum_{j=1}^{n-1} W_{ij}}{n-1}, \quad j \neq i \text{ and } i,j \in N_p \tag{3}$$

Furthermore, in order to calculate W_{ij}, we need to change the DAC of the grant i to a DAC set that includes four codes, i.e., the code of scientific departments, the code of research areas, the code of research fields and the code of research directions, respectively. The DAC of the grant j needs this change as well. Let C_i and C_j denote the DAC set of the grant i and j, respectively. We have

$$W_{ij} = \begin{cases} \frac{1}{\left|C_i \cap C_j\right| + 1}, & C_i \neq C_j \\ 0, & C_i = C_j \end{cases} \tag{4}$$

where |.| indicates the size of a set.

If we divide DIRD_p by n the total number of grants, we can have the average DIRD as follows. The AVG_DIRD has a value from 0 to 1.

$$\mathrm{AVG\_DIRD}_p = \frac{\mathrm{DIRD}_p}{n} \tag{5}$$

Using formula (3) and (4), the DIRD can be calculated accordingly. Each individual has only one corresponding DIRD of himself. In order to simply understand the above formulations, the calculation based on the individual as shown in Table 3 will be an example in the following. First, let us calculate the interdisciplinary diversity of his first grant, denoted as D_1. Here, the DAC of the first grant is needed to pairwise compare with the second, third and fourth grant of him. To do pairwise comparison to calculate W_{12}, W_{13}, W_{14}, the DAC is needed to changed to a set of four codes. The DAC of the first, second, third, fourth grant is changed as shown in Table 4, respectively.

Then, based on formula (4), W_{12} is cross-research-areas and the value is 1/2. W_{13} is cross-scientific-departments and the value is 1. W_{13} is disciplinary unchanged and the value is 0. Then D_1 can be calculated as (1/2 + 1+0)/(4−1) = 1/2. To calculate D_2, W_{21} is equal to 1/2, W_{23} is equal to 1, and W_{24} is equal to 1/2 as well. Then, D_2 can be calculated as (1/2 + 1+1/2)/(4−1) = 2/3. Similarly, W_{31}, W_{32}, W_{34} is equal to 1, 1, 1, respectively. Therefore, D_3 can be calculated as (1 + 1+1)/(4−1) = 1. Finally, D_4 is the same as D_1 in this example. Finally, individual research disciplines (DIRD) is the sum of D_1, D_2, D_3, D_4 and is equal to (1/2 + 2/3 + 1+1/2) = 8/3. AVG_DIRD is calculated through dividing the DIRD by 4 and is 2/3.

Table 4 An example of transformation from DAC to DAC set

No.	DAC	DAC set
1	H0109	{H, H01, H0109, H010900}
2	H0223	{H, H02, H0203, H020300}
3	C110301	{C, C11, C1103, C110301}
4	H0109	{H, H01, H0109, H010900}

Table 5 The values of the interdisciplinary score W_{ij}

Level	Interdisciplinary type	W_{ij}
CL1	Cross-scientific-departments	1
CL2	Cross-research-areas	1/2
CL3	Cross-research-fields	1/3
CL4	Cross-research-directions	1/4
CL5	Disciplinary unchanged	0

In summary, in the pairwise comparison, the interdisciplinary score W_{ij} can have the following five interdisciplinary types, as shown in Table 5.

In contrast, DIRD is more distinguishable than AVG_DIRD in the analysis. If two individuals have the equal value of AVG_DIRD and different total number of grants, we would like to see that the individual with the larger total number of grants has more DIRD. It can be judged by DIRD that takes fully into account the total number of grants. However, AVG_DIRD has a value from 0 to 1, which makes it more suitable to classify the individuals into the corresponding five interdisciplinary classes as shown in Table 5. Therefore, we will investigate both in the following analyses.

The challenging problem of name ambiguities in the dataset is solved using the name and his/her affiliation information together to disambiguate the unique individuals sponsored by NSFC (Wu and Ding 2013). Nevertheless, it is still possible to make some errors in the disambiguation. However, these random errors can be omitted in some sense in our analysis because we investigate DIRDs for the whole 37,330 sponsored individual in different scientific department, research areas, universities at the aggregate level and not for a single individual.

Furthermore, this study dedicates to investigate the interdisciplinary research. However, the samples with the sponsored money <20,000 RMB Yuan are sponsored conference and cannot exactly represent individual's disciplines. Therefore, these samples are excluded in the further analysis. Then, because the meaningful calculation of DIRD and AVG_DIRD needs at least two sponsored grants for a unique individual, the samples where individuals have less than two sponsored grants are excluded. We classify an individual into the scientific department that the majority of his/her DACs belong to. If the numbers of DACs that belong to at least two scientific departments respectively are equal to each other, the individual will be randomly classified into one of these scientific departments that have the same number of belonged DACs. The same rule is also applied in the classification of individuals into different research areas.

Results

Based on the above methods and dataset, in the following, we will investigate DIRD across scientific departments, research areas and universities.

Table 6 Multivariate analysis of variance (MANOVA) and tests of between-subjects effects (dependent variable: DIRD)

Source	Type III sum of squares	*df*	Mean square	*F*	Sig
Corrected model	7356.461[a]	604	12.180	18.592	0.000
Intercept	1427.152	1	1427.152	2178.570	0.000
985-Universities	23.441	1	23.441	35.784	0.000
211-Universities	0.646	1	0.646	0.987	0.321
Scientific dept	43.222	7	6.175	9.426	0.000
Research area	591.634	85	6.960	10.625	0.000
Scientific dept * Research area	2136.837	263	8.125	12.403	0.000
Scientific dept * 211-Universities	12.243	7	1.749	2.670	0.009
Scientific dept * 985-Universities	10.483	7	1.498	2.286	0.025
Error	24,058.059	36,725	0.655		
Total	53,480.865	37,330			
Corrected total	31,414.519	37,329			

[a] $R^2 = 0.234$ (Adjusted $R^2 = 0.222$)

Firstly, in order to answer the question Q1 and Q2, we first apply multivariate analysis of variance (MANOVA) to test between-subjects effects in terms of scientific departments and research areas, and universities. The results are shown in Table 6. It is shown all the Sig. values except for the factor of 211-Universities are zero. That indicates there are very highly significant differences of DIRDs among different scientific departments, research areas and universities. We also test the interaction effects combining the factor of scientific departments with other factors. It is shown all the interaction effects on DIRDs are significant. In the following, we will further investigate the question Q1, Q2.

Disciplinary diversity of research areas

To further investigate the question Q1, the DIRDs of eight scientific departments (from A to E) and 86 research areas are plotted in Figs. 3 and 6, respectively. As shown in Fig. 3, the DIRDs of the department of Chemical sciences (B) and Life sciences (C) have relatively highest values with a small confidence interval, and the department of Earth sciences (D) and Management science (G) have relatively lowest values with a small confidence interval. The lowness of DIRDs in the scientific department of Management science is partly because a majority of applicants who are from school of management, school of public administration, school of information management etc. and so on usually use their own methods with the type of social science and it is hard for them to make interdisciplinary research with individuals from other scientific departments. In addition, it is shown the two fast-growing disciplines, i.e., Information science (F) and Medical science (H), also have relatively high values with a small confidence interval, which represent their high requirements of interdisciplinary research to solve more complex problems of their own. However, the discipline of Engineering and materials science (E) does not need very high interdisciplinary research at all. It also happens in the discipline of Mathematical and physical science (A), which includes the most basic research with the longest scientific history.

We also plot the number of zero and non-zero DIRDs in each scientific department, as shown in Fig. 4. Life sciences (C) and Medical science (H) have the largest number of unique sponsored individuals, and about one third individuals would like to keep

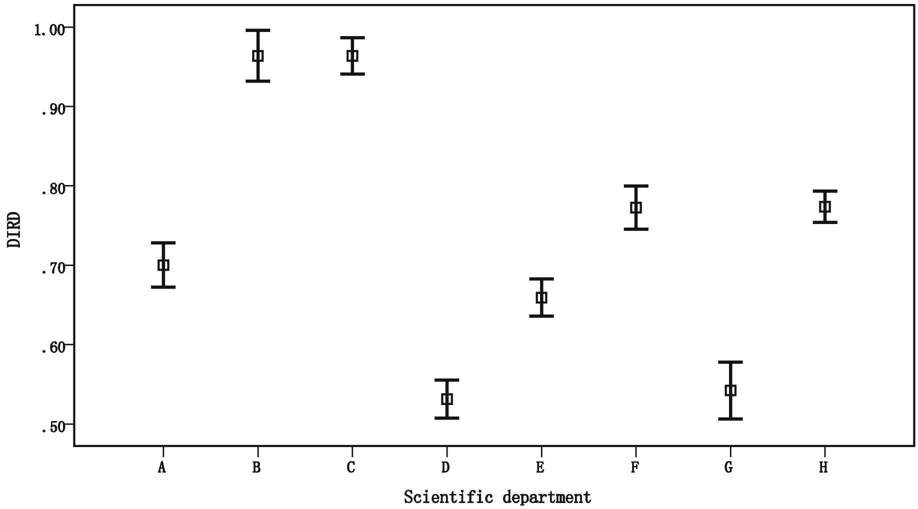

Fig. 3 Diversity of individual research disciplines (DIRD) of scientific departments

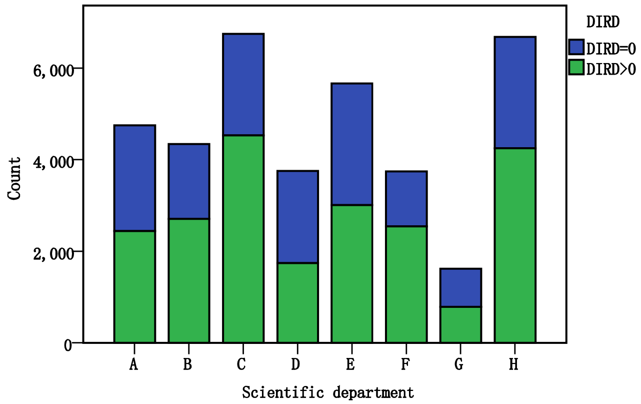

Fig. 4 The number of zero and non-zero DIRDs in each scientific department

themselves in their own disciplines and never changed over years. Individuals in Management science (G) and Earth sciences (D) are the most non-interdisciplinary and above half individuals focus on their own disciplines over years. It can explain the relatively lowest values in these two scientific departments, which we have found above.

In order to further understand the distributions of non-zero DIRDs in each scientific department, the numbers of five interdisciplinary classes of average DIRDs (AVG_DIRDs) are plotted in Fig. 5. Different interdisciplinary behaviors are shown in different scientific departments. The highest bar in C to H categories, except for CL5 bar of zero DIRD, is CL2 bar, which indicates individuals in the C, D, E, F, G, H scientific departments prefer cross-research-areas interdisciplinary applications. In contrast, in Mathematical and physical science (A), individuals prefer cross-research-directions (CL4) applications. In Chemical sciences (B), individuals prefer to cross-scientific-departments (CL1), which

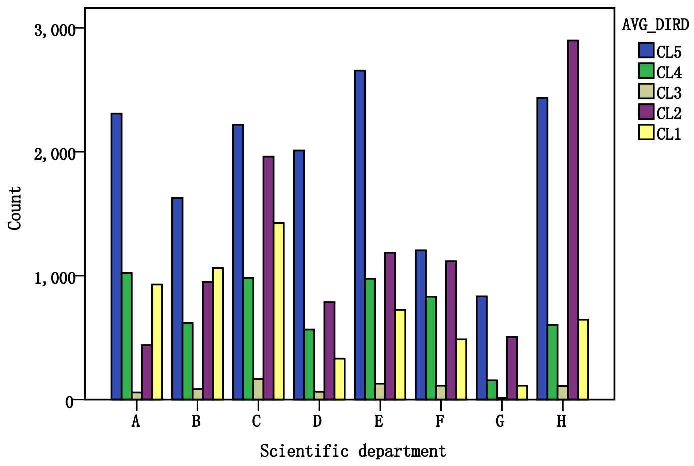

Fig. 5 The number of five classes of AVG_DIRDs in each scientific department (CL1, CL2, CL3, CL4, CL5 are corresponded to five levels of interdisciplinary value as shown in Table 5, i.e., CL5 (0); CL4 (0, 1/4]; CL3 (1/4, 1/3]; CL2 (1/3, 1/2]; CL1 (1/2, 1])

partly explain its highest value of DIRD in all the scientific departments. Moreover, the lowest bar in all the categories is CL3 bar, which indicates individuals in all the scientific departments do not like to make cross-research-fields interdisciplinary applications.

As shown in Fig. 5, it is interesting to find that cross-scientific-departments applications (CL1) are a little bit commonly used by the sponsored individuals. More than seven percent individuals always take cross-scientific-departments strategy, by which they change their DAC that starts from A to H across scientific departments in each application. In our dataset, the individuals who are always cross-scientific-departments have at most four sponsored grants, and only have the total three cases in all the individuals. In addition, 84 individuals have three sponsored grants and the other 2598 individuals have two sponsored grants.

As shown in Fig. 6, the research area of Immunology (C8) has the highest DIRD with a relatively large confidence interval, and Mathematics (A1) and Astronomy (A03) have the lowest DIRD with a small confidence interval. Geology (D02) and Traditional Chinese Medicine (H27) have relatively lowest DIRDs with a small confidence interval as well. It is indicated that these research areas with low DIRDs do not have strong requirement of integrating interdisciplinary knowledge because of their own intrinsic ecological system of knowledge (Berkes et al. 2000). In the Medical science (H) and Life sciences (C), the confidence interval is much large to represent high dispersion of DIRDs in these disciplines.

The numbers of zero and non-zero DIRDs in each research area are plotted in Fig. 7 as well. It is shown that Mathematics (A1) has the largest number of unique sponsored individuals and it is also the most non-interdisciplinary research area. Therefore, it can be explained that Mathematics (A1) has the lowest DIRD. Oncology (H16) also has a relatively large number of unique sponsored individuals. However, compared to Mathematics (A1), the majority of individuals prefer to make interdisciplinary applications. Moreover, although Immunology (C08), Rehabilitation Medicine (H17), Special Medicine (H21), Forensic Medicine (H23) and Geriatrics (H25) are narrow research areas where are only a small number of unique sponsored individuals, the DIRD in these research areas is high, which indicates their high requirement of interdisciplinary research to develop the research area.

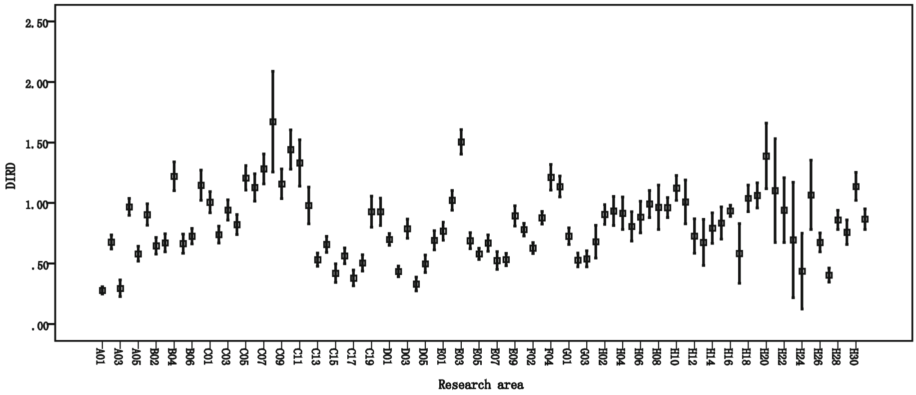

Fig. 6 Diversity of individual research disciplines (DIRD) of research areas (The corresponding name of each research area can be found in "Appendix")

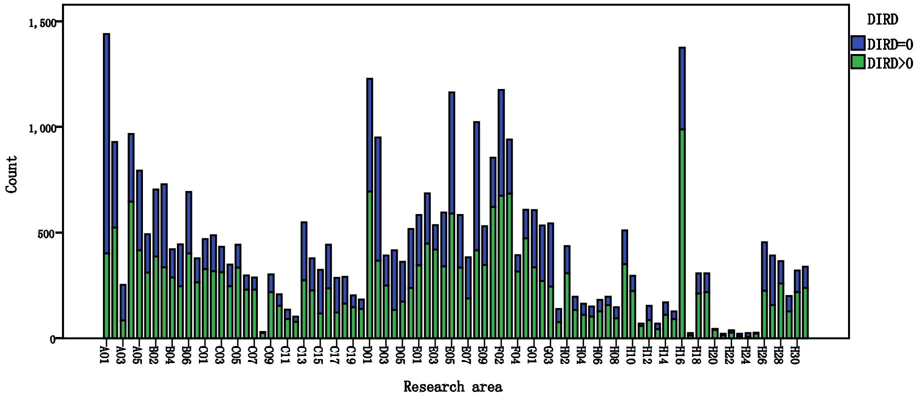

Fig. 7 The number of zero and non-zero DIRDs in each research area (The corresponding name of each research area can be found in "Appendix")

Disciplinary diversity of universities

To further investigate the question Q2 and understand the interaction effects of scientific department with 985-universities and 211-universities found in MANOVA, we plot their DIRDs in Figs. 8, 9, respectively. It is shown that 985-universities in all the scientific departments have larger DIRDs than non-985 universities. Especially, in Life sciences (C), the difference of DIRDs between 985 universities and non-985 universities is largest, and in Medical sciences (H), the difference of DIRDs is smallest. The analysis indicates that scientists in 86 985-universities have stronger ability to make interdisciplinary applications and carry out interdisciplinary research than non-985 universities, especially in Life Science.

In contrast, according to MANOVA, 211 universities do not have significant difference of DIRDs with non-211 universities. As shown in Fig. 9, the DIRDs of 211 universities are not absolutely larger than non-211 universities in all the scientific departments. Especially, in

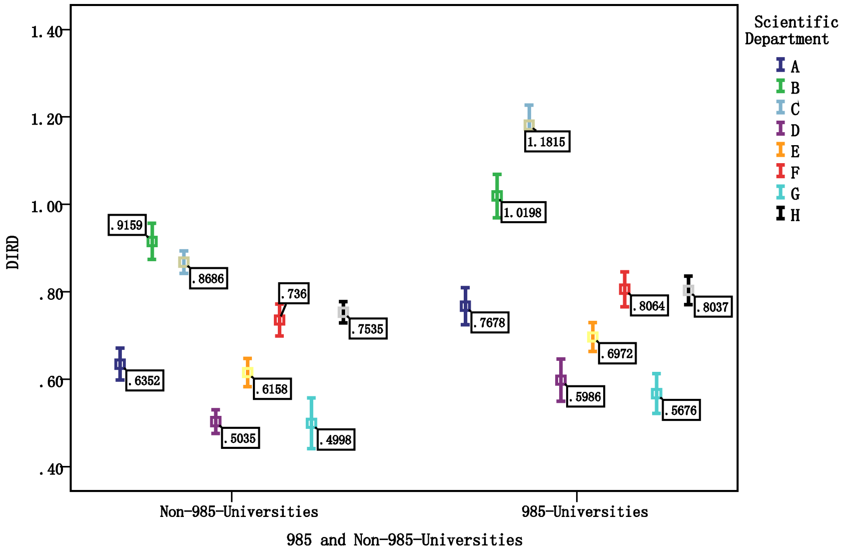

Fig. 8 The DIRDs of 985 and non-985 universities

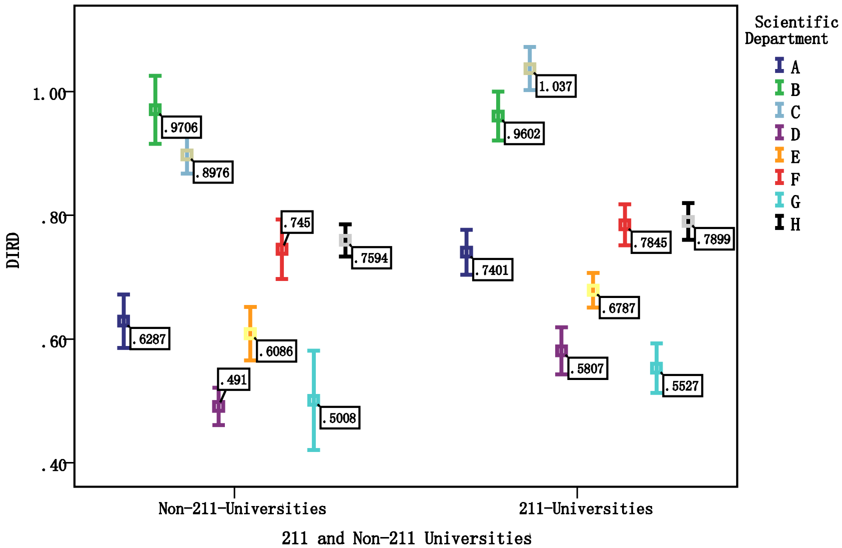

Fig. 9 The DIRDs of 211 and non-211 universities

Chemical sciences (B), the DIRDs of non-211 universities are a little bit larger than 211 universities. In Life sciences (C), the difference of DIRDs between 211 universities and non-211 universities is largest, and in Chemical sciences (B), the absolute difference of DIRDs is smallest. The analysis indicates that scientists in 112 211-universities, except for the scientists in Chemical sciences (B), prefer a little bit more interdisciplinary applications.

Conclusions

In the application of scientific funding, the selection of DACs always relate to the selection of expert reviewers whose opinions decide the approval of a proposal. However, it is found that more than 59 % individuals change their DACs during applications of NSFC over years. The interdisciplinary applications need a strong ability to extend knowledge across disciplines, to arrange social capital and human resources, and to make interdisciplinary research to make greater scientific achievements. This paper tries to understand interdisciplinary applications and measure individual interdisciplinarity through investigating the DIRD across different research disciplines and universities, based on the dataset of scientific funding.

In the paper, we introduce two research questions based on a qualitative analysis of interdisciplinary applications of scientific funding. Then, we formulate the algorithm to calculate the DIRD and give a calculation example. We then propose to classify interdisciplinary applications into five classes, namely cross-scientific-departments, cross-research-areas, cross-research-fields, cross-research-directions and disciplinary unchanged. Moreover, based on a large dataset downloaded from the ISIS system of NSFC, the DIRDs of all the 37,330 unique individuals are automatically calculated. The quantitative methods of MANOVA and statistical analyses are used to understand different interdisciplinary behaviors across different scientific departments, research areas and universities. Then, the findings are somehow explained from the perspective of social-ecological system (Berkes et al. 2000).

The findings answer two research questions Q1 and Q2 to indicate that there are highly significant differences of DIRDs among different scientific departments, research areas and universities. Individuals in the department of Chemical sciences and Life sciences have relatively highest DIRDs. The majority of individuals in almost all the scientific departments prefer cross-research-areas interdisciplinary applications. The research area of Immunology has the highest DIRD. It is also shown that 985-universities in all the scientific departments have larger DIRDs than non-985 universities. The top-class universities exhibit stronger ability to carry out interdisciplinary research than other universities in China.

The findings in this paper provide new insights to funding agencies and departments of research management in universities in terms of managing scientific funding. In addition, the methods for analyzing the NSFC-sponsored individuals can be hopefully extended to the investigation of data from other funding agencies. Scientists need interdisciplinary applications to be successful in the competition of scientific funding and introduce great research innovations; however, their different intentions and preferences for interdisciplinarity should be studied further. In the future, the influence of DIRD on individuals' sponsored funding will also be a good research question for further investigation. In addition, relating interdisciplinary applications to the output of publications is also possible (Yang et al. 2013). Funding schemes and disciplinary portfolios differ among countries (Leydesdorff and Wagner 2009); therefore, cross-national studies based on scientific agencies of other countries will further clarify the DIRD in interdisciplinary studies in scientific academia.

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Appendix

See Table 7.

Table 7 86 research areas and their corresponding codes

A01	Mathematics	C09	Neuroscience, cognitive science and psychology	E03	Organic polymer materials	H06	Motor system
A02	Mechanics	C10	Biomechanics and tissue engineering	E04	Metallurgy and mining	H07	Endocrine system/metabolic and nutritional support
A03	Astronomy	C11	Physiology and integrative biology	E05	Mechanical engineering	H08	Hematologic system
A04	PhysicsI	C12	Reproductive biology and developmental biology	E06	Engineering thermophysics and energy utilization	H09	Nervous system and mental illness
A05	PhysicsII	C13	Agronomy foundation and crop science	E07	Electrical science and engineering	H10	Medical immunology
B01	Inorganic chemistry	C14	Plant protection	E08	Built environment and structural engineering	H11	Skin and its appendages
B02	Organic chemistry	C15	Horticulture and plant nutrition	E09	Water conservancy science and ocean engineering	H12	Ophthalmology
B03	Physical chemistry	C16	Forestry	F01	Electronics and information systems	H13	Otolaryngology head and neck sciences
B04	Polymer science	C17	Animal husbandry and grassland science	F02	Computer science	H14	Oral craniofacial sciences
B05	Analytical chemistry	C18	Veterinary science	F03	Automation	H15	Severe medical/trauma/burns/plastic surgery
B06	Chemical engineering and industrial chemistry	C19	Fisheries science	F04	Semiconductor science and information device	H16	Oncology
B07	Environmental chemistry	C20	Food science	F05	Optics and optoelectronics	H17	Rehabilitation medicine
C01	Microbiology	D01	Geography	G01	Management science and engineering	H18	Medical Imaging and biomedical engineering
C02	Botany	D02	Geology	G02	Business administration	H19	Medical pathogenic microorganisms and infection
C03	Ecology	D03	Geochemistry	G03	Macroeconomic management and policy	H20	Laboratory medicine
C04	Zoology	D04	Geophysics and space physics	H01	Respiratory system	H21	Special medicine

Table 7 continued

C05	Biophysics, biochemistry and molecular biology	D05	Atmospheric science	H02	Circulatory system	H22	Radiation medicine
C06	Genetics and bioinformatics	D06	Marine science	H03	Digestive system	H23	Forensic medicine
C07	Cytobiology	E01	Metallic materials	H04	Reproductive system/perinatology/newborn	H24	Endemiology and occupational medicine
C08	Immunology	E02	Inorganic non-metallic materials	H05	Urinary system	H25	Geriatrics
H26	Preventive medicine	H28	Science of Chinese Pharmacology	H30	Materia medica		
H27	Traditional Chinese medicine	H29	Chinese and Western integrative medicine	H31	Pharmacology		

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