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Interdisciplinary research has consistently lower funding success

Lindell Bromham[1], Russell Dinnage[1] & Xia Hua[1]

Interdisciplinary research is widely considered a hothouse for innovation, and the only plausible approach to complex problems such as climate change[1,2]. One barrier to interdisciplinary research is the widespread perception that interdisciplinary projects are less likely to be funded than those with a narrower focus[3,4]. However, this commonly held belief has been difficult to evaluate objectively, partly because of lack of a comparable, quantitative measure of degree of interdisciplinarity that can be applied to funding application data[1]. Here we compare the degree to which research proposals span disparate fields by using a biodiversity metric that captures the relative representation of different fields (balance) and their degree of difference (disparity). The Australian Research Council's Discovery Programme provides an ideal test case, because a single annual nationwide competitive grants scheme covers fundamental research in all disciplines, including arts, humanities and sciences. Using data on all 18,476 proposals submitted to the scheme over 5 consecutive years, including successful and unsuccessful applications, we show that the greater the degree of interdisciplinarity, the lower the probability of being funded. The negative impact of interdisciplinarity is significant even when number of collaborators, primary research field and type of institution are taken into account. This is the first broad-scale quantitative assessment of success rates of interdisciplinary research proposals. The interdisciplinary distance metric allows efficient evaluation of trends in research funding, and could be used to identify proposals that require assessment strategies appropriate to interdisciplinary research[5].

The 5th Annual Meeting of the Global Research Council in New Delhi in May 2016 focused on interdisciplinarity as one of its main topics of concern, reflecting increasing interest in research that breaks free of traditional discipline boundaries, and the growing concern that interdisciplinary research is not adequately supported under current funding structures. Funding agencies play a key role in shaping interdisciplinary research[3], with both positive influence, such as dedicated programmes for interdisciplinary projects, and negative impacts, as perceived biases can discourage submission of interdisciplinary proposals to open funding calls. This leads to the 'paradox of interdisciplinarity': interdisciplinary research is often encouraged at policy level but poorly rewarded by funding instruments[4]. There is a clear need to test the widely held belief that interdisciplinary proposals fare poorly in competitive funding rounds: confirmation could prompt examination of evaluation strategies for interdisciplinary projects, while rejection of this claim might encourage more interdisciplinary proposals.

Critical to evaluation of current practice is the ability to compare levels of interdisciplinarity of research projects to track trends, evaluate outputs and compare success rates[6,7]. Measures of interdisciplinarity have typically relied on textual references, detecting use of words such as 'interdisciplinarity'[8], or bibliometric analysis, tracking patterns of author affiliation[6] or citations within publications[9–14]. But these approaches are limited in use for evaluating funding applications. Interpretation of the terms 'multidisciplinary', 'cross-disciplinary', 'interdisciplinary' and 'transdisciplinary' vary widely[11], and researchers will differ in their inclination to label their research as 'interdisciplinary'[2], particularly if they perceive that identification as interdisciplinary influences funding outcomes[15]. Because bibliometric analyses are primarily applied to publications[11], they may be of limited applicability in assessing funding proposals, where the outputs have not yet been published, and citations may not be in an analysable format. The lack of clear definitions and objective analyses is an impediment to evaluating the relative success of interdisciplinary proposals[1]. Conflicting findings have been reported using a range of approaches[4], and most studies of funding success of interdisciplinary research have selected only a sample of proposals for evaluation[15,16]. What is needed is a measure of the degree to which a proposal spans many different disciplines, independent of use of words such as 'interdisciplinarity' and without relying on cited publication data.

Although no single metric will capture all salient aspects of interdisciplinarity, developing a simple measure of the disciplinary spread of research proposals does provide a tractable way to compare the relative success of proposals having a narrow disciplinary focus with those with a broader research programme[17]. To this end, we use information supplied on funding applications to score each proposal on the disparity and balance of the component disciplines[12]. We base our analysis on methods established in evolutionary biology to account for relatedness between biological lineages, but instead of using an evolutionary tree (phylogeny), we use a hierarchical classification of research fields. This metric can be applied to any funding scheme where multiple discipline categories can be selected by applicants or identified from proposal documents[7].

We calculated this interdisciplinary distance (IDD) metric for all proposals submitted to the Australian Research Council Discovery Programme between 2010 and 2014 (Supplementary Table 1). This national competitive grants scheme funds fundamental research in all academic fields, receiving approximately 3,500 proposals in each annual funding call, with success rates being around 15–20% of proposals (Extended Data Table 1). Our analysis is unique in including all submitted proposals, both successful and unsuccessful, whereas most analyses are restricted to the published lists of funded proposals[7,18] or to samples of case studies[3].

Every application must nominate at least one of a defined set of 1,238 Field of Research codes, assigning a percentage weighting to each code selected. Field of Research codes are grouped into related disciplines: for example, the Division '06 Biological Sciences' contains nine groups, including '0603 Evolutionary Biology', which contains 12 Fields including '060309 Phylogeny and Comparative Analysis' (Supplementary Fig. 1). Because we wish to capture the disciplinary breadth of proposals, we need to measure not only the number and relative representation of disciplines selected, but also how disparate those research fields are. For example, we want to score a project that involves collaboration between biologists and artists as more interdisciplinary than one between biochemists and geneticists. Just as many biodiversity metrics use a phylogeny to measure disparity of species, research

[1]Research School of Biology, Australian National University, 116 Daley Road, Canberra 0200, Australia.

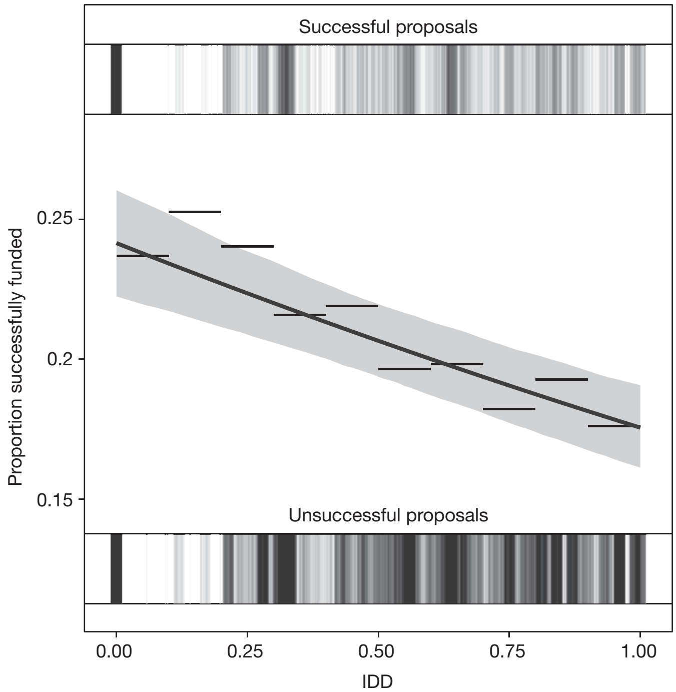

Figure 1 | Relationship between funding success and IDD score. The central black line is the regression line (success = $\text{logit}^{-1}[-1.35506 + -0.40268 \times \text{IDD}]$); grey area represents the confidence intervals (see Supplementary Information for details). The horizontal lines around the regression line represent the mean success rate for each of 10 'bins' of IDD values of width 0.1. Each horizontal line's y value represents the mean success rate of proposals whose IDD values fall within a 'bin' defined by the ends of the horizontal line. The bars at the top and bottom of the figure indicate the number of proposals for each IDD score, with darker lines corresponding to more proposals. Fitted line based on a generalized linear mixed model as described in the Supplementary Information ($z = -6.789$; $P = 1.13 \times 10^{-11}$; $n = 18,476$).

fields can be arranged as a dendrogram, where fields of enquiry that are more similar are more closely connected to each other than more distant fields. Our approach is not restricted to funding programmes that use hierarchically structured research codes, but can be applied to any research field identifiers by using patterns of co-occurrence to define clusters of similar fields[7].

We use the phylogenetic species evenness[19] metric to measure IDD. This metric was designed to compare biodiversity between samples (for example, between conservation areas), incorporating both evenness of species representation in the biota and relatedness between species[20]. IDD reflects both the relative contribution of disciplines within a proposal (balance) and scores collaborations between distantly related fields more highly than those between more closely related disciplines (disparity)[21]. The metric is standardized so it falls between 0 (single disciplinary) and 1 (maximum disparity with even representation), allowing direct comparison between proposals (Extended Data Fig. 1). Patterns of co-occurrence of field identifiers (for example, research codes or key words) can be used to generate a hierarchy of discipline relationships (see Supplementary Information). Basing this hierarchy on observed patterns of collaboration would rank proposals with respect to the relative novelty of the disciplinary combinations proposed[22].

The Australian Research Council provided de-identified data on all applications to the Discovery Programme for five annual funding rounds. We used a generalized linear mixed model to ask whether the IDD score of grant proposals is associated with funding success. We included as variables in the analysis the year of application, number of Field of Research codes selected per proposal, number of named chief investigators and institution (grouped into higher education networks: Extended Data Table 2). The response variable was a binary vector with two states: recommended for funding (1) or not recommended for funding (0). We provide details of the analysis and results in the Supplementary Information.

We find that IDD is consistently negatively correlated with funding success (slope = −0.40, $P = 1.1 \times 10^{-11}$; Fig. 1), independent of year of application, number of research codes selected and primary research field. Nearly all research fields have reduced funding success with increasing interdisciplinarity (Fig. 2 and Extended Data Table 3). If the association between IDD and funding success was largely a matter of averaging success rates of the component disciplines—so that less successful fields benefit from collaboration with more successful fields but more successful fields have their success rates reduced through collaboration—then we would expect many points both above and below $y = 0$ in Fig. 2. However, most fields have negative values of y, suggesting that proposals with high IDD are expected to have lower success rates than those with low IDD in most research divisions.

We conducted additional analyses using metrics that reflected only variety (number of codes) or balance (evenness) of disciplines (details in Supplementary Information), which demonstrated that it is both disparity and balance between disciplines that influence chance of funding success, justifying the use of the IDD metric which captures both of these aspects of interdisciplinarity. We also searched for relevant keywords in proposal titles and summaries, such as 'interdisciplinary', 'multidisciplinary', 'transdisciplinary' and 'cross-disciplinary'. We found that proposals with these keywords also had higher IDD measures and lower success rates, demonstrating that the metric-based approach echoes text-based analysis, yet with greater power to detect differences in funding rates (see Supplementary Information).

IDD reflects the interdisciplinarity of the project, not the inclusion of practitioners from different disciplines, because a single researcher can devise a project that spans different disciplinary traditions[11]. To test the influence of collaboration, we added the number of named chief investigators to the analysis. We find that proposals with more chief investigators have slightly higher success rates (slope = 0.03, $P = 0.003$), across all research fields, independently of any link between number of collaborators and interdisciplinarity (Supplementary Table 2). Although the relationship between number of chief investigators and IDD is positive, the effect is small (Spearman's $\rho = 0.09$), suggesting that the number of participants is not strongly associated with the interdisciplinarity of the project proposal.

Because of the perceived negative association between funding success and interdisciplinarity, interdisciplinary projects are often regarded as high-risk proposals[4]. Do institutions with higher rates of funding success submit more interdisciplinary proposals (using higher success rates to support risky proposals) or fewer (because higher success rates arise from narrowly focused research)? We find that overall funding success rates varied between institutions, with significantly higher funding success rates in leading research-intensive universities (Extended Data Table 2)[18]. Differences in IDD between institutions were very small ($R^2 = 0.001$) and the negative relationship between IDD and success rate was significant when institution was taken into account (slope = −0.39, $P = 7.6 \times 10^{-11}$; Supplementary Table 2). This suggests that the negative relationship between interdisciplinarity and funding success is not due to institutions with high funding success submitting more narrowly focused proposals (Extended Data Fig. 2).

Why do interdisciplinary proposals have lower funding success rates? It is widely believed that grant evaluation processes are biased against interdisciplinary projects, because proposals may be assigned to a panel or reviewers who are ill-equipped to evaluate all parts of the project[23], while more narrowly focused proposals may be better matched to assessor expertise[4]. Proposals that fit within a well-defined discipline may be more easily explained and justified, whereas the novelty of combinations of different perspectives may be more difficult to explain[22] or result in less-focused proposals[24].

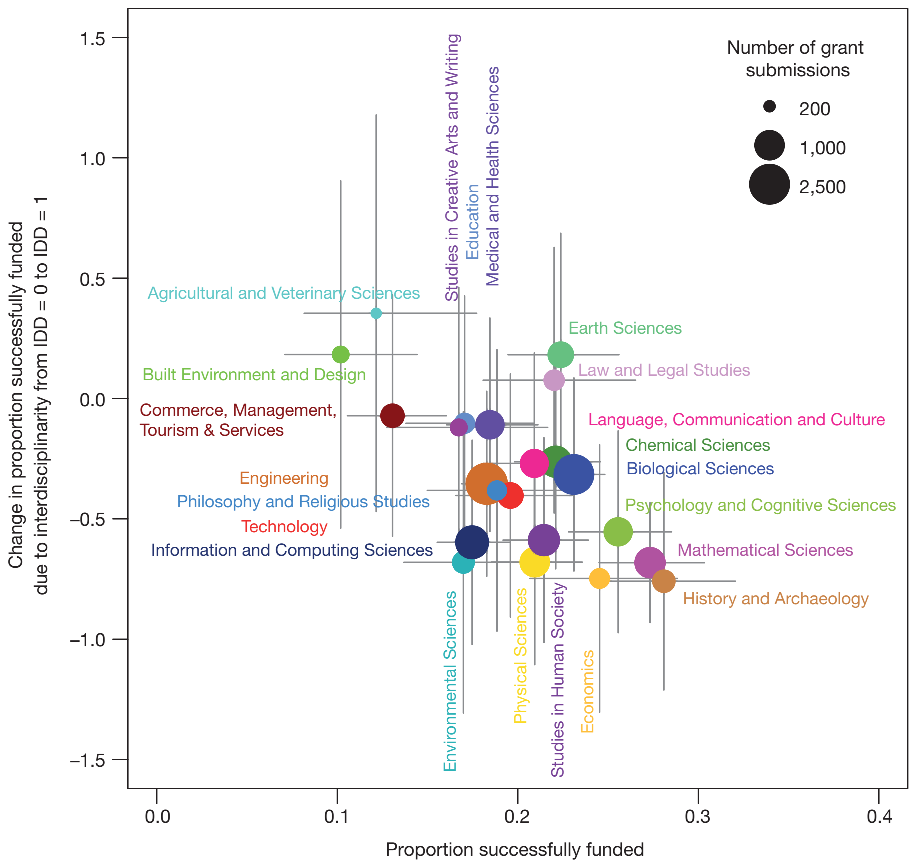

Figure 2 | Relationship between interdisciplinarity and funding success by research division. The x axis gives the success rate of a research division as the proportion of successfully funded proposals in that research division. The error bars along the x axis show the confidence interval of success rate approximated by Wilson interval. The number of proposals in each research division is given in Extended Data Table 1. The y axis gives the average predicted difference in logit success rates between proposals with maximum interdisciplinarity (IDD = 1) compared with proposals with a single primary Field of Research code (IDD = 0) for each division, so that $y = -0.5$ indicates that the logit success rates of proposals with IDD = 1 is 0.5 lower than the logit success rate of proposals with IDD = 0. The standard error of the predicted difference (the error bar along the y axis) is the square root of the sum of the squared standard error of the IDD coefficient and that of the interaction coefficient. The average difference of each research division and its error bar are predicted by the generalized linear mixed model in Extended Data Table 3.

While interdisciplinary research can have considerable benefits, it can also incur substantial costs, owing to the need to invest significant time in building collaborative relationships, developing a shared language and honing a common perspective from disparate viewpoints[25]. The outputs of interdisciplinary projects may be fewer and of different kinds to projects with a narrower disciplinary focus[26,27]. Research evaluation systems with a narrow range of measures of success—for example, number of primary research publications in peer-reviewed journals—may disadvantage interdisciplinary proposals where some key outputs are less easily measured, such as the establishment of collaborative networks or data-sharing agreements[23]. While some interdisciplinary studies produce significant advances, the average quality of interdisciplinary proposals may not be the same as more narrowly focused research. Studies of the long-term scholarly impact of interdisciplinary research have had mixed results: whereas some suggest greater benefits, others find no support for higher impact of interdisciplinary research[12–14].

Whatever the cause of the correlation, our result confirms the long-held belief that interdisciplinary proposals have lower funding success rates, providing the basis for further investigation into the development and evaluation of interdisciplinary research. Although IDD does not capture all key aspects of interdisciplinary research, it does provide a tractable and adaptable way of comparing interdisciplinarity between proposals and tracking trends in application rates and funding success. IDD can be applied to any funding programme where research fields are identified. Relatedness between disciplines can be defined a priori (for example, Field of Research codes), through clustering analysis of previous applications (see, for example, Extended Data Table 1), subjectively (based on experience) or by any other relevant means[7]. Such analyses will bring much needed clarity to determining whether interdisciplinary research programmes are being adequately supported under current funding models. In addition to enabling assessment of biases in success rates, the IDD metric could provide a way of identifying highly interdisciplinary proposals that might require special evaluation strategies, such as seeking reviewers who have experience in research spanning multiple fields.

Online Content Methods, along with any additional Extended Data display items and Source Data, are available in the online version of the paper; references unique to these sections appear only in the online paper.

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Supplementary Information is available in the online version of the paper.

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Author Information Reprints and permissions information is available at www.nature.com/reprints. The authors declare no competing financial interests. Readers are welcome to comment on the online version of the paper. Correspondence and requests for materials should be addressed to L.B. (lindell.bromham@anu.edu.au).

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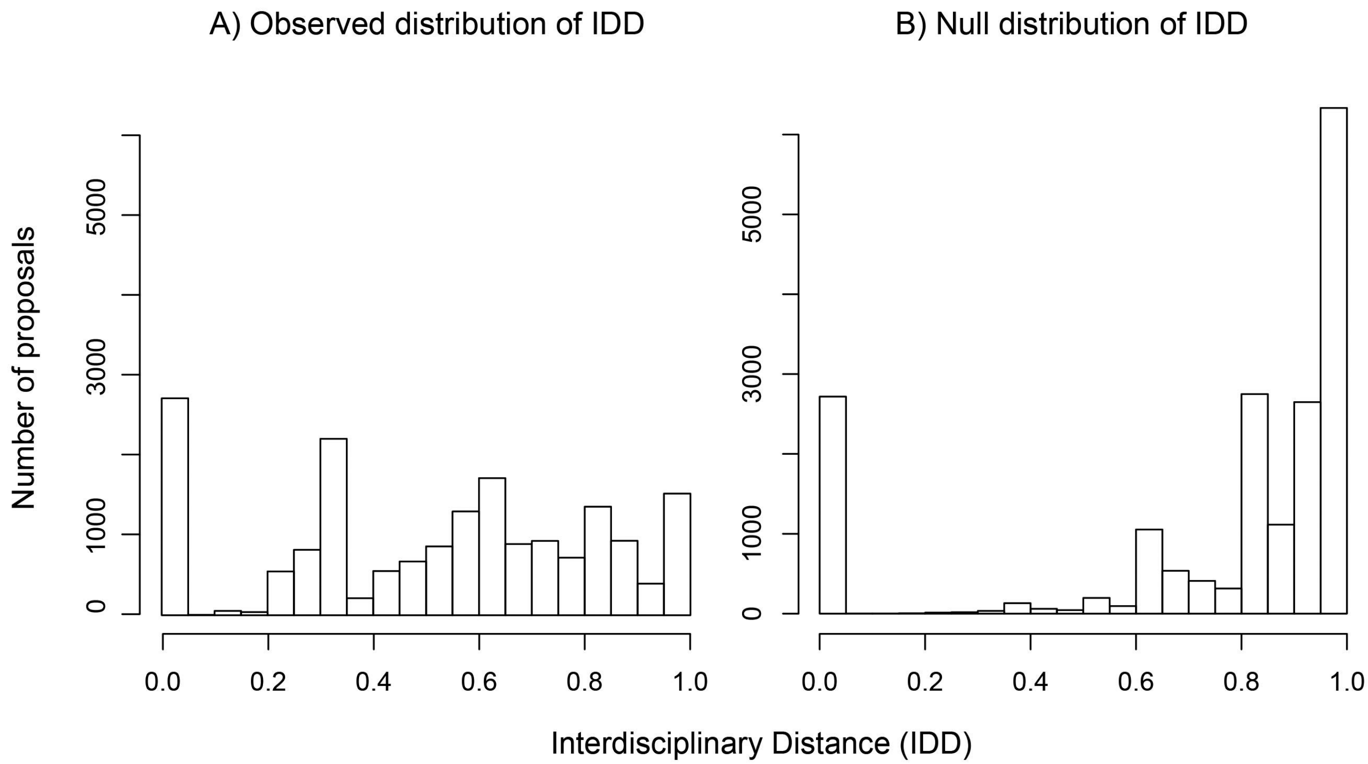
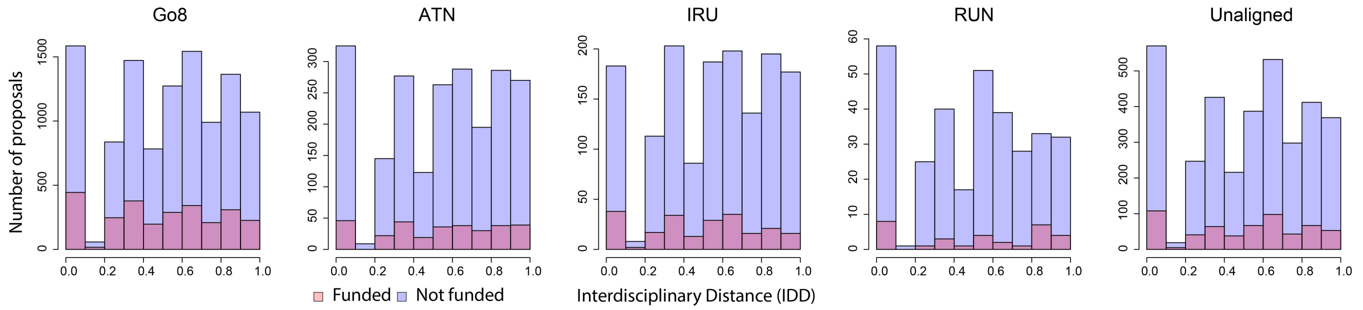


Extended Data Figure 1 | Comparison of observed distribution of IDD scores to a null distribution. a, Distribution of IDD scores for 18,476 proposals to the Australian Research Council Discovery Programme, pooled over 5 years (2010–2014). **b**, Null distribution of IDD scores generated by random sampling of Field of Research codes conditional on the observed frequencies of number of selected codes and percentage allocations.



Extended Data Figure 2 | Distribution of IDD scores by institutional networks. See Extended Data Table 2 for the membership of research networks. The research-intensive Group of Eight (Go8) universities submit more proposals to the Australian Research Council Discovery Programme and have higher funding success rates, but the overall patterns of interdisciplinarity scores and success rates are similar across institutions.

Extended Data Table 1 | Summary of proposals submitted to Australian Research Council Discovery Programme between 2010 and 2014

Domain	Divisions	Number of Proposals	% Success	Median IDD	Median codes
01 Information	01 Mathematical Sciences	893	27	0.54	3
	08 Information And Computing Sciences	1351	17	0.54	2
02 Matter	02 Physical Sciences	1003	21	0.51	3
	03 Chemical Sciences	1172	22	0.63	3
	09 Engineering	2823	18	0.56	3
	10 Technology	582	20	0.80	3
03 Environment	04 Earth Sciences	706	22	0.54	3
	05 Environmental Sciences	418	17	0.75	3
04 Life	06 Biological Sciences	2458	23	0.56	3
	07 Agricultural And Veterinary Sciences	181	12	0.77	3
	11 Medical And Health Sciences	905	18	0.65	3
05 Interaction	12 Built Environment And Design	265	10	0.51	2
	14 Economics	424	25	0.48	3
	15 Commerce, Management, Tourism & Services	582	13	0.33	2
06 Mind	13 Education	434	17	0.56	2
	17 Psychology And Cognitive Sciences	896	26	0.32	2
	19 Studies In Creative Arts And Writing	269	17	0.64	2
07 Society	16 Studies In Human Society	1161	21	0.56	3
	18 Law And Legal Studies	368	22	0.32	3
	20 Language, Communication And Culture	722	21	0.55	3
	21 History And Archaeology	534	28	0.33	2
	22 Philosophy And Religious Studies	329	19	0.50	3

The number of proposals with a primary identification to each Division in 5 years of pooled applications to the Australian Research Council Discovery Programme, with the percentage recommended for funding (% success), median interdisciplinary distance (IDD) and median number of six-digit FOR codes selected per application (Median codes). Divisions (first two digits of the FOR codes) have been clustered into Domains, as described in the Supplementary Information. Note that medical research is predominantly funded through a different scheme, as is research in collaboration with industry partners.

Extended Data Table 2 | Institutional networks

Network		Institutions	Proposals	Success	IDD
Group of Eight	Go8	University of Melbourne	10974	24%	0.56
		Australian National University			
		University of Sydney			
		University of Queensland			
		University of Western Australia			
		University of Adelaide			
		Monash University			
		University of New South Wales			
Innovative Research Universities	IRU	Charles Darwin University	1486	15%	0.57
		James Cook University			
		Murdoch University			
		Flinders University			
		LaTrobe University			
		Griffith University.			
Australian Technology Network	ATN	Queensland University of Technology	2181	14%	0.57
		University of Technology Sydney			
		RMIT University			
		University of South Australia			
		Curtin University.			
Regional Universities Network	RUN	Central Queensland University	324	10%	0.56
		Federation University Australia			
		Southern Cross University			
		University of New England			
		University of Southern Queensland			
		University of the Sunshine Coast			
Unaligned			3476	17%	0.56

Australian higher education institutions grouped by network, with the number proposals submitted to the Australian Research Council Discovery Programme over 5 years (2010–2014), the average percentage success rate (percentages that were recommended for funding) and the median IDD score of all proposals.

Extended Data Table 3 | Effect size of interdisciplinarity on funding success in each division

Division	Coeff	Int'n	Mean Cohen's D					Variance Cohen's D					Wtd avg
			Y1	Y2	Y3	Y4	Y5	Y1	Y2	Y3	Y4	Y5	
Mathematical Sciences	0	0	-0.24	-0.21	-0.26	-0.03	-0.29	0.16	0.16	0.18	0.17	0.18	-0.20
Physical Sciences	-0.37***	0.00	0.02	-0.32	-0.81	0.03	-0.16	0.15	0.20	0.19	0.18	0.18	-0.23
Chemical Sciences	-0.25*	0.42	-0.10	0.12	-0.27	-0.15	0.11	0.14	0.16	0.16	0.16	0.18	-0.06
Earth Sciences	-0.25*	0.86*	-0.07	-0.27	-0.01	0.13	0.01	0.18	0.21	0.21	0.21	0.23	-0.04
Environmental Sciences	-0.48**	0.00	-0.22	-0.19	0.10	-0.34	-0.10	0.25	0.31	0.34	0.29	0.30	-0.16
Biological Sciences	-0.20*	0.37	-0.09	-0.17	-0.03	0.08	-0.16	0.09	0.11	0.11	0.12	0.11	-0.08
Agricultural & Veterinary Sciences	-1.02***	1.04	0.14	0.21	-0.24	-0.04	-0.26	0.75	0.63	0.44	0.55	0.45	-0.07
Information & Computing Sciences	-0.60***	0.08	-0.24	-0.01	-0.18	-0.39	-0.04	0.15	0.18	0.15	0.16	0.17	-0.18
Engineering	-0.50***	0.33	-0.23	-0.03	-0.11	-0.08	-0.13	0.10	0.11	0.11	0.11	0.11	-0.11
Technology	-0.35*	0.28	0.11	-0.10	-0.41	-0.05	-0.20	0.21	0.24	0.25	0.28	0.22	-0.12
Medical & Health Sciences	-0.50***	0.57	-0.01	0.15	-0.13	-0.41	0.04	0.16	0.17	0.22	0.22	0.24	-0.06
Built Environment & Design	-1.17***	0.86	0.16	0.37	0.03	-0.67	-0.42	0.37	0.45	0.74	0.73	0.39	-0.07
Education	-0.59***	0.58	0.25	-0.13	-0.34	0.05	-0.18	0.26	0.31	0.29	0.32	0.28	-0.07
Economics	-0.17	-0.07	-0.23	-0.07	-0.05	-0.26	-0.24	0.27	0.24	0.29	0.22	0.28	-0.17
Commerce, Management, Tourism & Services	-0.90***	0.61	-0.21	-0.27	0.19	-0.01	0.65	0.24	0.24	0.30	0.30	0.43	0.01
Studies In Human Society	-0.31**	0.09	-0.32	-0.05	-0.03	-0.10	-0.36	0.16	0.17	0.16	0.16	0.17	-0.17
Psychology & Cognitive Sciences	-0.15	0.13	-0.41	-0.06	0.06	-0.21	-0.35	0.17	0.17	0.17	0.18	0.18	-0.19
Law & Legal Studies	-0.26+	0.76	0.22	0.30	-0.57	-0.07	-0.15	0.27	0.28	0.28	0.29	0.35	-0.05
Studies In Creative Arts & Writing	-0.60***	0.56	-0.46	-0.34	0.70	-0.32	0.37	0.38	0.36	0.38	0.39	0.37	-0.01
Language, Communication & Culture	-0.35**	0.41	0.00	-0.18	-0.03	-0.13	-0.10	0.17	0.21	0.21	0.22	0.24	-0.08
History & Archaeology	-0.03	-0.08	-0.37	-0.09	-0.51	-0.18	-0.10	0.19	0.21	0.24	0.25	0.23	-0.25
Philosophy & Religious Studies	-0.48**	0.30	-0.11	-0.20	-0.11	-0.31	0.21	0.27	0.31	0.31	0.39	0.37	-0.11

The generalized linear mixed model used to predict success rate has IDD, division and their interaction as fixed variables and year as a random variable. 'Mathematical Sciences' is used as the reference category for other divisions, so its coefficient and interaction are zeros. Coefficients show differences in success rates of other divisions compared with Mathematical Sciences. Interaction shows differences in the effect of interdisciplinarity on success rates of other divisions compared with Mathematical Sciences. The coefficient of IDD = −0.68**. A likelihood ratio test suggests that including IDD as a fixed variable significantly increases model fit to the data ($\chi_{22}^2 = 57.94$, $P = 4.5 \times 10^{-5}$). ***$P = 0$; **$P = 0.001$; *$P = 0.01$; $^+P = 0.05$. Coeff, coefficient; Int'n, interaction; Y, year; Wtd avg, weighted average.