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Research interdisciplinarity: STEM versus non-STEM

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Abstract

Research collaboration among interdisciplinary teams has become a common trend in recent days. However, there is a lack of evidence in literature regarding which disciplines play dominant roles in interdisciplinary research settings. It is also unclear whether the dominant role of disciplines vary between STEM (Science, Technology, Engineering, and Mathematics) and non-STEM focused research. This study considers metadata of the research projects funded by the Australian Research Council Discovery Grant Project scheme. Applying network analytics, this study investigates the contribution of individual disciplines in the successfully funded projects. It is noted that the disciplines *Engineering*, *Biological Sciences* and *Technology* appear as the principal disciplines in interdisciplinary research having a STEM focus. By contrast, non-STEM interdisciplinary research is led by three disciplines—*Studies in Human Societies*, *Language, Communication and Culture*, and *History and Archaeology*. For projects entailing interdisciplinarity between STEM and non-STEM disciplines, the STEM discipline of *Medical and Health Sciences* and the non-STEM disciplines of *Psychology and Cognitive Science* and *Studies in Human Societies* appear as the leading contributors. Overall, the network-based visualisation reveals that research interdisciplinarity is implemented in a heterogeneous way across STEM and non-STEM disciplines, and there are gaps in inter-disciplinary collaborations among some disciplines.

Keywords Interdisciplinary research · STEM and non-STEM

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Introduction

Interdisciplinary research has become increasingly common in recent days. This type of research is very important in addressing many real-life problems where a joint effort from experts working in multiple research domains is required. The National Science Foundation of the USA define interdisciplinary research as a mode of research, conducted by teams or individuals, by integrating different methodological perspectives (e.g., information, data, techniques and tools), concepts and/or theories from two or more disciplines to solve problems (National Science Foundation 2020). A similar view is posed by the Australian Research Council (ARC), which notes interdisciplinary research as those involving investigators across disciplines for solving a problem or providing different perspectives to a problem as well those that involve one or more researchers applying approaches utilised across disciplines or outcomes from different disciplines to solve problems or issues (Australian Research Council 2016). Solutions of such problems are beyond the scope of a single discipline or area of research practice. Interdisciplinary research enables inputs from multiple domains, which eventually facilitates in developing novel conceptual and methodological frameworks to provide extraordinary solutions for many current societal issues (Barthel and Seidl 2017).

Recent literature has emphasised on the importance of interdisciplinary research in solving many contemporary societal and research problems (Khan et al. 2019; Bromham et al. 2016). Simultaneously, literature has also pointed out various issues that motivate and deter interdisciplinary undertakings. For instance, there is an evidence that demographic attributes of researchers like gender and work experience can characterise engagements in interdisciplinary research (Van Rijnsoever and Hessels 2011). Recent statistics also show that researchers from some countries demonstrate higher interest in interdisciplinary research compared with investigators from other countries (Van Noorden 2015). Studies further identify funding availability, professional issues, team characteristic, epistemological orientation, scope of research problems and institutional characteristic as factors that influence interdisciplinary research engagements (Porter et al. 2006). Personal motivations and interests of researchers, enjoyment of working within multidisciplinary team settings and potential impacts on society are further noted as drivers of such research (Milman et al. 2017). Additionally, ranking of journals (Rafols et al. 2012), communication gap among disciplines and longer required timeframe (Milman et al. 2017), and costs and lack of incentives (Schuitema and Sintov 2017) are noted as challenges for interdisciplinary initiatives. There is also a call for a change of mindset and broadening of scopes to overcome deficiencies in interdisciplinary research (Gustafsson and Bowen 2017). A related work proposes the "Interdisciplinary Research Management Framework" for an organised conceptualisation of team culture, research outcomes, external engagements, and operational processes pertaining to an interdisciplinary research activity (König et al. 2013). Another recent study proposes a five steps approach for effective interdisciplinary investigations (Danermark 2019).

Evaluation of interdisciplinary research has been another active area of investigation. Researchers, for instance, have quantified research interdisciplinarity using different metadata, such as project grant information, co-authors' affiliations and target journal type (Adams et al. 2016; Stirling 2007). There have also been other bibliometric evaluation including characteristics of publications and patterns of citations (Porter et al. 2006). Research further notes that diversities in Web of Science categories for interdisciplinary publications can lead to positive citation impacts (Yegros-Yegros et al. 2015). Outcomes in terms of publications and grant proposals, career development of investigators, institutional views, and formation of centres have also received attention for evaluation of interdisciplinary studies (McLeish and Strang 2016). A recent research uses a multilayered network to characterize the impacts of interdisciplinary undertakings (Omodei et al. 2017).

Despite such a wide exploration, some gaps exist concerning interdisciplinary research activities. The metadata of different published articles (e.g., journal, conference proceeding and book chapter) do not provide any specific information about the underlying discipline(s) involved in the corresponding research. Also, quantitative measures, though widely used, may not capture the dynamics of interdisciplinary research at a social level (Wagner et al. 2011). While a network dynamic based evaluation can be useful, the outcome of the approach can be difficult to interpret (Wagner et al. 2011). As such, there lies the opportunity to explore the domain of interdisciplinary science further, especially using network dynamics for its inherent capability to capture complex associations.

Notably, discipline codes for interdisciplinary outcomes in existing literature have largely either been assigned by the respective researchers or guessed from the publication avenues and characteristics. These do not necessarily reflect the discipline level orientations of authors of those publications. For some research undertaking, like applications for research grants, the respective authors themselves assign discipline codes for their grant proposals, and further assign weights to those discipline codes. Even though such assignment of codes reflects the opinions of respective authors in determining the interdisciplinarity of the corresponding research activity, existing literature, to the best of our knowledge, has largely overlooked assessing interdisciplinarity from this perspective. It can be argued that affiliations could reveal co-authors are from different disciplines. However, the underlying research focus may not span multiple disciplines. In the same way, an interdisciplinary journal does not necessarily publish only those articles that have an interdisciplinary co-author team or address an interdisciplinary problem. Thus, an assessment of opinion of the research team regarding the interdisciplinarity nature of the underlying research effort can reveal interesting insights, yet which has been ignored in existing works. This research fills the gap by exploiting network dynamics and highlights the extent different fields of research relate in interdisciplinary projects. Further, interdisciplinarity may not have the same meaning to STEM (Science, Technology, Engineering, and Mathematics) and non-STEM researchers. As an existing work also shows, there are notable variations among the orientation towards multidisciplinary research activity across disciplines (Van Noorden 2015). There is, however, a lack of research that explores both the inter-group and intra-group interdisciplinarity among the STEM and non-STEM disciplines, and the underlying social nature (i.e., the extent the different fields of research associate across interdisciplinarity projects). This research contributes to the existing body of knowledge also from this perspective.

Methods and materials

Data source

In research grant applications, investigators from one or more disciplines aim to address concurrent and challenging societal problems. In some cases (e.g., Australian Research Council), investigators need to explicitly mention the contribution of each discipline in the application. The metadata of those applications can therefore be used to explore research

Table 1 List of STEM and non-STEM disciplines (Australian Research Council 2016). STEM stands for science, technology, engineering and mathematics

SI	STEM	Non-STEM
1	Agricultural and veterinary sciences	Built environment and design
2	Biological sciences	Commerce, management, tourism and services
3	Chemical sciences	Economics
4	Earth sciences	Education
5	Engineering	History and archaeology
6	Environmental sciences	Language, communication and culture
7	Information and computing sciences	Law and legal studies
8	Mathematical sciences	Philosophy and religious studies
9	Medical and health sciences	Psychology and cognitive sciences
10	Physical sciences	Studies in creative arts and writing
11	Technology	Studies in human society

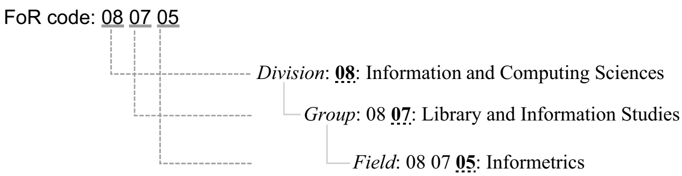


Fig. 1 Discipline information of a FoR code

interdisciplinarity. This study used the metadata of successful ARC grants. The ARC gathers discipline information in its all grant applications using a field of research (FoR) framework (Fields of Research 2020). This framework categorises all research areas into 22 *divisions*, each of these *divisions* further splits into multiple *groups* and finally each *group* splits into multiple *fields*. The 22 divisions have been listed in Table 1, along with their categorisation into STEM and non-STEM classes. Each FoR code consists of six digits; two digits for *division*, two digits for *group* and the last two digits for *field*. An example of a six-digit FoR code is illustrated in Fig. 1. The ARC defines a grant application (i.e., a research project) as *interdisciplinary* only when the that application has been assigned to two or more distinct FoR codes across the most significant two-digit level (i.e., *division* level) (Australian Research Council 2016).

Every year the ARC offers research projects under the discover program in the these five schemes (Australian Research Council 2016): Discovery Projects; Discovery Early Career Researcher Award; Future Fellowships; Australian Laureate Fellowships; and Discovery Indigenous. Among these five schemes, the ARC offers the highest number of projects under the Discovery Projects (DP) scheme. Only individual researchers can apply for the second, third and fourth schemes. There are limited number of Discovery Indigenous projects offered every year. Successful DP projects between 2009 and 2018 (inclusive) were considered as data for this research. DP projects that have the same FoR codes at the *division* level, and thereby do not fall under the interdisciplinary category, were excluded. Table 2 shows descriptive statistics about this research data. Inter-STEM projects are those projects that have at least one FoR code from each

Table 2 Descriptive statistics about the research data, which consist of discovery projects (DP) that are funded by Australian Research Council between 2009 and 2018 (inclusive)

Year	Number of successful DPs $(a+e)$	Number of Non interdisciplinary DPs (a) (%)	Interdisciplinary			
			STEM only (b)	Non-STEM only (c)	Inter-STEM (d)	Number of interdisciplinary DPs $e = b + c + d$ (%)
2009	1903	1504 (79)	244	101	54	399 (21)
2010	1896	1479 (78)	239	109	69	417 (22)
2011	1979	1560 (79)	269	99	51	419 (21)
2012	2079	1648 (79)	277	97	57	431 (21)
2013	2349	1974 (84)	243	83	49	375 (16)
2014	2123	1742 (82)	248	84	49	381 (18)
2015	1795	1484 (83)	206	69	36	311 (17)
2016	1517	1276 (84)	155	56	30	241 (16)
2017	1139	940 (83)	126	42	31	199 (17)
2018	1246	1045 (84)	137	35	29	201 (16)

of STEM and non-STEM groups. As notable from this table, out of total number of DP projects, 16–22% successful projects are interdisciplinary and a majority of these involve STEM only disciplines. However, statistical tables like this one do not clarify how the different FoR codes are linked to each other in such research undertakings. This is where this research contributes by a network-based approach, as discussed in the next two sub-sections.

Participation strength network

A participation strength network (PSN) shows the strength of relations between different disciplines in a network structure where each node represents a discipline, an edge (i.e., link) between two nodes represents the participation of the underlying disciplines in at least a successful grant application, and the thickness of the link between two nodes represents the participation frequency and weight of the underlying disciplines represented by those nodes in successful grant applications (Khan et al. 2019). In an ARC DP grant application, investigators of each application need to mention at least two relevant FoR codes and their weights. The sum of the weights of all FoR codes of an application must be 100%.

Khan et al. (2019) first proposed the method for constructing a PSN from the FoR codes of grant applications. This study adopted a modified approach in generating a PSN from FoR codes. The underlying principles of these two approaches are same. However, this modified approach generates an undirected PSN; whereas, the approach proposed by Khan et al. (2019) generates a directed network. An undirected PSN provides a better interpretation of the network analyses and visualisations carried out in this study. As outlined in Fig. 2, a network is constructed for each project based on its FoR code information in the first step. This network can be thought a PSN at project level. For a project, the total weights of two FoR codes are used in the following formula in assigning a weight for the link between them.

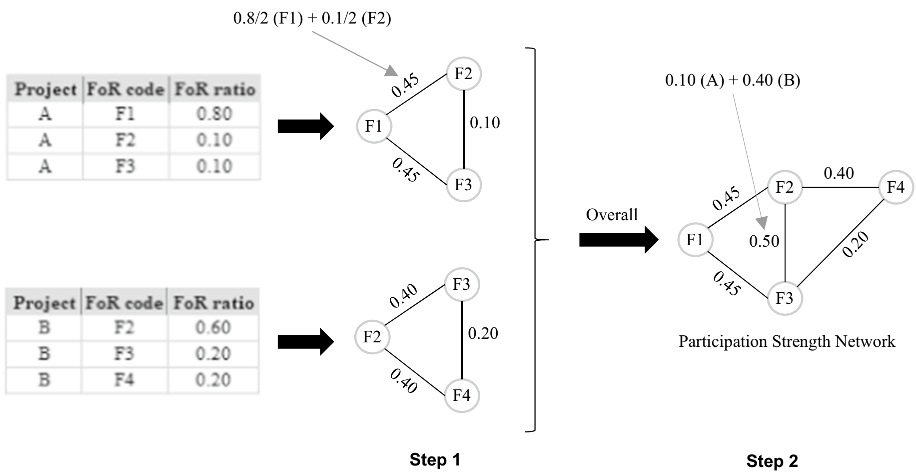


Fig. 2 Construction of a PSN from an abstract data

$$\mathrm{LW}_{F_\mathrm{i},F_\mathrm{j}}^{P_\mathrm{k}} = \frac{W_{F_\mathrm{i}}^{P_\mathrm{k}} + W_{F_\mathrm{j}}^{P_\mathrm{k}}}{2} \tag{1}$$

where $\mathrm{LW}_{F_\mathrm{i},F_\mathrm{j}}^{P_\mathrm{k}}$ is the link weight between FoR codes F_i and F_j in project k. $W_{F_\mathrm{i}}^{P_\mathrm{k}}$ and $W_{F_\mathrm{j}}^{P_\mathrm{k}}$are the given weights (assigned by investigators) of FoR codesF_i and F_j ,respectively, in project k.

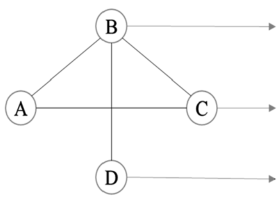
In the second step, all individual networks for each project are aggregated using the following formula to construct the final PSN.

$$\mathrm{LW}_{F_\mathrm{i},F_\mathrm{j}}^{A} = \sum_{k=1}^{n} \mathrm{LW}_{F_\mathrm{i},F_\mathrm{j}}^{P_k} \tag{2}$$

where $\mathrm{LW}_{F_\mathrm{i},F_\mathrm{j}}^{A}$ is the link weight between FoR codes F_i and F_j in the aggregated network (i.e., final PSN). $\mathrm{LW}_{F_\mathrm{i},F_\mathrm{j}}^{P_k}$ is the link weight between FoR codes F_i and F_j in project k, and n is the total number of DP projects considered for constructing the aggregated network.

Network centrality measures

A centrality measure indicates the position of a node regarding its connectivity with all other remaining network nodes from different perspectives. This study considers the three basic centrality measures—degree, close and betweenness centrality. The degree centrality indicates the activity and popularity of a node in a network and can be quantified by counting its all connections with other nodes (Wasserman and Faust 2003). The closeness centrality represents to what extent a node is close to all member nodes of the network (Wasserman and Faust 2003). The betweenness centrality denotes the importance of a node in a network in terms of its frequency of falling on the shortest paths between any pair of other network nodes (Wasserman and Faust 2003). Each of these three centrality measures can be normalised to get a value between 0 and 1. Using an abstract network, Fig. 3 shows how to calculate these three centrality measures.



$$\text{Betweenness centrality (B)} = \frac{\sum \textit{Number of times B falls within the shortest paths}}{\sum \textit{Possible maximum number of shortest paths B can fall}} = \frac{2\,(ABC\ \&\ ABD)}{3} = 0.67$$

$$\text{Degree centrality (C)} = \frac{\textit{Total connections C has}}{\textit{Possible maximum connections C can have}} = \frac{2}{3} = 0.67$$

$$\text{Closeness centrality (D)} = \frac{\sum \textit{Possible shortest distances to all from D}}{\sum \textit{Existing distances to all from D}} = \frac{1+1+1}{1+2+2} = 0.60$$

Fig. 3 Illustration of the calculation of three centrality measures using an abstract network

Results

Figure 4 shows the PSN among all STEM disciplines. This figure uses FoR code information of all interdisciplinary ARC discovery grant applications that were successful between years 2009 and 2018 (inclusive) (Australian Research Council 2017). As evident in this figure, *Engineering* and *Biological Sciences* disciplines appeared more frequently with other STEM disciplines in successful research grant projects. Although *Medical and Health Sciences* and *Environmental Sciences* do not show a strong connection with other disciplines, each of these two disciplines has a strong tie with the *Biological Sciences* discipline. This indicates these two discipline pairs (i.e., *Biological Sciences* ↔ *Environment Sciences* and *Biological Sciences* ↔ *Medical and Health Sciences*) appeared more often in interdisciplinary STEM research projects. Similarly, the *Technology* discipline has a strong tie with the *Engineering* discipline. Overall, out of 11 STEM disciplines only few of them have a superior node-level and/or link-level appearances in the corresponding PSN. Based on the three centrality measures, Table 3 shows the top-5 disciplines that played major roles in

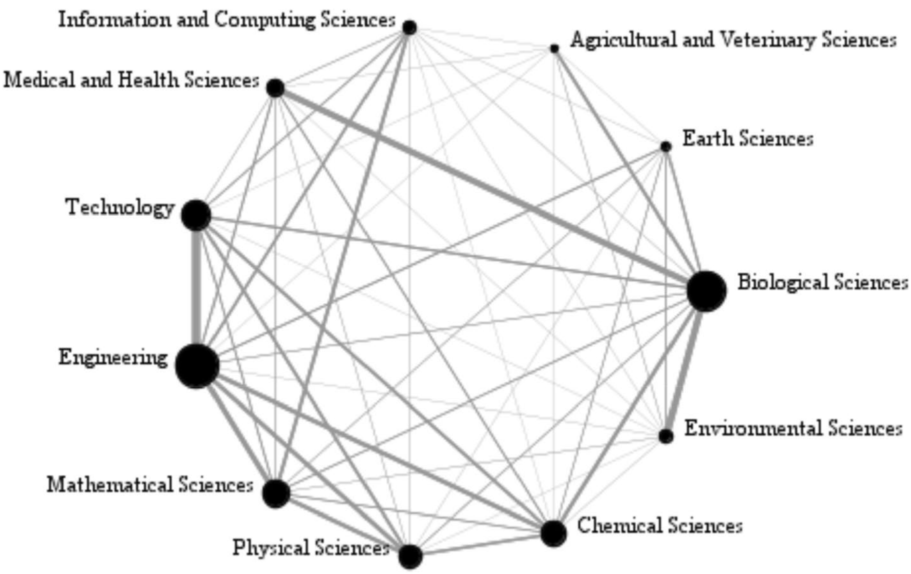


Fig. 4 The participation strength network among STEM disciplines. The node size is set in proportion to its number of direction connections and their weights with other disciplines within the network. The thickness of an edge is proportional to its weight value

Table 3 The top-5 disciplines in the participation strength network considering all STEM projects in respect to the three centrality measures used in this study. The number inside each bracket is the corresponding centrality value

Rank	Degree	Betweenness	Closeness
1	Medical and health sciences (0.13)	Information and computing sciences (0.38)	Agricultural and veterinary sciences (0.06)
2	Information and computing sciences (0.05)	Agricultural and veterinary sciences (0.37)	Information and computing sciences (0.06)
3	Mathematical sciences (0.03)	Environmental sciences (0.34)	Technology (0.05)
4	Biological sciences (0.02)	Earth sciences (0.06)	Environmental sciences (0.05)
5	Earth sciences (0.02)	Technology (0.04)	Chemical sciences (0.05)

all STEM projects. Notably, the *Information and Computing Sciences* discipline (shaded) is positioned in all three lists of this table, indicating its dominant role in STEM projects. A reason behind this superiority of some disciplines is explained in the discussion section, though the anomaly arises potentially due to relatively higher funding success of some disciplines and the research priorities historically emphasised in Australia.

Figure 5 shows the PSN among non-STEM disciplines. The discipline *Studies in Human Societies* has the largest node size, indicating its superior appearance and connection with other non-STEM disciplines in interdisciplinary non-STEM research projects. This discipline is followed by *Language, Communication and Culture* and *History and Archaeology*. As revealed by their link weight, three non-STEM discipline pairs (*Studies in Human Societies* ↔ *History and Archaeology*, *Studies in Human Societies* ↔ *Language, Communication and Culture*, and *History and Archaeology* ↔ *Language, Communication and Culture*) appear more often in interdisciplinary research projects. The disciplines *Law and Legal Studies* has a weak tie with all non-STEM disciplines except the *Studies in Human Societies* discipline. Similarly, *Studies in Creative Arts and Writing* discipline does not have a strong appearance but has a strong tie with *History and Archaeology* and *Language, Communication and Culture* disciplines. Table 4 shows the top-5 disciplines, based on the three centrality measures in non-STEM projects.

Figure 6 shows the PSN only between STEM and non-STEM disciplines. The discipline *Medical and Health Sciences* has the highest appearance among all STEM disciplines. On the other side, the discipline *Psychology and Cognitive Sciences* has the most appearance among all non-STEM disciplines, followed by the *Studies in Human Societies* discipline. The STEM discipline of *Medical and Health Sciences* has a strong tie with the non-STEM disciplines of *Psychology and Cognitive Sciences* and *Studies in Human Societies*. It is interesting to note that although the discipline *Psychology and Cognitive Sciences* does not have a strong appearance and connectivity in the non-STEM PSN (Fig. 5) it has a strong appearance and connectivity in Fig. 6. It indicates that this discipline plays an important role in the interdisciplinarity between STEM and non-STEM disciplines. The same is true for the STEM discipline of *Medical and Health Sciences*. The disciplines *Engineering* and *Biological Sciences* have a strong appearance in Fig. 4, but they have a weak appearance in

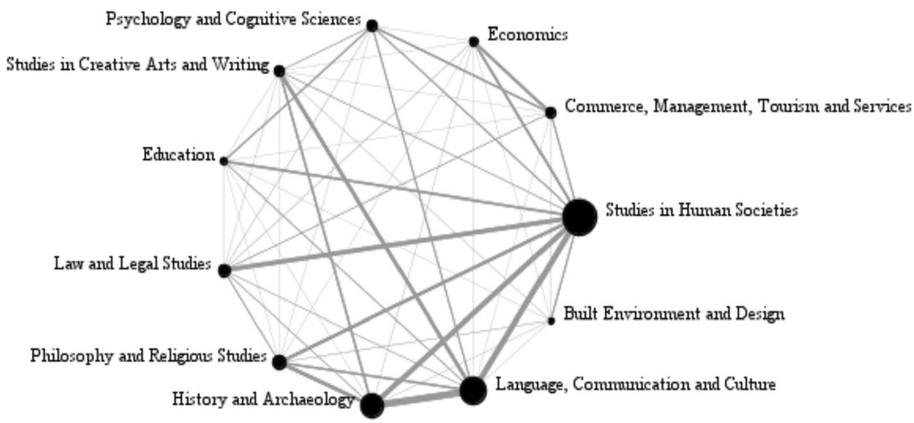


Fig. 5 The participation strength network among non-STEM disciplines. The node size is set in proportion to its number of direction connections and their weights with other disciplines within the network. The thickness of an edge is proportional to its weight value

Table 4 The top-5 disciplines in the participation strength network considering all non-STEM projects in respect to the three centrality measures used in this study. The number inside each bracket is the corresponding centrality value. Only four disciplines have a betweenness centrality value. Others have a betweenness centrality value of 0

Rank	Degree	Betweenness	Closeness
1	Studies in human societies (0.41)	Economics (0.56)	Economics (0.22)
2	Language, communication and culture (0.32)	Education (0.42)	Built environment and design (0.21)
3	History and archaeology (0.28)	Built environment and design (0.33)	Studies in creative arts and writing (0.20)
4	Philosophy and religious studies (0.17)	Studies in creative arts and writing (0.29)	Education (0.20)
5	Law and legal studies (0.13)		Commerce, management, tourism and services (0.19)

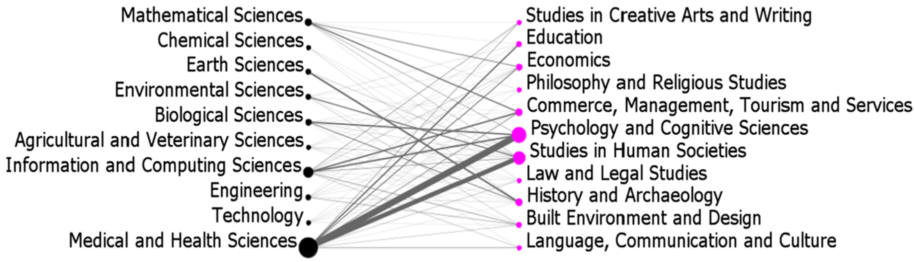


Fig. 6 The participation strength network between STEM and non-STEM disciplines. The node size is set in proportion to its number of direction connections and their weights with other disciplines within the network. The thickness of an edge is proportional to its weight value

Fig. 6, indicating their weaker contribution towards the interdisciplinarity between STEM and non-STEM disciplines. This fact is also true for the non-STEM disciplines of *History and Archaeology* and *Language, Communication and Culture*. The discipline *Studies in Human Societies* has a strong contribution towards the research interdisciplinarity among all non-STEM disciplines as well as between STEM and non-STEM disciplines. The discipline *Physical Sciences* is absent in Fig. 6, indicating that it does not contribute to the interdisciplinarity between STEM and non-STEM disciplines.

Finally, the PSN involving all disciplines considered in this study is presented in Fig. 7. There are 22 nodes in this figure, representing the 22 disciplines (11 STEM and 11 non-STEM). From a visual inspection, it seems that *Engineering*, *Biological Sciences*, *Medical and Health Sciences* and *Technology* have a strong contribution towards the research effort entailing STEM and non-STEM disciplines. Table 5 shows the top-10 disciplines based on each of three centrality measures considered in this study. Two disciplines (*Technology* and *Environmental Sciences*) position in these three top-10 lists, indicating their superior contribution towards the interdisciplinary research among all STEM and non-STEM disciplines.

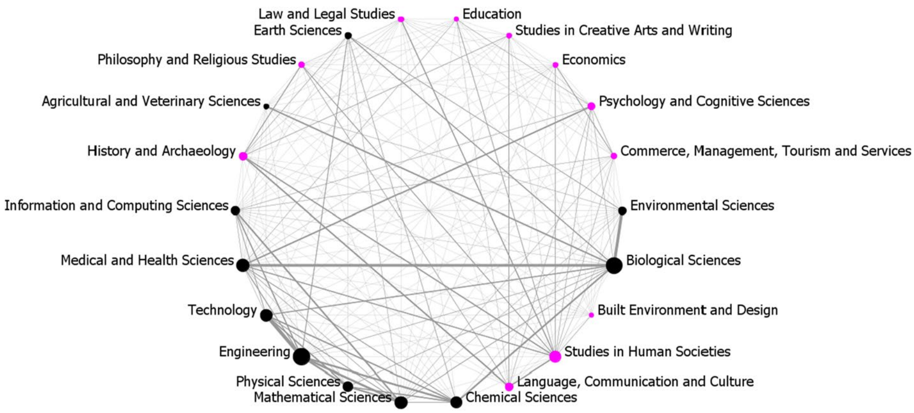


Fig. 7 The participation strength network among all 22 disciplines based on the entire research dataset of this study. Black and Red colour nodes represent STEM and non-STEM disciplines, respectively. The node size is set in proportion to its number of direction connections and their weights with other disciplines within the network. The thickness of an edge is proportional to its weight value

Table 5 The top-10 disciplines in the participation strength network among all 22 disciplines based on the entire research data of this study with respect to three network centrality measures. The number inside each bracket is the centrality value of the corresponding discipline. The shaded disciplines (i.e., Technology and Environmental Sciences) are the ones that are positioned in all three top-10 lists

Rank	Centrality measure under consideration		
	Degree centrality	Betweenness centrality	Closeness centrality
1	Engineering (0.16)	*Technology (0.24)*	*Technology (0.19)*
2	Biological sciences (0.15)	Economics (0.23)	Economics (0.19)
3	Medical and health sciences (0.11)	Law and legal studies (0.21)	Built environment and design (0.19)
4	*Technology (0.11)*	Agricultural and veterinary sciences (0.2)	Agricultural and veterinary sciences (0.18)
5	Mathematical sciences (0.11)	Built environment and design (0.16)	Law and legal studies (0.16)
6	Studies in human societies (0.1)	*Environmental sciences (0.12)*	*Environmental sciences (0.15)*
7	Chemical sciences (0.1)	Education (0.09)	Information and computing sciences (0.15)
8	Physical sciences (0.08)	Studies in creative arts and writing (0.07)	Education (0.15)
9	Information and computing sciences (0.07)	Biological sciences (0.06)	Chemical sciences (0.14)
10	*Environmental sciences (0.06)*	History and archaeology (0.06)	Studies in creative arts and writing (0.14)

Discussion

When pitching projects for funding, researchers have considered inter-disciplinary collaborations but a few disciplines play a leading role in such collaborations. Some disciplines dominate in the research interdisciplinarity among STEM disciplines and some others among non-STEM disciplines, while few disciplines have an equal emphasis in collaborations between STEM and non-STEM disciplines. Further, while connections between several disciplines appear as strong in STEM only interdisciplinary projects, non-STEM only interdisciplinary projects appear to have weaker inter-connectivity among the relevant disciplines. Also, for collaboration between STEM and non-STEM disciplines, *Medical and Health Sciences*, *Psychology and Cognitive Sciences* and *Studies in Human Societies*, interestingly, appear to have strong connections. In this respect, it is worth noting the success in funding of the interdisciplinary and non-interdisciplinary projects. As notable from Table 6, STEM discipline based interdisciplinary projects have substantially higher funding success than non-STEM interdisciplinary projects. This difference is statistically significant. It is further evident from the mean values of this table that the increased number of STEM disciplines involved in an interdisciplinary project leads, on average, to a higher amount of grant success. This may also explain why the connections between non-STEM appear somewhat loose compared to STEM-based undertakings.

An exploration of the national research priorities of Australia during the data collection period of this study can further explain the superior positioning of few STEM disciplines in STEM only interdisciplinary projects as well as in the STEM and non-STEM interdisciplinary projects. The ARC identified four national research priorities in research: (i) An environmentally sustainable Australia; (ii) Promoting and maintaining good health; (iii) Frontier technologies for building and transforming Australian industries; and (iv) Safeguarding Australia (ARC Act 2001). The explicit mentioning of '*health*' and '*technology*' may have boosted the undertakings of the relevant STEM disciplines (i.e., '*Medical and health sciences*' and '*Technology*', respectively) in interdisciplinary projects.

Existing literature, notably, has focused on interdisciplinarity generally in a passive manner with respective investigators making assumptions from various meta-data. This research is different due to considering the orientation towards interdisciplinarity by researchers when pitching their projects for funding. Overall, as the results suggest, interdisciplinarity and openness to potential inputs and collaborations from cross-disciplines

Table 6 Comparison of funding amount among different types of research projects using the *t test*. Inter-STEM denotes those interdisciplinary projects that have at least one FoR code is from each of STEM and non-STEM groups

Test no	Group	N	Mean	STD	*t* value	Sig. (2-tailed)
1	Interdisciplinary	3374	$310,390	182,092	7.35	0.000
	Non-interdisciplinary	5956	$283,878	158,350		
2	STEM	2144	$344,205	183,010	15.31	0.000
	Non-STEM	775	$231,992	150,312		
3	STEM	2144	$344,205	183,010	6.32	0.000
	Inter-STEM	455	$284,582	182,133		
4	Inter-STEM	455	$284,582	182,133	5.47	0.000
	Non-STEM	775	$231,992	150,312		

have different appeals to researchers depending on nature of the project. Consequently, the participation strength of different disciplines concerning their level of contribution towards research interdisciplinarity also vary noticeably.

An existing research suggests that, despite the benefit of interdisciplinarity in forming new knowledge, researchers have generally considered a narrow range of disciplines when publishing (Yegros-Yegros et al. 2015). Our research highlights that this narrowness can persist in also pitching for funding, even when funding agencies often encourage interdisciplinarity. There is also a view that researchers may feel interconnection between distinctly different disciplines as risky (Yegros-Yegros et al. 2015). Perhaps, this feeling of riskiness explains the weaker connectivity among some STEM and non-STEM disciplines. Another existing research identifies that research interdisciplinarity is more motivated by industry connection than incentives from academic careers (Carayol and Thi 2005). Potentially, this explains the prominent position of information technology, engineering, medical science, and social studies in the network structure, with these disciplines' direct linkage to different productive industrial activities. Simultaneously, a lack of clear link to commercial application possibly also reflects a lower level of interdisciplinarity among some disciplines especially those in the non-STEM category.

Even so, interdisciplinarity can play a significant role in solving many different issues. This is evident from call and encouragement for such undertakings from different areas including sports science (Piggott et al. 2019), life stage study (Susman et al. 2019), climate change (Milman et al. 2017), energy studies (Schuitema and Sintov 2017) and tourism research following the COVID-19 crisis (Wen et al. 2020). Gustafsson and Bowen (2017) also recommend a change of mindset by researchers when undertaking interdisciplinary collaboration, while Leahey (2018) points to the possibility of high visibility for interdisciplinary researchers.

Notably, Bromham et al. (2016) suggest that interdisciplinary research undertakings are often less funded. A similar view is expressed by Pedersen (2016), who notes funding barriers towards incorporating social science disciplines in interdisciplinary research. Our research, however, shows that interdisciplinary research undertakings, especially that involving STEM disciplines, are well supported in the ARC scheme. Thus, more than just funding, some shifts in thinking at researcher level may boost more interdisciplinarity among the weakly associated STEM and non-STEM disciplines noted in this research. There is a view that high interdisciplinarity in research may lead to project failures (Yegros-Yegros et al. 2015), yet research also shows that flexibility in funding and institutional strong encouragement towards interdisciplinary team building can lead to effective results (Gibson et al. 2019). Thus, higher institutional encouragement and relaxing funding requirements for non-STEM, and STEM and non-STEM cross-over interdisciplinary research may enhance interdisciplinarity undertakings.

Conclusion

Research interdisciplinarity is a multifaceted issue, and the level of emphasis on interdisciplinarity between STEM and non-STEM disciplines varies considerably. In this article, the network-based visualisation reveals the heterogeneous ways interdisciplinarity is pursued by researchers across STEM and non-STEM disciplines when seeking funding. Several gaps in inter-disciplinary collaborations among some disciplines are notable. This understanding of the nature of research interdisciplinarity can be beneficial in multiple respects.

First, this has revealed a common sense about where our interdisciplinary research efforts are heading. Apparently, STEM-based interdisciplinary research projects are well funded, including those that link STEM and non-STEM disciplines. There is also an emphasis on STEM related areas in research priorities. However, there is apparently a need to rethink about interdisciplinarity in non-STEM disciplines. The roles social sciences can play in addressing future societal challenges also need attention, and an enhanced coloration across STEM and non-STEM disciplines may in fact benefit disciplines from both areas. Overall, this article provides some useful information that may assist policymakers in making future guidelines for distributing the available research funding.

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