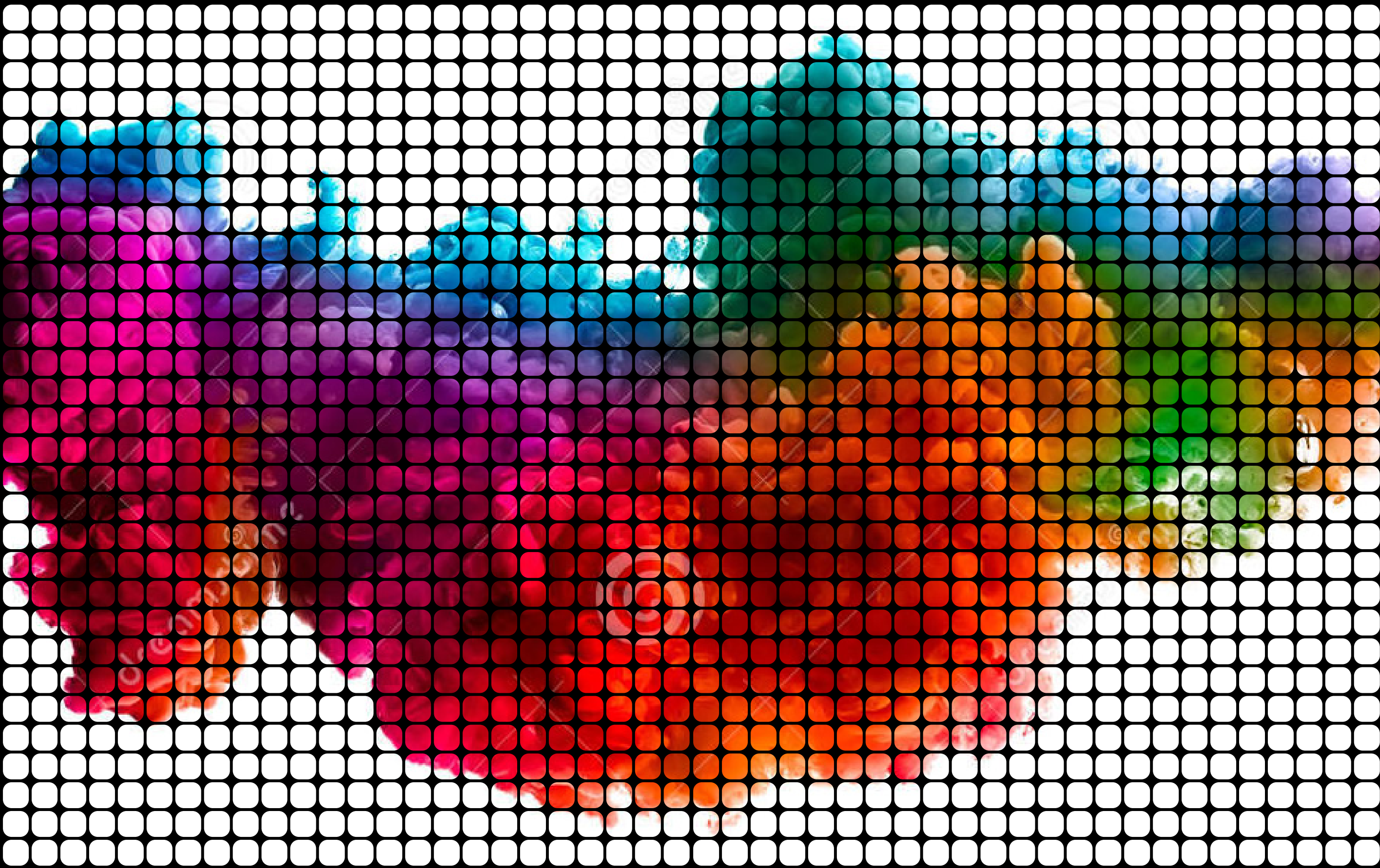

Digital Research Reports

Interdisciplinary research: methodologies for identification and assessment

Do we know what we are measuring?

Jonathan Adams, Tamar Loach and Martin Szomszor

NOVEMBER 2016

DIGITAL science

RESEARCH COUNCILS UK

About the Authors

Jonathan Adams joined Digital Science as Chief Scientist in October 2013. Previously he was the lead founder of Evidence Ltd (2000-2009) and Director of Research Evaluation for Thomson Reuters (2009-2013). Jonathan led the 2008 review of research evaluation in New Zealand and was a member of the Australian Research Council (ARC) indicators development group for its research excellence assessment (ERA). In 2004 he chaired the EC Evaluation Monitoring Committee for Framework Programme 6. In 2006 he chaired the Monitoring Group of the European Research Fund for Coal & Steel. In 2010 he was an Expert Advisor to the interim evaluation of the EU's 7th Framework Programme for Research (FP7).

Tamar Loach is the Research Analyst at Digital Science. Her background is in theoretical physics, and she has undertaken research projects both in this area and on alternative research metrics with the Complexity and Networks group, all at Imperial College London. In 2014 she was an invited subject matter expert at the EC IPTS centre for a workshop on alternative reputation mechanisms for scholars and has recently reported for NESTA on such metrics in medical research.

Martin Szomszor is Consultant Data Scientist at Digital Science. Previously Head of Data Science and founder of the Global Research Identifier Database (GRID), Martin has worked on a range of research metrics projects, applying his extensive knowledge of machine learning, data integration, and visualisation techniques to uncover novel insights and inform the academic research lifecycle. He was previously Deputy Head of Centre at the City eHealth Research Centre (2009-2011) where he led research on the use of social media for epidemic intelligence and was Chair of the 4th International Conference on Electronic Healthcare for the 21st Century. Martin was also a Research Fellow at the University of Southampton (2006-2009) where he worked on various Linked Data, Semantic Web, and Social Network analyses projects. Martin has a BSc and PhD in Computer Science.

About Digital Science

Digital Science is a technology company serving the needs of research. At the centre of our mission is the support of researchers within research institutions, funding bodies, publishers and governments, for whom we provide a range of software, content and consultancy solutions. We believe passionately that tomorrow's research will be different and better than today's.

Visit www.digital-science.com

About Consultancy

Our consultancy team delivers custom reporting and analysis to help you make better decisions faster. With in-depth knowledge of the historical and current research ecosystem, our unique perspective helps get the most value from data on the research lifecycle. Our team of data scientists are experts in using innovative analytical techniques to develop revealing visualisations and powerful insights. We understand the changing research landscape, and we can help you develop an evidence base on which to build the best research management and policy decisions.

Acknowledgements

This Digital Research Report summarises a project commissioned by Research Councils UK (RCUK) and is informed by a Steering Group that included Dr Ian Viney, Dr Beverley Sherbon and Gavin Reddick (Medical Research Council, MRC, which chaired the group), Dr Sumi David (Arts & Humanities Research Council, AHRC), Dr Steven Hill and Kim Hackett (Higher Education Funding Council for England, HEFCE) and expert advisors Professor Michael Hopkins (SPRU, University of Sussex) and Professor Ismael Rafols (INGENIO, Universitat Politecnica de Valencia). This project is part of a series of studies by the UK Research and HE Funding Councils into the nature of research and interdisciplinarity.

The full text of the main report, which has detailed analytical Annexes, is available at url to come

Data for the study were sourced from:
Dimensions grants funding database www.uberresearch.com/dimensions-for-funders/
PubMed www.ncbi.nlm.nih.gov/pubmed
Thomson Reuters *Web of Science* www.thomsonreuters.com/en/products-services/scholarly-scientific-research/scholarly-search-and-discovery/web-of-science.html
The *Web of Science* data were collated and analysed by Science-Metrix, Montreal, Canada. Science-Metrix is not responsible for interpretation or opinions expressed in this report. http://www.science-metrix.com/

This report has been published by Digital Science, which is operated by global media company the Holtzbrinck Publishing Group.

The Campus, 4 Crinan Street, London N1 9XW   consultancy@digital-science.com

ISBN 978-0-9929477-8-1

Interdisciplinary research: methodologies for identification and assessment

The objective of the study behind this report was to compare the consistency of indicators of 'interdisciplinarity', and to identify a preferred methodology. The outcome was a diverse set of results that proved seriously inconsistent. This raises questions about how interdisciplinarity is identified and assessed, and reveals a gap between research metadata and research activity. The results highlight issues around the responsible use of 'metrics' and the importance of knowing whether quantitative proxy indicators address the assumed target.

Interdisciplinarity is important to discovery and innovation. It becomes more so as established research disciplines mature (studies from Subramanyam (1983) onwards). It is also seen to add significant impact to research outcomes (studies from ABRC (1987) through SUPRC (1997) to King's College (2015)). It is therefore important to be able to identify interdisciplinary activity, know where it occurs and ensure it is properly assessed.

But there is a challenge. Many researchers know interdisciplinarity when they see it, but not all see the same thing, and that makes life difficult for research funders and policy makers. An objective consensus method for identification and eventual quantification is therefore highly desirable. It is tempting to take a straightforward, purely quantitative approach to mapping connections between researchers as a measure of interdisciplinarity. However, attempts to do this (e.g. Elsevier, 2015) prove simplistic and produce results at odds with qualitative analyses that explore in depth the nature of the interdisciplinary research landscape (Aldrich, 2014; McLeish and Strang, 2014; Technopolis & SPRU, 2016) and the challenge of assessing it (Strang and McLeish, 2015).

Studies have long been equivocal as to how interdisciplinary research (IDR) should be measured (Chubin *et al.*, 1983; Porter and Chubin, 1985), whether IDR proposals tend to suffer in peer review (e.g. Porter and Rossini, 1985; Rinia *et al.*, 2001a), and whether IDR does in practice suffer in peer review (e.g. Rinia *et al.*, 2001b; Van Raan, 2003; Rafols et al., 2012). In the work on which this report is based, we found a lack of objective consensus in the literature as to the definition of 'interdisciplinary', a deficit that currently impedes efforts towards incentivising interdisciplinary approaches. Further, from the range of analyses we carried out, we found that quantitative assessment fails adequately to provide a consistent account of IDR. Our recommendation is that much greater clarity on definitions and more nuanced assessment approaches, combining metrics with peer review and interpretation, are required. [SEE SIDE BOX]

Present policy research often implicitly assumes that IDR can readily be identified and tracked. This assumption may have appeared because the use of research metadata to create informative indices has been successfully applied in other areas of research management.

Issues with the lack of consensus as to what is deemed 'interdisciplinary':

Multiple concepts and imprecise definitions of IDR challenge its objective identification. Most observers are imprecise about the aspect (or component) to which they refer.

Any one piece of research has many such components (e.g. people, objectives, activity, outputs, impacts).

The metadata associated with these are used to create ***proxy*** indicators - as a more objective substitute for subjective observer judgment - that are inferred to describe the nature of the research itself.

Each proxy indicator delivers different insights about the nature of the research.

The same project may be indexed as interdisciplinary for one parameter (say, departmental affiliations) but not for another (say, diversity of references).

The spread of indices we evaluated delivered results that were inconsistent, and sometimes contradictory. Variance depended on both the specific dataset and the application of specific methodology.

It is essential to consider a framework for analysis, drawing on multiple indicators, rather than expecting any simplistic index to produce an informative outcome on its own.

Analysis of multiple data sources and methodologies reveal not only inconsistencies but also conflicts between indicators.

Direct assessment of research activity needs expert judgment, which is costly and onerous, so proxy indicators based on metadata around research inputs and outputs are widely used. The widespread use of relative citation counts to index research impact has created an assumption - wholly untested - that similar proxies can be applied legitimately to other research attributes. Bibliographic analysis alone has been used to relate interdisciplinarity to national and disciplinary research performance (Elsevier, 2015). The present report challenges the assumption that this is valid and responsible use of metrics. Analysis of multiple data sources and methodologies reveal not only inconsistencies but also conflicts between indicators. We do not adequately understand what we are measuring if we think all these indicators equally reflect the disciplinarity of the underlying research.

Our analyses clarified the reality that proxy indicators do not provide direct information about the interdisciplinary nature of the research itself, only about the interdisciplinarity of the metadata. For example, Katz and Hicks (1995) long ago noted the challenge of classifying journal content in a world where journals have an innate disciplinary focus that guides the content of the articles they contain. This compromises the value of the data for management purposes and any management group using such analyses should be made fully aware of this distinction. However, these analyses are not useless. Although a single definitive indicator will not usually exist, a more sophisticated 'framework' approach to indexing multiple interdisciplinarity for any one project could be informative, in tandem with expert review and interpretation for research evaluation.

Methodology

We recognise a distinction between research that brings disciplines together (multidisciplinary research, MDR) and research that has cross-disciplinary outcomes (interdisciplinary research, IDR). Our study compared indices of disciplinarity using metadata associated with (1) inputs (project grants) and (2) outputs (journal articles) and derived from (A) the multidisciplinary (MDR) nature of research teams (via address lists) and (B) the interdisciplinary (IDR) nature of research descriptions (via summary text and reference lists). The format (**Table 1**) is a two-way comparison between MDR and IDR analyses for each data source, and between sources for the MDR/IDR interaction (see Van den Besselaar and Heimeriks (2001), Technopolis and SPRU (2015) for related discussions about definitions of IDR, MDR and variant definitions).

A satisfactory index needs information on the variety of disciplines, their balance (or relative frequency) and their disparity (the 'distance' between them) (Stirling, 2007). Differences in content and structure between data sources could influence outcomes, so to improve consistency:

- Analyses focussed on the UK and similar research economies: (1) Anglophone group: Australia and Canada; and (2) European group: Germany, the Netherlands and Sweden.
- A common time period (2004-2013) was used insofar as possible.
- Data were aggregated at a common disciplinary level to ANZSRC divisional Fields of Research (FoRs: ANZSRC, 2008).
- In practice, investigator addresses proved too sparse so a third approach, publication text analysis, was added.

Readers unfamiliar with these data and methodologies may wish to refer to the main report at this point.

	Multidisciplinary (MD) research	Interdisciplinary (ID) research
Input funding - grant analyses carried out by Digital Science	Diversity of departmental addresses of principal co-investigators (PIs)	Textual analysis of project summaries
Output publications - article analyses carried out by Science-Metrix	Diversity of departmental addresses of co-authors	Categorical analysis of lists of cited references
Output publications – article analyses carried out by Digital Science		Textual analysis of article summaries

Table 1. Summary structure of the comparative analytical approach. Insufficient data coverage meant that the analysis of departmental addresses of co-investigators on grants could not be completed.

Results – overall field level

The outcomes described by the indicators listed in **Table 1** are inconsistent. **Table 2** summarises MDR and IDR indices for four analyses at the level of the ANZSRC Fields of Research (FoRs - ANZSRC, 2008) and for the aggregate data (i.e. the broadest possible overview using the maximum dataset). More results are described in the main report and an independent analysis of citing and cited papers in *Nature* reveals further disparity where a different categorical structure is used (Van Noorden, 2015).

Article reference analysis, probably the most widespread analytical approach in current usage (this was applied here by Science-Metrix to Thomson Reuters *Web of Science* data), is used to rank the results in Table 2. The table is a colour spectrum across banded quartiles of index values (specific values are not shown since the general lack of consistency suggests they carry spurious precision).

It is important to recognize there is interaction between the choice of data source, disciplinary variety and the specific outcomes of any analysis, and that this becomes more problematic for selective data sources: Thomson Reuters *Web of Science* data are richer and more fine-grained in science than social science and humanities; PubMed data are richer in bio-medical fields.

If the analysis is restricted to just the Thomson Reuters *Web of Science* data, and if the comparison is restricted to just the UK results and to just the most recent period, then the lack of consistency between the multidisciplinary address analysis and the interdisciplinary cited reference analysis becomes quite clear. Not only is there no statistically significant positive relationship between the two indices, but in fact the association is slightly but non-significantly negative.

In summary, the results are:

- Inequity in analytical coverage and information due to sparse data for article-based indicators outside STEM subjects.

Field of Research	Science–Metrix		Digital Science	
Medical & Health Sciences	0.20	0.03	0.07	0.02
Psychology & Cognitive Sciences	0.07	0.04	0.10	0.03
Biological Sciences	0.21	0.07	0.06	0.02
Physical Sciences	0.14	0.08	0.15	0.07
Education	0.06	0.09	0.23	0.15
Commerce, Mgt, Tourism & Services	0.08	0.09	0.12	0.04
Chemical Sciences	0.14	0.10	0.09	0.04
Mathematical Sciences	0.09	0.14	0.15	0.11
Environmental Sciences	0.17	0.16	0.19	0.07
Agricultural & Veterinary Sciences	0.14	0.18	0.13	0.07
Economics	0.05	0.20	0.19	0.08
Engineering	0.11	0.20	0.10	0.06
Earth Sciences	0.15	0.21	0.21	0.16
Studies In Human Society	0.05	0.21	0.10	0.10
Technology	0.17	0.22	0.06	0.04
Language, Communication & Culture	0.00	0.23	0.13	0.21
Studies In Creative Arts & Writing	0.01	0.25	0.15	0.19
Law & Legal Studies	0.02	0.27	0.23	0.19
Information & Computing Sciences	0.09	0.31	0.18	0.13
Philosophy & Religious Studies	0.01	0.34	0.30	0.18
History & Archaeology	0.03	0.40	0.06	0.16
Built Environment & Design	0.07	0.47	0.16	0.27

Table 2. Inconsistency in the relative index values given by analyses of interdisciplinarity of research clustered at the level of ANZSRC Division-level Fields of Research (FoR). Index values are colour-banded into quartiles within each indicator set (column): BLUE denotes lower index values in that set; RED denotes higher values.

- Negative association between index values for the article address analysis and the three other analyses.
- Disparities in the correlations between the other analyses. For example:
  - Both Technology and Language & Culture have extremely varied outcomes.
  - Environmental Sciences is interdisciplinary for article addresses and project grant text, but mono-disciplinary for article references and abstract text.

Contradiction between two indicators does not mean either are invalid. The central issue that emerges is uncertainty about the connection between the disciplinary diversity for metadata of associated components and the disciplinary diversity of the underpinning research activity.

- Address diversity may reflect knowledge brought to bear but refers only indirectly to objectives (e.g. solo researchers can be interdisciplinary; institutional structures vary).
- Project grant text abstracts are a close description of research activity but provide a limited data-volume for analysis, and full text is not always publicly available.
- Outputs (such as articles) contain content, notably reference lists, are 'tuned' (or adapted) by authors for specific journals (the same could be true for some monograph series).
- Article abstracts may better reflect research content than a 'tuned' reference list, but the concordance between article abstracts and article content has never been examined.

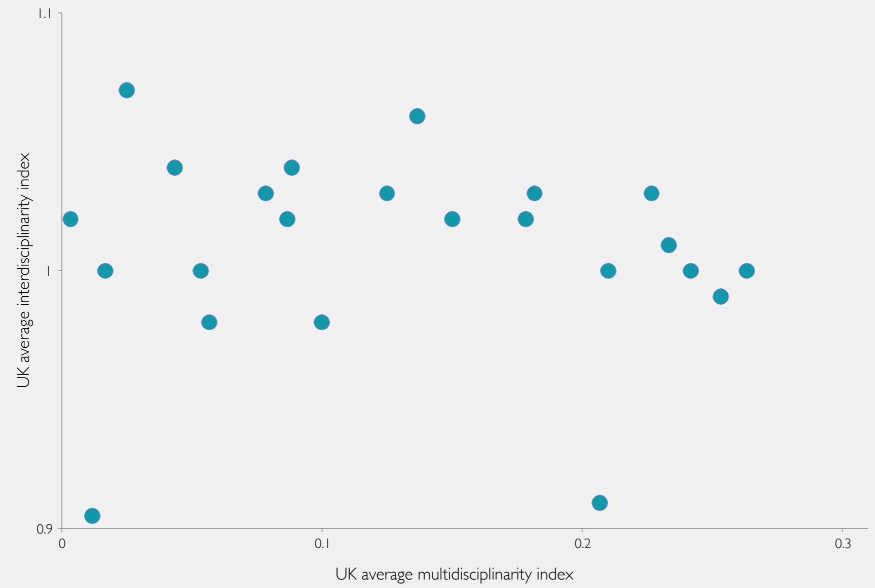

Figure 1. UK articles (2008-13) in Thomson Reuters *Web of Science*, aggregated at the ANZSCR FoR Division level. The graph compares the average MD author-address index and the average ID cited-reference index for the same pool of articles. The correlation is non-significant (r^2=0.003; data analysis by Science-Metrix).

Results – overall country level

The broad overview (**Table 2**) contains variance between countries. **Table 3** summarises the UK's IDR and MDR index values relative to the comparator countries, with Germany as a benchmark in volume and performance on e.g. citation indicators.

Generally, the UK tends to have a lower ID and MD index than other countries, though almost invariably a higher index value than Germany, but in some analyses it is closer to the average of the group. On the whole, UK index values rise over time, though not for every analysis, but such values similarly rise for most countries so these changes may in fact be due simply to universal factors buried in the data. One factor might be collaboration, and the UK is in fact highly collaborative as noted in the Digital Research Report on international collaboration trends (Adams and Gurney, 2016)

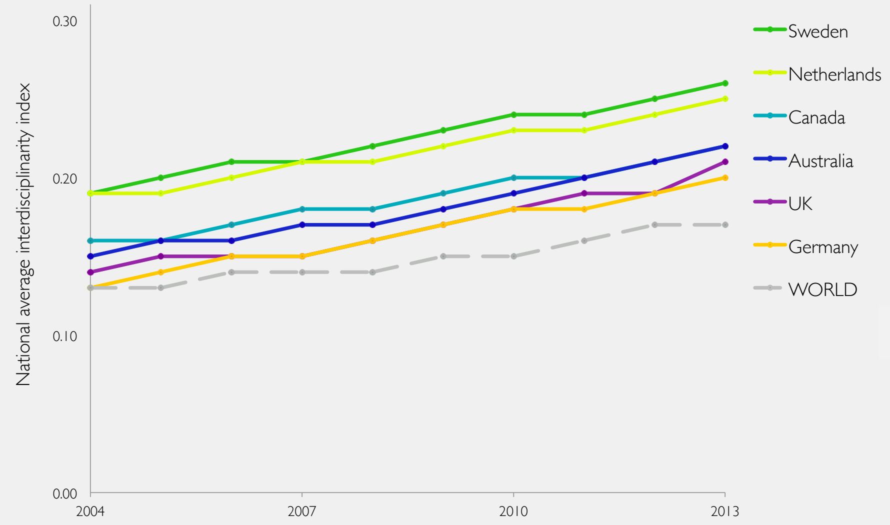

Figure 2. The trajectory of rising multidisciplinarity among author addresses for articles in Thomson Reuters *Web of Science* grouped and with average MD indices at country level (data analysis by Science-Metrix).

	Other countries	Trend
Research grants text	UK ID index similar to other EU countries and slightly better than Germany UK ID index lower than Australia and slightly better than Canada	No trend in EU data Slight rise over period in Anglophone data
Article addresses	UK MD index below other countries, except Germany, but all above world average	Steadily rising values for all countries over period
Article reference lists	UK ID index was above other countries but recently average though always above Germany	Steadily rising values for all countries over period
***Nature* citing and cited analysis**	UK ID index higher than Germany but lower than other countries	N/A

Table 3. Comparison of the MD and ID index values from different methodologies and datasets, for the UK compared to other countries, noting Germany as a comparator of similar volume and focus.

Results – UK field level

Inconsistency between fields in relative indicator values also arises when the data are analysed within countries. For example, UK Environmental Sciences index values are low but rising in Anglophone grant data, but high and erratic in the sparser EU grant data. Clearly, the specific data sample used for analysis influences the detailed outcome and it is essential to specify the precise context since no result can be assumed to be general.

The data across the different comparative approaches are richest, and therefore most likely to be robust against erratic annual changes and outliers, in the bio/medical Fields of Research (FoRs). **Table 4** reviews the UK's position in Biological Sciences and in Medicine & Health. This shows not only inconsistency in relative standing for these fields compared to other FoRs, but also variation in trend over the period. Furthermore, a deconstruction of medicine and health in the *Nature* analysis (Van Noorden 2015) reveals a disparity in outcome that is buried in the other analyses.

Table 4. Comparison of the MDR and IDR index values from different methodologies and datasets, for the fields of Biological Sciences and for Medicine & Health within the UK compared to other countries, noting Germany as a comparator of similar volume and focus.

Table 4. Comparison of the MDR and IDR index values from different methodologies and datasets, for the fields of Biological Sciences and for Medicine & Health within the UK compared to other countries, noting Germany as a comparator of similar volume and focus.

	Field ID results	Trend 2004-2013
Research grants text	Biology and Medicine/Health much lower ID than other fields	No trend for EU Rise in Anglophone data but overall trend may be due to just ICTS and Environmental
Article addresses	Biology and Medicine/Health higher MD than other fields; very similar ranking for Germany	Steadily rising values for all fields through period
Article reference lists	Biology and Medicine/Health low within main group around world average	No trend
PubMed article abstracts	Biology and Medicine/Health well below others at start but less so at end	Most Divisions steady but Biology rising steadily and Medicine/Health rising slightly
***Nature* citing and cited analysis**	Health high ID relative to other fields but Clinical Medicine relatively lower	N/A

The influence of data source and structure

Inconsistency in outcomes for different proxy indicators arise overall (**Table 2**), between comparator countries (**Table 3**), and for relative values across fields (**Table 4**, **Figure 1**). Specific variances can be related to individual datasets and to the choice of categorical structures. The specific datasets used here each have limitations. However, there is a generic disjunction between the metadata and the analytical purpose and there are confounding factors cutting across the analyses that are revealed by further review.

- **Associations between ID index values and both category volume and address count**: Article volume is growing globally as are the numbers of authors, their addresses, and their geographical spread. These variables affect frequency and disparity and thus interact with the structure of the network for address analysis. We must infer that the results are compromised until a more complete statistical analysis can demonstrate otherwise.
- **Publication data analysis**: The MD index increases with higher paper counts at category level. Countries with higher MD indices also have more addresses per paper. The rise of address count with time could account for the observed rise in MD values.
- **Article address analysis**: The MD index increases uniformly for all countries (Figure 2) and for all categories within the UK, Germany and Sweden. Such evenness may be associated with metadata changes, and requires further investigation to account for the variance such changes may cause.
- **Article reference list analysis**: The absolute ID index increases over time for all countries. There are no temporal changes in relative index values, e.g. for the UK and Germany, so the overall ID change is a global phenomenon. The volume of data also grows over time, so the observed increase in index values may be purely volume driven: further investigation is essential.
- **Article reference list analysis** also uses a relatively narrow slice of data, which might capture relative outlier records (albeit at a similar rate for each country), although tests show that varying the threshold for this slice has no exceptional influence. However, any narrow slice may tend covertly to capture or to exclude particular parts of the activity portfolio.
- **Data choices** made about source (e.g. Anglophone or EU grant data) and structure (e.g. FoR or NSF biomedical categories) affect outcomes. Methodological constraints may interact with data use and influence outcomes: reference lists are matched to an analytical database; match rates vary by discipline and affect matched data volume; outcomes vary by country due to journal use; and long reference lists are associated with higher ID index values (Campbell *et al.*, 2015).

Conclusions and recommendations

Article reference lists are a conventional analytical tool, but possibly the least satisfactory source of indicator data.

No single indicator of interdisciplinarity (either MDR or IDR) analysed here should, used alone, satisfy any stakeholder. They show diverse inconsistency - in terms of change over time, difference between disciplines and trajectory for countries - that raises doubts as to their specific relevance. Some cover only some disciplines adequately. Collectively they may be more informative, however, if they were used as a framework to support expert review.

No single indicator has yet been clearly associated with a peer assessment of the inter/disciplinarity of the underlying research. Such indicators fail a basic 'valid and equitable' requirement since they fail the test of mutual consistency across data sources and methods. Without analytical consistency it is unclear how to achieve peer consensus on what research is interdisciplinary.

Article reference lists are a conventional analytical tool, but possibly the least satisfactory source of indicator data. First, only STEM disciplines are supported by sufficient well-curated data to be properly addressed. Second, our analysis reveals a problematic association between index values and list length (i.e. data volume). Third, match rates, journal usage, and cultural factors may also affect analyses. Fourth, reference lists may not be objective representations of the underlying activity.

It is also unclear whether indices based on metadata are equitable for all research modes and all countries. For example:

- Blue-skies research and research near to application and impact do not necessarily exhibit the same structures, outputs and outcomes and cannot be assessed in the same way.
- Smaller EU countries have consistently different index values (in this study) that may be associated with the social culture of research in a smaller domestic community (and this observation could well extend to smaller and larger discipline categories).

Overall, our recommendations are that:

(1) Quantitative proxy indicators of interdisciplinarity based on research activity metadata should only be used in concert, for consistency checking, and should preferably be used in a framework that defines expectations and relationships.

(2) Any analyst of the inter/disciplinarity of research activity should set out clearly their interpretation of interdisciplinarity, the relevance of their particular metadata to that interpretation, and in that context the appropriateness (detail and scope) of their data source and analytical methodology.

(3) Text analysis for research proposals and journal articles, either as abstracts if necessary or preferably as full document text, should be explored as a potential indicator of the research activity.

Text is equally and equitably applicable to all subjects, which author counts and reference lists are not. An obvious source would be article texts, but these are most accessible for STEM subjects. Other publications (books, monographs and grey literature) are appropriate in other disciplines.

Comparison should be made between abstracts and full text, to see whether abstracts adequately reflect the content of the grant proposals and journal articles they represent.

(4) Research funders should, in their published award information, include the departmental affiliations of all principal investigator affiliations, to enable disciplinary diversity of research teams to be evaluated externally as well as internally.

Wagner *et al* (2011) suggested that 'combinations of quantitative measures and qualitative assessments being applied within evaluation studies appear to reveal [ID] processes but carry burdens of expense, intrusion, and lack of reproducibility year-upon-year … development is needed before metrics can adequately reflect the actual phenomenon of [ID]'.

This study wholly supports those conclusions, but we suggest that the more comprehensive internal access that funding bodies such as Research Councils have to their (often confidential) metadata may offer them an amenable route to a set of Wagner's 'combinations of measures' that would satisfy expert committees.

References

ABRC. (1987). A strategy for the science base, 50 pp. A discussion document for the Secretary of State for Education and Science. HMSO, London. ISBN 0 11 270627 4

Adams J and Gurney K A. (2016). The implications of international research collaboration for UK universities. Digital Research Report; Digital Science, London. ISBN 978 09 9294774 3

Aldrich J H. (2014). Interdisciplinarity: its role in a discipline-based academy. A report by the task force of the American political science association. Oxford University Press, Oxford. ISBN 978 19 933134 5

ANZSRC. (2008). See documentation at: http://www.abs.gov.au/ausstats/abs@.nsf/0/4AE1B46AE2048A28CA25741800044242?opendocument

Campbell D, Deschamps P, Côté G, Roberge G, Lefebvre C and Archambault É. (2015). Development of an "interdisciplinarity" metrics at the paper level and its application in a comparative analysis of the most publishing ERA and non-ERA universities. Proceedings of the 20th International Conference on Science and Technology Indicators

Chubin D E, Porter A L, Rossini F A and Connolly T. (1983). Indicators of interdisciplinary research. Report to the NSF Division of Science Resources Studies, grant no SRS-810566. National Science Foundation, Washington DC.

Elsevier. (2015). A review of the UK's interdisciplinary research using a citation-based approach. Report to the UK HE funding bodies and MRC.

Katz J S and Hicks D. (1995). The classification of interdisciplinary journals: a new approach. Pp 245-254, in, Koenig M and Bookstein A (eds). Proceedings of the 5th International conference on Scientometrics and Informetrics.

King's College London and Digital Science. (2015). The nature, scale and beneficiaries of research impact: an initial analysis of Research Excellence Framework (REF) 2014 impact case studies.

McLeish T B and Strang V. (2014). Leading interdisciplinary research: transforming the academic landscape. Leadership Foundation for Higher Education, London.

Porter A L and Chubin D E. (1985). An indicator of cross-disciplinary research. Scientometrics, 8, 161-176.

Porter A L and Rossini F A. (1985). Peer-review of interdisciplinary research proposals. Science, Technology and Human Values, 10, 33-38.

Rafols I, Leydesdorff L, O'Hare A, Nightingale P and Stirling A. (2012). How journal rankings can suppress interdisciplinary research: a comparison between innovation studies and business & management. Research Policy, 41, 1262-1282.

Rinia E J, van Leeuwen T N, van Vuren H G and van Raan A F J. (2001a). Influence of interdisciplinarity on peer-review and bibliometric evaluations in physics research. Research Policy, 30, 357-361.

Rinia E J, van Leeuwen T N, Bruins E E W, van Vuren H G and van Raan A F J. (2001b). Citation delay in interdisciplinary knowledge exchange. Scientometrics, 51, 293-309.

SUPRC (Scottish Universities Policy Research Consortium). (1997). Interdisciplinary research: process, structures and evaluation. SHEFC-funded regional strategic initiative.

Stirling A. (2007). A general framework for analysing diversity in science, technology and society. Journal of the Royal Society, Interface, 4, 707-719.

Strang V and McLeish T B. (2015). Evaluating interdisciplinary research: a practical guide. Durham University, Institute of Advanced Study.

Subramanyam K. (1983). Bibliometric studies of research collaboration. Journal of Information Science, 6, 33-38.

Technopolis and SPRU. (2016). Landscape Review of Interdisciplinary Research in the UK. Report to HEFCE and RCUK. http://www.hefce.ac.uk/pubs/rereports/Year/2016/interdis/Title,110229,en.html

Van den Besselaar P and Heimeriks G. (2001). Disciplinary, multidisciplinary, interdisciplinary: concepts and indicators. Pp 705-716, in, David M and Wilson C S (eds), Proceedings of the 8th International conference on Scientometrics and Informetrics. University of New South Wales, Australia.

Van Noorden R. (2015). Interdisciplinary research by the numbers. Nature, 525, 306-307. (Presents and discusses analyses by Vincent Lariviere and Cassidy Sugimoto).

Van Raan A F J. (2003). The use of bibliometric analysis in research performance assessment and monitoring of interdisciplinary scientific developments. Technikfolgenabschätzung – Theorie und Praxis, 12, 20-29.

Wagner C S, Roessner J D, Bobb K, Klein J T, Boyack K W, Keyton J, Rafols I and Börner K. (2011), Approaches to understanding and measuring interdisciplinary scientific research (IDR): A review of the literature. Journal of Informetrics, 165, 14–26.

DIGITAL science

Work smart. Discover more.

Part of the **Digital Science** family

readcube	BIORAFT
labguru	Altmetric
figshare	Overleaf
Dimensions	SYMPLECTIC Elements
GRID	TETRASCIENCE

digital-science.com