An Overview of Prior NCSES Work Related to Convergence

National Center for Science and Engineering Statistics

Social, Behavioral and Economic Sciences

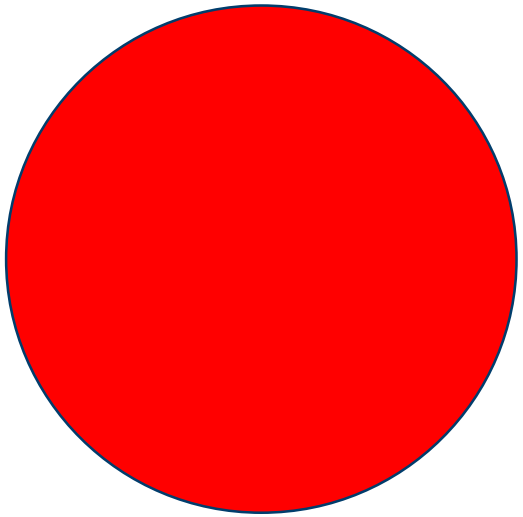
National Science Foundation

Overview

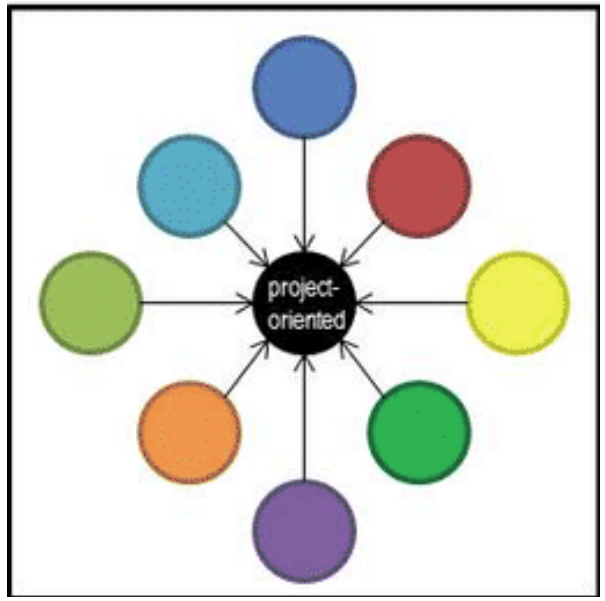
1. Background
2. Interdisciplinary Research and Taxonomies
3. Survey-based Measurement of Interdisciplinary R&D
4. Bibliometric Indicators and Interdisciplinary R&D
5. Takeaways

Definitions: From particular branches of knowledge to integration

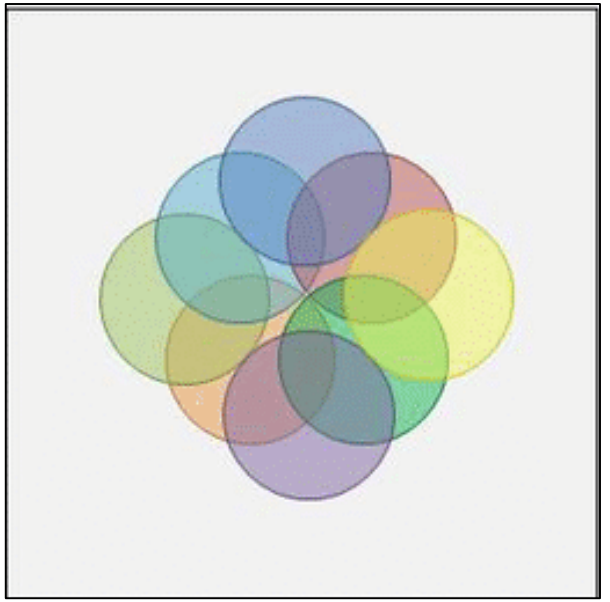
Unidisciplinarity



Multidisciplinarity

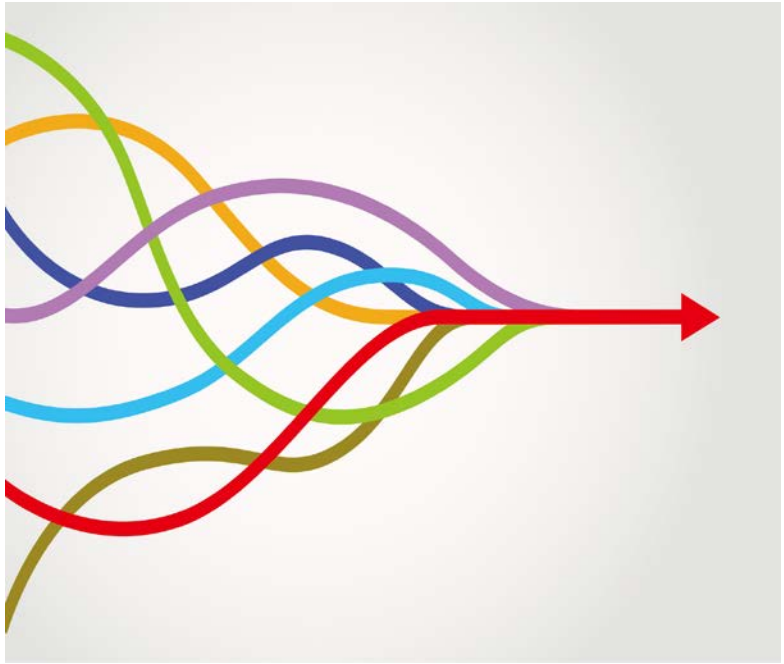


Transdisciplinarity



See National Academies (2014) Box 3-1 pp 44-45 for a complete set of definitions.

Deep integration across disciplines to tackle compelling scientific and societal challenges



Convergence

An approach to problem solving that cuts across disciplinary boundaries.

Deep integration across disciplines to tackle compelling scientific and societal challenges

National Academies (2014)

NCSES leaders provided insight on key questions

1) What has NCSES done that contributes to the measurement of convergence and its impact?
2) Are there any NCSES programs/experiments/pilots related to measuring convergence work that might be the base for workshop sessions?
3) Is the current working definition adequate for the creation of national indicators using current surveys and reports?
4) Are current methodological approaches for NCSES surveys and indicators appropriate for the measurement of convergence?
5) Are indicators based on non-survey techniques (e.g., bibliometrics/ scientometrics of citations, network analysis/modeling) adequate for assessing convergence research and its impact, and can/should NCSES seek to develop them?

NCSES work suggests importance of convergence measurement

- Recognition research is increasingly becoming problem oriented, so defining the value of interdisciplinary research is increasing in importance.
- Interdisciplinary research may be more important for societal impact than scientific impact.

Measurement of interdisciplinary R&D and taxonomies of fields of research

Workshop on the Classification of R&D and Interdisciplinary Research

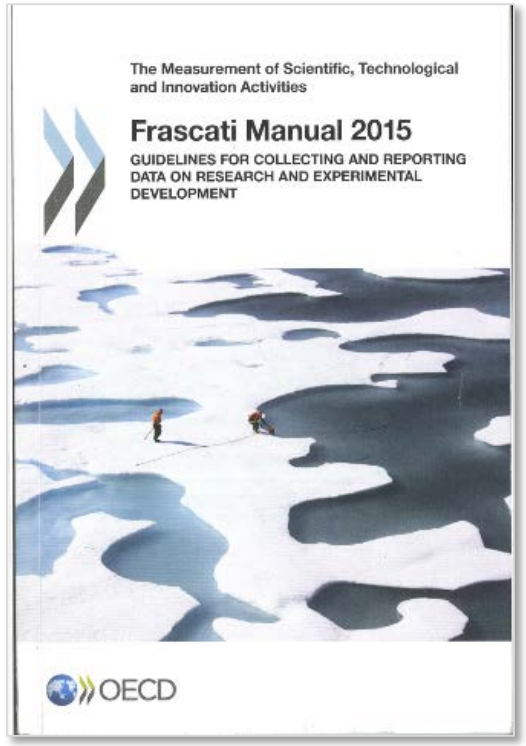
- Measurement: Top down; bottom up; hybrid
- Apportionment

Conclusions

1. Emerging fields of R&D and interdisciplinary R&D areas are difficult to detect, describe, and measure. Classification on the disciplinary fields of science may contribute to this difficulty.
2. Fields of R&D are composites of disciplinary inputs, research objectives or research problems, and deployment of technologies and production of technologies.
3. A pure discipline-based classification does not appear to provide the requisite complexity and flexibility to match the complexity of R&D activities. Exploration of novel approaches may be warranted.

Source: Christina Freyman and Jeffrey Alexander. 2012. Summary: Workshop on the Classification of R&D and Interdisciplinary Research. SRI International.

International guidance regarding interdisciplinary R&D and fields of research



The Frascati Manual: Guidelines for Collecting and Reporting Data on Research and Experimental Development

- Provides Fields of Research and Development to classify R&D-performing units and distribute their R&D resources according to the knowledge domain.
- Interdisciplinary R&D may be able to be reported by survey respondents in some sectors by using a combination particular fields of research.
- Experimental development in the businesses sector likely involves interdisciplinary technology areas and a combination of multiple fields that are not easily and individually identified. Because of such difficulties, this manual cannot specifically recommend such a breakdown of BERD across FORD fields.

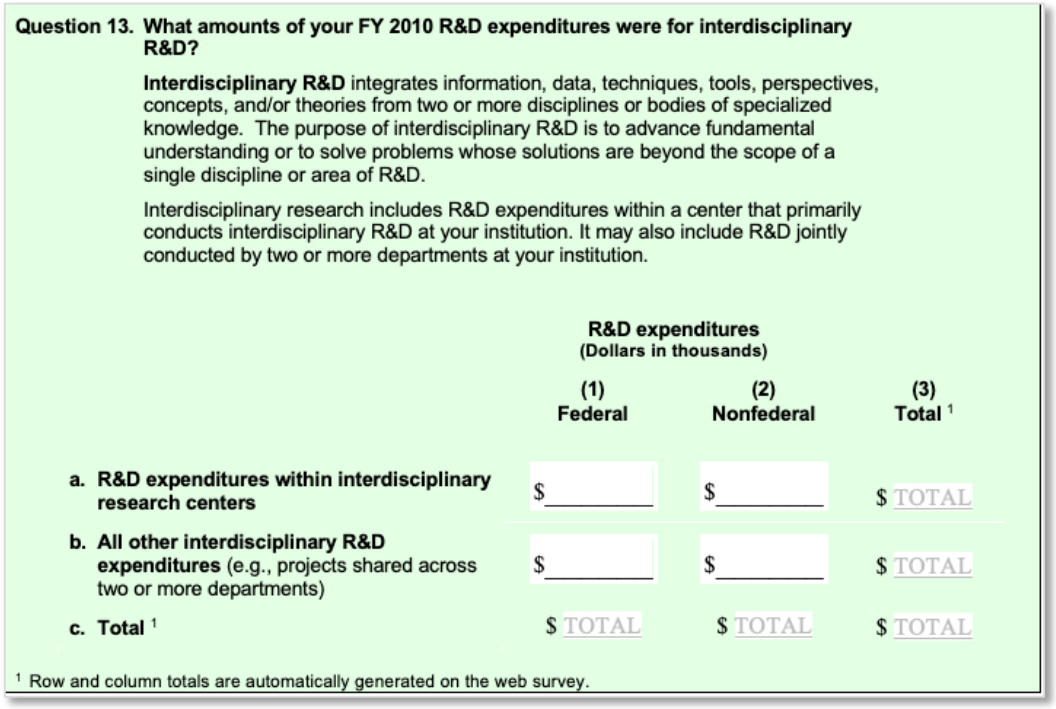
Source: OECD (2015), *Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development*, The Measurement of Scientific, Technological and Innovation Activities, OECD Publishing, Paris, https://doi.org/10.1787/9789264239012-en.

Surveys updated disciplines yet did not change classification of interdisciplinary R&D

- Revisions to the fields of R&D to report expenditures reflect the types of R&D currently being conducted at universities and colleges .
- Revisions make NCSES survey fields more consistent with the taxonomy used in other statistical agencies.
- Specific changes include the following:
  - Fields are listed in alphabetical order. The names of some fields have been revised to better reflect the disciplines included in those fields.
  - New disciplines have been added as examples under many fields.
  - Some disciplines have been reclassified under different fields.
  - Four new fields have been added.
- Classification of Interdisciplinary R&D remains unchanged.
  - **Other Sciences:** Use this category for R&D that involves at least one S&E field if it is impossible to report multidisciplinary or interdisciplinary R&D expenditures in specific fields.
  - **Other Non-S&E Fields**: Also, use this category for R&D that involves multiple non-S&E fields if it is impossible to report multidisciplinary or interdisciplinary R&D expenditures in specific fields

Source: Higher Education Research and Development Survey FY2016, https://www.nsf.gov/statistics/srvyherd/surveys/srvyherd_2016.pdf and Survey of Doctoral Recipients (2017 Cycle), https://www.nsf.gov/statistics/srvydoctoratework/overview.htm

HERD unable to produce consistent measurement of the concept



Question 13. What amounts of your FY 2010 R&D expenditures were for interdisciplinary R&D?

Interdisciplinary R&D integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge. The purpose of interdisciplinary R&D is to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of R&D.

Interdisciplinary research includes R&D expenditures within a center that primarily conducts interdisciplinary R&D at your institution. It may also include R&D jointly conducted by two or more departments at your institution.

	R&D expenditures (Dollars in thousands)		
	(1) Federal	(2) Nonfederal	(3) Total [1]
a. R&D expenditures within interdisciplinary research centers	$_____	$_____	$ TOTAL
b. All other interdisciplinary R&D expenditures (e.g., projects shared across two or more departments)	$_____	$_____	$ TOTAL
c. Total [1]	$ TOTAL	$ TOTAL	$ TOTAL

[1] Row and column totals are automatically generated on the web survey.

HERD Revision Process

Site Visits: In 2009 HERD underwent major revision. NCSES drafted interdisciplinary R&D questions based on site visits with more than 20 universities.

Pilot testing: Phone debriefings conducted with each of the 40 pilot respondents after they completed the survey.

Revised Questionnaire: 13 respondents - 4 pilot institutions and 9 additional institutions – completed a revised questionnaire.

Cognitive testing (13 respondents—4 from the pilot)

Conducted cognitive testing interviews by telephone with each of these 13 institutions.

Findings: Despite multiple attempts to operationalize the definition of interdisciplinary R&D, survey items on interdisciplinary R&D expenditures did not produce consistent measurements of the concept.

Higher education R&D surveys do account for interdisciplinary R&D

HERD respondents include measures interdisciplinary R&D expenditure in either individual or residual categories.

Other Sciences: Use this category for R&D that involves at least one S&E field if it is impossible to report multidisciplinary or interdisciplinary R&D expenditures in specific fields.

Other Non-S&E Fields: Also, use this category for R&D that involves multiple non-S&E fields if it is impossible to report multidisciplinary or interdisciplinary R&D expenditures in specific fields.

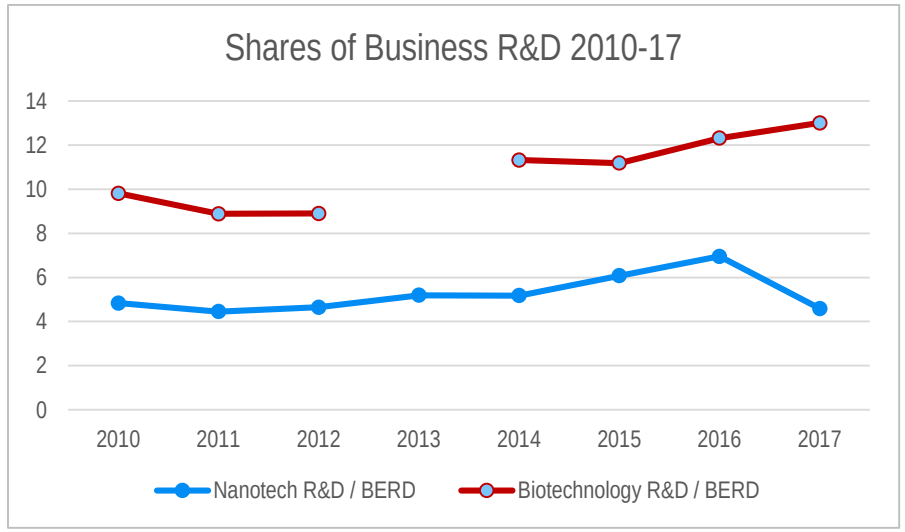
Some topics leveraged to produce international comparable data

5-11 **What percentage of the amount reported in Question 5-2 was for biotechnology?** For list-based definition see Question by Question Guidance at https://www.census.gov/programs-surveys/brds/information/brdshelp.html#q5-11

Biotechnology – The application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services.

5-12 **What percentage of the amount reported in Question 5-2 was for nanotechnology?** For list-based definition see Question by Question Guidance at https://www.census.gov/programs-surveys/brds/information/brdshelp.html#q5-12

Nanotechnology – The application of science and technology to organisms, organic and inorganic materials, as well as parts, products, and models thereof, at the nanometer-scale (but not exclusively below 1000 nanometers).



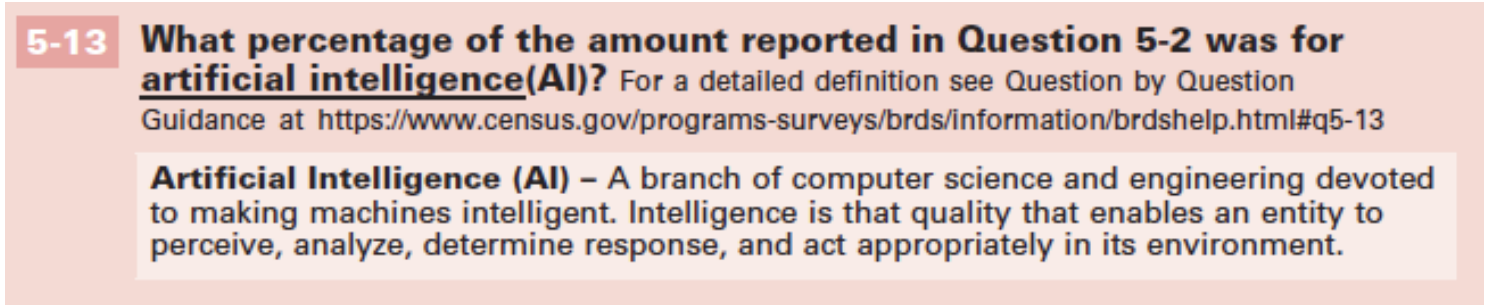
Source: OECD Key Biotechnology Indicators (https://www.oecd.org/sti/inno/keybiotechnologyindicators.htm), OECD Key Nanotechnology indicators (https://www.oecd.org/sti/nanotechnology-indicators.htm).

Companies with domestic R&D paid for by the company and others and performed by the company in the certain technology focus areas, by company size: 2017

Size of companies	Biotechnology R&D		Nanotechnology R&D	
	Companies (number)	Amount (Millions of U.S. Dollars)	Companies (number)	Amount (Millions of U.S. Dollars)
All companies (number of domestic employees)	1,772	51,637	867	18,237
Small companies (10-49)	853	2,908	411	581
Medium companies (50-249)	574	7,265	274	717
Large companies (250+)	345	41,465	182	16,937

Source: National Center for Science and Engineering Statistics, National Science Foundation. 2020. *Business Research and Development: 2017.* Detailed Statistical Tables NSF 20-311. Alexandria, VA. Available at https://ncses.nsf.gov/pubs/nsf20311/.

Some topics remain a work in progress



5-13 **What percentage of the amount reported in Question 5-2 was for artificial intelligence(AI)?** For a detailed definition see Question by Question Guidance at https://www.census.gov/programs-surveys/brds/information/brdshelp.html#q5-13

Artificial Intelligence (AI) – A branch of computer science and engineering devoted to making machines intelligent. Intelligence is that quality that enables an entity to perceive, analyze, determine response, and act appropriately in its environment.

5-13 What percentage of the amount reported in Question 5-2 was for artificial intelligence (AI)?

Artificial Intelligence (AI) – A branch of computer science and engineering devoted to making machines intelligent. Intelligence is that quality that enables an entity to perceive, analyze, determine response and act appropriately in its environment.

Systems with artificial intelligence perform functions including, but not limited to, speech recognition, machine vision, or machine learning:

Speech recognition transforms human speech into a format useful for computer applications (for example, a digital assistant)

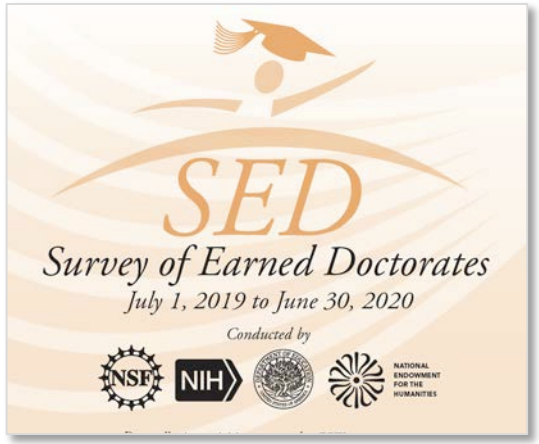
Machine vision uses sensors and software that allow images to be used as an input for computer applications (for example, systems that sort or inspect objects or support navigation in mobile equipment)

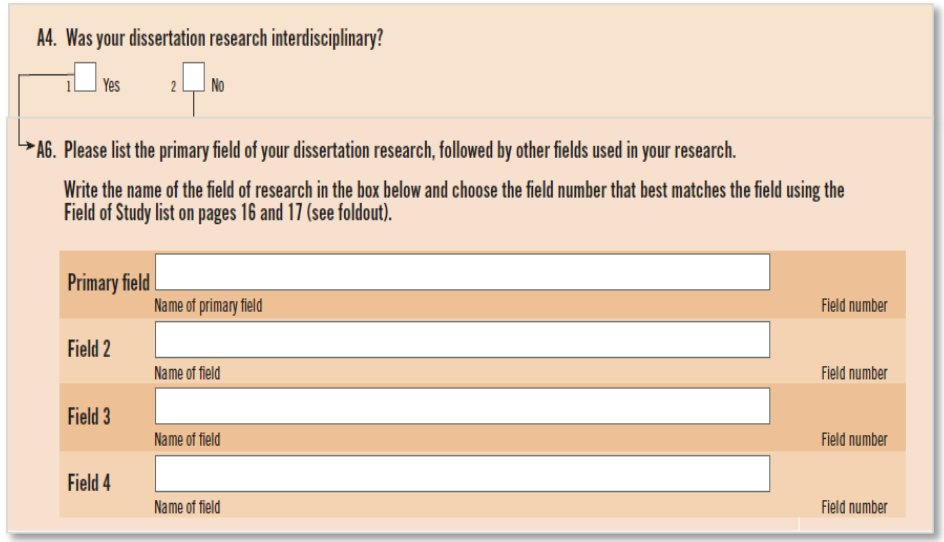
Machine learning uses statistical software and data to “learn” and make better predictions without reprogramming (for example, recommender systems for websites, or sales and demand forecasting)

Artificial Intelligence technologies also include virtual agents, deep learning platforms, decision management systems, biometrics, text analytics, and natural language generation and processing.

Include the total cost of an R&D project for AI in the calculation for this question, even if the project has other applications. This means that the percentages reported in Questions 5-10 through 5-13 could sum to more than 100%.

Measure interdisciplinary work by leveraging individual fields





Doctorate recipients who reported one or more dissertation research fields: 2001–18

Year	All doctorate recipients	Reported research field		Reported 2 or more research fields[a]		Research fields reported		
		Number	% all recipients	Number	% reporting field	Two	Three	Four
2001	40,744	37,326	91.6	8,969	24.0	8,969	na	na
2002	40,031	36,277	90.6	10,234	28.2	10,234	na	na
2003	40,762	37,101	91.0	10,273	27.7	10,273	na	na
2004	42,122	38,231	90.8	10,652	27.9	9,976	401	275
2005	43,385	39,191	90.3	11,757	30.0	10,915	568	274
2006	45,620	41,190	90.3	11,505	27.9	10,663	557	285
2007	48,132	43,367	90.1	12,289	28.3	11,433	565	291
2008	48,776	44,110	90.4	12,666	28.7	12,052	421	193
2009	49,552	44,957	90.7	13,056	29.0	12,436	384	236
2010	48,028	43,831	91.3	14,313	32.7	11,530	1,920	863
2011	48,910	44,378	90.7	15,415	34.7	12,908	1,766	741
2012	50,943	45,937	90.2	17,347	37.8	15,885	1,015	447
2013	52,703	47,422	90.0	18,737	39.5	18,032	473	232
2014	53,989	47,880	88.7	18,600	38.8	12,329	4,422	1,849
2015	54,889	48,678	88.7	18,946	38.9	11,658	5,224	2,064
2016	54,798	48,978	89.4	21,915	44.7	16,352	4,433	1,130
2017	54,559	48,603	89.1	18,603	38.3	13,366	3,955	1,282
2018	55,195	49,485	89.7	17,808	36.0	12,724	3,889	1,195

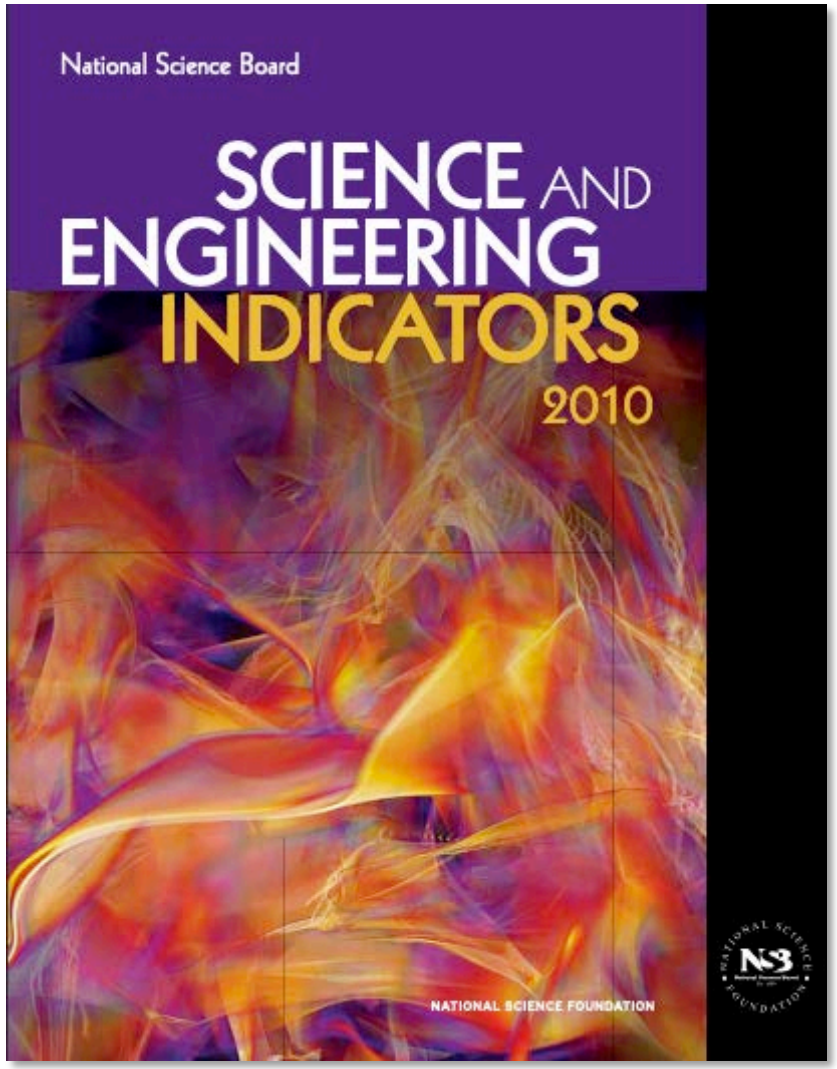
SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Earned Doctorates.

Microdata analysis leveraging NCSES Human Resources Surveys

- Millar MM, Dillman DA. 2012. *Trends in Interdisciplinary Dissertation Research: An Analysis of the Survey of Earned Doctorates.* Working Paper NCSES 12-200. Arlington, VA: National Science Foundation, National Center for Science and Engineering Statistics. Available at http://www.nsf.gov/statistics/ncses12200/.

- Kniffin KM, Hanks AS, Xuechao Q, Wang B, and Weinberg BA. 2020. *Dissertators with Distantly Related Foci Face Divergent Near-Term Outcomes.* NBER Working Paper No. 27825. Available at https://www.nber.org/papers/w27825.pdf.

SEI 2010 presented research panel findings



Can bibliometric data provide accurate indicators of interdisciplinary research?

- Indicators of interdisciplinary research based solely on bibliometrics unsatisfactory for management and policy purposes (SEI 2010).
- Premature to identify one or a small set of indicators or measures of interdisciplinary research (SEI 2010).

Status of NCSES efforts:

- This is a key area of bibliometrics that is monitored and tracked on ongoing basis.
  - Unidimensional measures do not measure diversity of knowledge output.
  - High levels of aggregation yield inconsistent results
  - Benefits of interdisciplinarity are not monotonically increasing.
- Interdisciplinary research may be more important for societal impact than scientific impact.

Science and Engineering indicators 2010

Can Bibliometric Data Provide Accurate Indicators of Interdisciplinary Research?

To address the need for indicators of interdisciplinary research (IDR), NSF/SRS commissioned a panel of researchers* to review recent attempts to measure the growth of interdisciplinary S&E research. The panel reviewed 74 publications dealing with IDR. It concluded that, despite increased study of IDR in the literature, existing indicators of IDR based solely on bibliometric data were unsatisfactory for management and policy purposes and relied on an overly simplistic concept of IDR (Wagner, Roessner, and Bobb 2009; Wagner et al. 2009). The panel also found that problems with current data sources and analytical techniques raise questions about the validity of these measures.

The panel concluded that conceptualization of IDR involves both the *outputs* of research and research *processes*: it stressed that both social developments (e.g., new S&E working relationships, new career trajectories, new institutions) and cognitive developments (e.g., new theory, new ways of using existing data, new problem frameworks) are essential markers of IDR. Bibliometric data alone do not capture these dimensions of IDR.

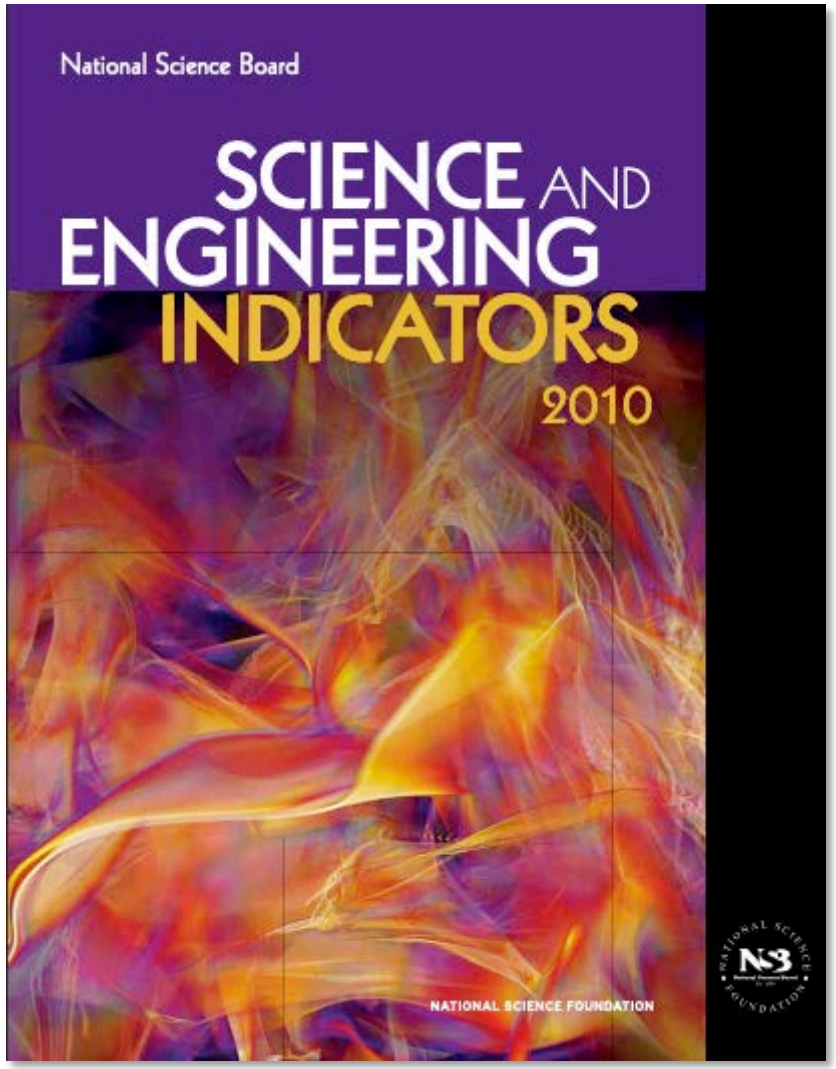
The panel identified an emerging consensus that studies of IDR need measures of *knowledge integration* that could be applied to the work of either a team of researchers or an individual. However, they found limited agreement on what such integration entails and even less agreement on what would count as evidence of it.

The panel also assessed the limitations of current attempts at measurement of IDR, most of which use Thomson Reuters data products. These are organized into a structure based on the discipline of the *journal* in which articles are published. Studies then measure the "cognitive distance" reflected by the diversity of citations in their target data (authors, articles, journals) from the Thomson Reuters journal structure and treat this distance as the measure of IDR.

Alternative analytical techniques are under development. These use statistical and visualization techniques that seek to detect certain hidden structures in the data that may indicate IDR. However, these techniques still require validation. Bibliometric measures will also need to be supplemented by survey data, ethnographic studies, expert review, and other evidence to confirm the degree of interdisciplinarity in research output. Indicators of IDR may also vary depending on user needs. For example, measurements of IDR appropriate for projects, programs, and nations are likely to be different. The panel summarized its conclusions as follows (Wagner, Roessner, and Bobb 2009, p 9-10, 16):

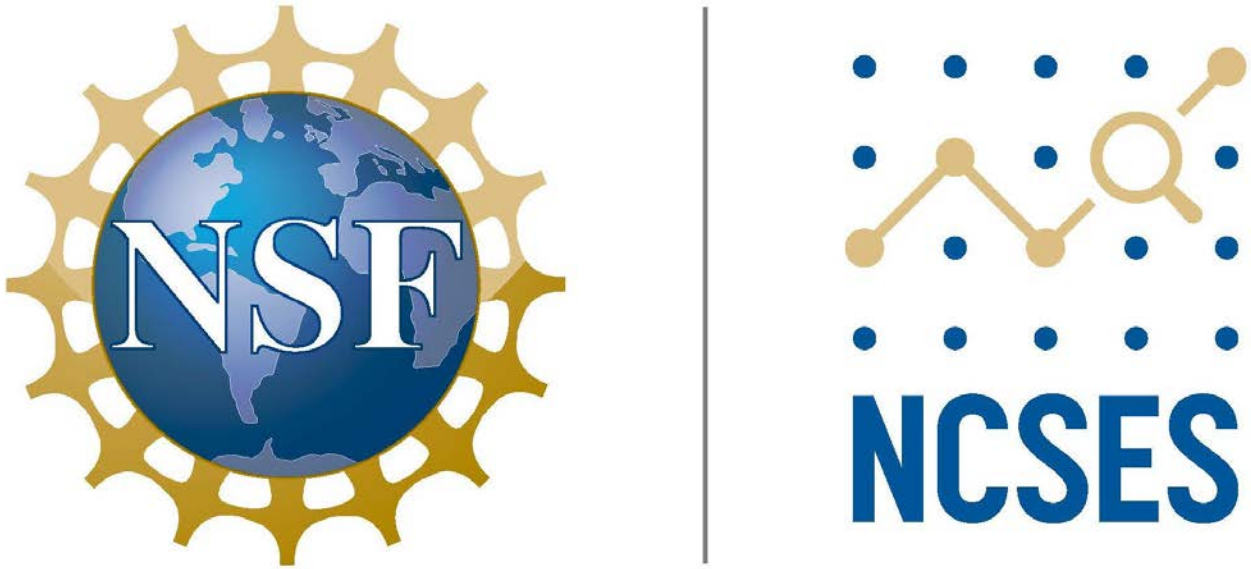
- The Panel's consensus…is that it is premature to identify one or a small set of indicators or measures of interdisciplinary research…in part, because of a lack of understanding of how current attempts to measure IDR conform to the actual process and practice of interdisciplinary research, and the outcomes resulting from that practice.
- The literature is rich and maturing, but has not reached a point that permits meaningful assessment of IDR, especially for public policy and research management purposes.

*The assessment was performed by three researchers at SRI International, Caroline S. Wagner, J. David Roessner, and Kamau Bobb, working with the following experts on interdisciplinarity and visualization: Katy Börner, Indiana University; Kevin W. Boyack, SciTech Strategies, Inc.; Joann Keyton, North Carolina State University; Julie Thompson Klein, Wayne State University; and Ismael Rafols, University of Sussex. These eight researchers are referred to as the "panel" in this sidebar.



Insights from previous NCSES activities related to interdisciplinary R&D

- Assessing the potential of measuring convergence research activities continue to be an important activity.
- There has been success measuring particular topics related to convergence.
  - NCSES Business R&D Surveys.
  - Hybrid of Top down/Bottoms up approaches successful at other agencies.
  - NCSES exploratory activities leveraging topic modelling to examine pandemics and COVID-19.
- Building measures of convergence from traditional discipline-based taxonomies may be possible.
  - Used in NCSES human resources statistic.
  - Recommended approach according to international guidance.



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