A Comparative Study of Interdisciplinarity in Sciences in Brazil, South Korea, Turkey, and USA

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A comparative study is done of interdisciplinary citations in 2013 between physics, chemistry, and molecular biology, in Brazil, South Korea, Turkey, and USA. Several surprising conclusions emerge from our tabular and graphical analysis: The cross-science citation rates are in general strikingly similar, between Brazil, South Korea, Turkey, and USA. One apparent exception is the comparatively more tenuous relation between molecular biology and physics in Brazil and USA. Other slight exceptions are the higher amount of citing of physicists by chemists in South Korea, of chemists by molecular biologists in Turkey, and of molecular biologists by chemists in Brazil and USA. Chemists are, by a sizable margin, the most cross-science citing scientists in this group of three sciences. Physicist are, again by a sizable margin, the least cross-science citing scientists in this group of three sciences. In all four countries, the strongest cross-science citation is from chemistry to physics and the weakest cross-science citation is from physics to molecular biology. Our findings are consistent with a V-shaped backbone connectivity, as opposed to a Δ connectivity, as also found in a previous study of earlier citation years.

I. INTRODUCTION

While interdisciplinarity is currently much vaunted as the scientific mode of operation, intense specialization in any one field or, in fact, topic may run counter to cross-disciplinary efforts. Another characteristic of current science is the burgeoning of a multicontinental multicenter research environment, which brings the question of whether different regional, historical and current, academic traditions affect the conduct of scientific research. We have investigated simultaneously both of these issues, by conducting a comparative study between the Brazil, South Korea, Turkey, and USA, as to the cross-referencing between published research papers in chemistry, molecular biology, and physics. Our interdisciplinary and academic intercultural findings, based on collected data, are surprising on both of the mentioned issues.

Our study involves cross-disciplinary citations between fields A and B, where A and B are chemistry, molecular biology, and physics, a priori deemed derivatively connected basic sciences, in articles published in a set of major journals (Tables I-III) in each field in the year 2013. The study is repeated for Brazil, South Korea, USA, and Turkey. These countries were chosen because of the dominance in scientific research of the USA, and the rapid development of the transcontinentally and mutually distant Brazil, South Korea, and Turkey. Our study was inspired by Ref.[1], where the cross-citation network between fields is studied for earlier years, without distinguishing with respect to country. Similar studies have been made for the citation network between different journals in the same field [2] and on the relevance of cross-science citations [3]. Detailed intercultural comparative studies are in Refs.[4–7].

II. METHODOLOGY

In our study, 67, 33, 22 journals (Tables I-III), respectively in chemistry, molecular biology, physics, were used. Of these, 46, 8, 17 journals (emphasized in Tables I-III) were searched for cross-science citing publications as described below and yielded 958, 26, 159 cross-science citing publications, given to 116, 199, 161 journals. Thus, 7696, 138, 756 cross-science citations were given from respectively chemistry, molecular biology, physics, by authors with institutional addresses in Brazil, Turkey, South Korea, or USA. These cross-science citations were given as 777, 2649, 5164 to respectively chemistry, molecular biology, physics. In these, publications with author addresses from more than one of our studied countries were not included. Thus, a total of 8590 cross-science citations entered our study.

In order to effectively compare the citation practices from each country, the pool of sample publications in each science must be as similar as possible between the countries. The number of publications by Brazilian, South Korean, and USA scientists in 2013 exceeds those by Turkish scientists in most, but not all, of the selected chemistry, molecular biology, and physics journals (Tables I-III). Therefore, the sample size of Brazilian, South Korean, and USA papers was equalized to the number of Turkish papers published in 2013: The Brazilian, South Korean, and USA publications in each journal were ordered chronologically. Then, in each journal, the used pool of publications was chronologically expanded equally both ways starting from the median publication until the number of publications was equalized to that of Turkish publications in the same journal in 2013. For example, there are 17 papers published by Turkish physicists in the Physical Review A in 2013. Thus, the chronologically median publications in Physical Review A in 2013 by Brazilian, South Korean, and USA physicists

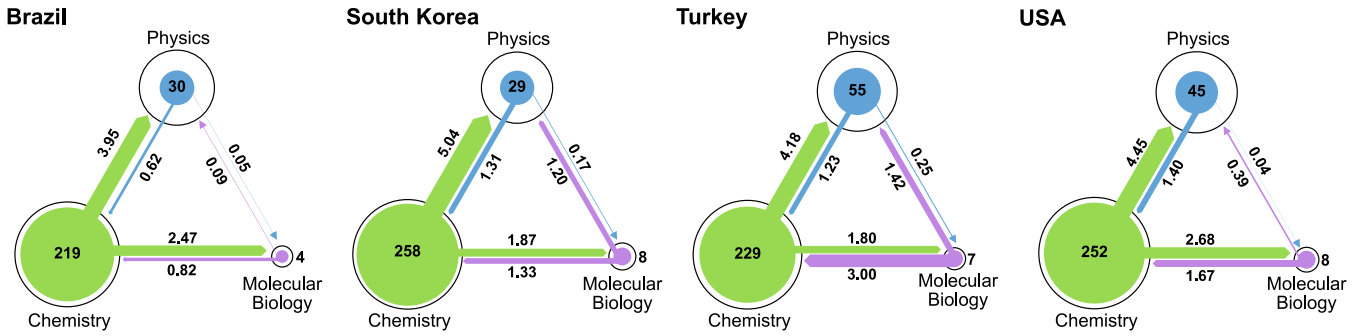

FIG. 1: Interdisciplinary citations given in 2013, as described in the text, between chemistry, molecular biology, and physics, in Brazil, South Korea, Turkey, and USA. The direction of each arrow is from the field giving citations towards the field being cited. The width of each arrow is proportional to the average number of such citations per publication, also written next to the arrow. In a given field, approximately the same number of publications is used for each country. Thus, the area inside the drawn circle is proportional to the total number of publications in the pool. For each country and each field, the area of the colored circle is proportional to the total number of papers giving such cross-science citations, also written inside or next to the colored circle.

were found and the pool was expanded equally in both chronological direction until there were 17 papers in the pool from each country. In several cases, the number of Turkish publications in a given journal exceeded the number of Brazilian, South Korean, or USA publications. In these instances, the pool of Turkish publications was not decreased and all of the Brazilian, South Korean, or USA publications were included.

The same pool of publications, for each country and each science, was used for determining the citation flow from this science to each of the two other sciences. For instance, there were 158 physics publications by Turkish authors in the selected journals. This same set of 158 papers was used to determine the average number, per publication, of citations to chemistry and to molecular biology. The standard deviation was also determined. When calculating the average and the standard deviation, citations to all publications in the other science are of course included, regardless of the country of the publication receiving the citation. The results are given in Fig. 1 and Tables IV-VI.

III. RESULTS AND DISCUSSION

In Fig. 1, for each country and each science, the area of the colored circles is proportional to the total number of publications giving cross-science citations to the two other sciences, also given numerically inside or next to the colored circles. The area inside the drawn circles is proportional to the total number of publications considered. Therefore, as explained above, for each field the latter areas are similar, but not strictly equal, between the countries. The widths of the arrows are in turn proportional to the average number of citations, per publication, from the field they originate to the field they are pointing. The corresponding numerical data are given next to the arrows and in Tables IV-V.

Several surprising conclusions emerge from these data: 1) The cross-science citation rates are in general strikingly similar, between Brazil, South Korea, Turkey, and USA. Thus, the common problems, methodology, instant communications, and personal mobility in a given science appears to have transcended geographically widely separated regional cultures. 2) One apparent exception to the above is the comparatively more tenuous relation between molecular biology and physics in Brazil and USA. Other slight exceptions are the higher amount of citing of physicists by chemists in South Korea, of chemists by molecular biologists in Turkey, and of molecular biologists by chemists in Brazil and USA. From both items here, it is seen that Brazil and USA are following a similar (Western Hemisphere) track. 3) Chemists are, by a sizable margin, the most cross-science citing scientists in this group of three sciences. Physicist, although reputed to be more generalists, are, again by a sizable margin, the least cross-science citing scientists in this group of three sciences. (Fig.1 and Table VI) 4) In all four countries, the strongest cross-science citation is from chemistry to physics and the weakest cross-science citation is from physics to molecular biology. 5) Our findings are consistent with a V-shaped backbone connectivity, as opposed to a Δ connectivity, consistently with what was found for earlier citation years in Ref.[1].

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[1] Maps of random walks on complex networks reveal community structure, M. Rosvall and C. T. Bergstrom, Proc. Nat. Acad. Sci. **105** (4) 1118-1123 (2008).

[2] Exploring the astronomy literature landscape, E. A. Henneken, A. Accomazzi, M. J. Kurtz, C. S. Grant, D. Thompson, E. Bohlen, S. S. Murray, M. Rosvall, and C. Bergstrom, in Astronomical Data Analysis Software and Systems XVIII, Eds. D. A. Bohlender, D. Durand, and P. Dowler, **411**, 384-387 (2009).

[3] The transmission sense of information, C. T. Bergstrom and R. Rosvall, Biol. Philos. **26**, 159176 (2011).

[4] Centres and Peripheries: Research Styles and Publication Patterns in 'Top' US Journals and their European Alternatives, 1960-2010, B. Üsdiken, J. Management Studies **51**, 764-789 (2014).

[5] International influence in science: beyond center and periphery, T. Schott, Social Science Research **17**, 21938 (1988).

[6] Ties between center and periphery in the scientific world-system: accumulation of rewards, dominance and self-reliance in the center, T. Schott, J. World-Systems Research **4**, 112144 (1988).

[7] International Collaboration in Multilayered Center-Periphery in the Globalization of Science and Technology, K. Hwang, Science Technology Human Values **33**, 101-133 (2008).

Analytical Chemistry	
Analyst	***J. American Society for Mass Spectrometry***
Analytica Chimica Acta	***Journal of Chromatography A***
Analytical and Bioanalytical Chemistry	***Sensors and Actuators B - Chemical***
Analytical Chemistry	***Talanta***
Electroanalytical Chemistry	
Applied Chemistry	
ACS Combinatorial Science	***Journal of Agricultural and Food Chemistry***
Dyes and Pigments	Journal of Combinatorial Chemistry
Food Chemistry	***Microporous and Mesoporous Materials***
Food Hydrocolloids	Molecular Diversity
Inorganic Chemistry	
Advances in Inorganic Chemistry	***Journal of Inorganic Biochemistry***
Dalton Transactions	Journal of Solid State Chemistry
European Journal of Inorganic Chemistry	Organometallics
Journal of Biological Inorganic Chemistry	
Multidisciplinary Chemistry	
ACS Nano	Journal of Controlled Release
Angewandte Chemie - International Edition	***Journal of the American Chemical Society***
Chemical Science	***Tetrahedron - Asymmetry***
Energy and Environmental Science	
Organic Chemistry	
Advanced Synthesis and Catalysis	***European Journal of Organic Chemistry***
Bioconjugate Chemistry	***Journal of Organic Chemistry***
Biomacromolecules	***Organic and Biomolecular Chemistry***
Current Organic Chemistry	***Organic Letters***
Physical Chemistry	
ACS Catalysis	***Faraday Discussions***
Advanced Energy Materials	***Journal of Catalysis***
Advanced Functional Materials	***Journal of Chemical Theory and Computation***
Advanced Materials	***Journal of Physical Chemistry B***
Advances in Colloid and Interface Science	***Journal of Physical Chemistry C***
Catalysis Science and Technology	***Journal of Physical Chemistry Letters***
ChemCatChem	***Langmuir***
Chemistry of Materials	***Physical Chemistry Chemical Physics***
Colloids and Surfaces B - Biointerfaces	Structure and Bonding
Polymer Science	
Advances in Polymer Science	Macromolecular Rapid Communications
Carbohydrate Polymers	***Macromolecules***
Journal of Membrane Science	Plasma Processes and Polymers
Journal of Polymer Science A - Polymer Chemistry	***Polymer Chemistry UK***
Macromolecular Bioscience	***Soft Matter***

TABLE I: The 67 chemistry journals listed in this Table were used, for 2013, in our study. Cross-disciplinary citations between chemistry, molecular biology, and physics, from Brazil, South Korea, Turkey, and USA, were searched from the 46 journals emphasized by bold italics, as described in Sec.II.

General Molecular Biology	
Biochimica Biophysica Acta: Molecular Cell Research	Molecular and Cellular Biology
Cell	***Molecular and Cellular Proteomics***
Journal of Molecular Biology	Molecular Biology of the Cell
Molecular Microbiology	Molecular Plant
Molecular Cell	***Oncogene***
Molecular Biology and Evolution	***PLoS Computational Biology***
Molecular Aspects of Medicine	***PLoS Genetics***
EMBO Journal	Structure
EMBO Reports	
Biochemistry and Biophysics	
ACS Chemical Biology	***Journal of Biological Chemistry***
Acta Crystallographica D: Biological Crystallography	J. Proteins: Structure, Function, Genetics
Biochemical Journal	Journal of Structural Biology
Biophysical Journal	Nature Chemical Biology
FASEB Journal	Nature Structural and Molecular Biology
Journal of Applied Crystallography	New Phytologist
Biotechnology and Biomaterials	
Bio Materials	Nature Biotechnology
Biotechnology Advances	Nature Methods

TABLE II: The 33 molecular biology journals listed in this Table were used, for 2013, in our study. Cross-disciplinary citations between chemistry, molecular biology, and physics, from Brazil, South Korea, Turkey, and USA, were searched from the 8 journals emphasized by bold italics, as described in Sec.II.

Journal	Topic
European Physical Journal A	Hadrons and Nuclei
European Physical Journal B	Condensed Matter and Complex Systems
European Physical Journal C	Particles and Fields
European Physical Journal D	Atomic, Molecular, Optical and Plasma Physics
European Physical Journal E	Soft Matter and Biological Physics
European Physical Journal H	Historical Perspectives on Contemporary Physics
European Physical Journal AP	Applied Physics
European Physical Journal ST	Special Topics
European Physical Journal PLUS	Archiving and Documentation
Europhysics Letters	General Interest Impact
Physica A	Statistical Mechanics and its Applications
Physica B	Condensed Matter
Physica C	Superconductivity and its Applications
Physica D	Nonlinear Phenomena
Physica E	Low-dimensional Systems and Nanostructures
Physical Review A	Atomic, Molecular, and Optical Physics
Physical Review B	Condensed Matter and Materials Physics
Physical Review C	Nuclear Physics
Physical Review D	Particles, Fields, Gravitation, and Cosmology
Physical Review E	Statistical, Nonlinear, and Soft Matter Physics
Physical Review X	Cross-Topic, Cross-Field, Cross-Disciplinary
Physical Review Letters	General Interest Impact

TABLE III: The 22 physics journals listed in this Table were used, for 2013, in our study. Cross-disciplinary citations between chemistry, molecular biology, and physics, from Brazil, South Korea, Turkey, and USA, were searched from the 17 journals emphasized by bold italics, as described in Sec.II.

Cross-Science (CS) Citation from Science A to Science B	No. of Sci. A Papers Considered	No. of CS Citing Sci. A Papers	Ratio Sci. A CS Citing/ Considered	CS Cit. per Sci. A Paper	CS Cit. Standard Deviation	No. of CS Cited Sci. B Papers
Brazil						
Chemistry to M. Biology	272	144	0.5294	2.4743	5.1083	673
Chemistry to Physics	272	144	0.5294	3.9485	7.1090	1074
M. Biology to Chemistry	11	3	0.2727	0.8182	1.4025	9
M. Biology to Physics	11	1	0.0909	0.0909	0.2875	1
Physics to Chemistry	140	30	0.2143	0.6214	2.3612	87
Physics to M. Biology	140	3	0.0214	0.0500	0.3841	7
South Korea						
Chemistry to M. Biology	295	138	0.4678	1.8712	3.2443	552
Chemistry to Physics	295	179	0.6068	5.0373	7.7048	1486
M. Biology to Chemistry	15	6	0.4000	1.3333	3.6998	20
M. Biology to Physics	15	4	0.2667	1.2000	2.6128	18
Physics to Chemistry	126	27	0.2143	1.3095	3.3129	165
Physics to M. Biology	126	4	0.0317	0.1746	1.3515	22
Turkey						
Chemistry to M. Biology	293	152	0.5188	1.7986	2.9229	527
Chemistry to Physics	293	146	0.4983	4.1809	8.1105	1225
M. Biology to Chemistry	12	7	0.5833	3.0000	3.5355	36
M. Biology to Physics	12	4	0.3333	1.4167	2.4650	17
Physics to Chemistry	158	55	0.3481	1.2278	2.5256	194
Physics to M. Biology	158	1	0.0063	0.2468	3.0928	39
USA						
Chemistry to M. Biology	307	158	0.5147	2.6808	4.8531	823
Chemistry to Physics	307	174	0.5668	4.3518	8.4530	1336
M. Biology to Chemistry	18	7	0.3889	1.6667	2.5197	30
M. Biology to Physics	18	4	0.2222	0.3889	0.8085	7
Physics to Chemistry	168	44	0.2619	1.4048	3.4645	236
Physics to M. Biology	168	4	0.0238	0.0357	0.2413	6

TABLE IV: Cross-science citations between chemistry, molecular biology, and physics, grouped by country.

Cross-Science (CS) Citation from Science A to Science B	No. of Sci. A Papers Considered	No. of CS Citing Sci. A Papers	Ratio Sci. A CS Citing/ Considered	CS Cit. per Sci. A Paper	CS Cit. Standard Deviation	No. of CS Cited Sci. B Papers
	Chemistry	to M. Biology,	M. Biology to	Chemistry		
Brazil	272, 11	144, 3	0.5294, 0.2727	2.4743, 0.8182	5.1083, 1.4025	673, 9
South Korea	295, 15	138, 6	0.4678, 0.4000	1.8712, 1.3333	3.2443, 3.6998	552, 20
Turkey	293, 12	152, 7	0.5188, 0.5833	1.7986, 3.0000	2.9229, 3.5355	527, 36
USA	307,18	158, 7	0.5147, 0.3889	2.6808, 1.6667	4.8531, 2.5197	823, 30
	M. Biology	to Physics,	Physics to	M. Biology		
Brazil	11, 140	1, 3	0.0909, 0.0214	0.0909, 0.0500	0.2875, 0.3841	1, 7
South Korea	15, 126	4, 4	0.2667, 0.0317	1.2000, 0.1746	2.6128, 1.3515	18, 22
Turkey	12, 158	4, 1	0.3333, 0.0063	1.4167, 0.2468	2.4650, 3.0928	17, 39
USA	18, 168	4, 4	0.2222, 0.0238	0.3889, 0.0357	0.8085, 0.2413	7, 6
	Physics	to Chemistry,	Chemistry to	Physics		
Brazil	140, 272	30, 144	0.2143, 0.5294	0.6214, 3.9485	2.3612, 7.1090	87, 1074
South Korea	126, 295	27, 179	0.2143, 0.6068	1.3095, 5.0373	3.3129, 7.7048	165, 1486
Turkey	158, 293	55, 146	0.3481, 0.4983	1.2278, 4.1809	2.5256, 8.1105	194, 1225
USA	168, 307	44, 174	0.2619, 0.5668	1.4048, 4.3518	3.4645, 8.4530	236, 1336

TABLE V: Cross-science citations from Brazil, South Korea, Turkey, and USA, grouped by sciences.

Cross-Science Citation Ratios	Brazil	South Korea	Turkey	USA
Chemistry	0.9265	0.8746	0.7816	0.7134
M. Biology	0.3636	0.4667	0.5833	0.4444
Physics	0.2143	0.2302	0.3481	0.2679

TABLE VI: Fraction of publications giving cross-science citations from chemistry (to molecular biology and/or physics), from molecular biology (to physics and/or chemistry), and from physics (to chemistry and/or molecular biology).