Bibliometric survey and network analysis of biomimetics and nature inspiration in engineering science

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SUPPLEMENTARY MATERIALS

1   Annex 1 – Publishing dynamics of WoS Categories

In order to visualize the publishing dynamics of WoS categories over the period from 2005 to 2019. in the supplementary materials, we provide figures showing the evolution by "annual sorting" period of the number of documents for the first 20 WoS categories of the NIE corpus, and a table for the evolution rate of each WoS categories.

The trends for these first 10 categories (Figure S1) reveal a significant increase in the number of documents regardless of the category considered, with a multiplying factor between 2 and 5 between 2005 and 2019. However, the evolutions are not all monotonous. The trends in the number of documents in the predominant WoS 'Materials Science, Multidiciplinary 'category, and 'Nanoscience & Nanotechnology' and 'Physics. Applied' are remarkable with a very strong increase over the period. The number of documents in some WoS categories, such as 'Robotics 'and 'Engineering. Electrical & Electronic' have decreased significantly since 2017.
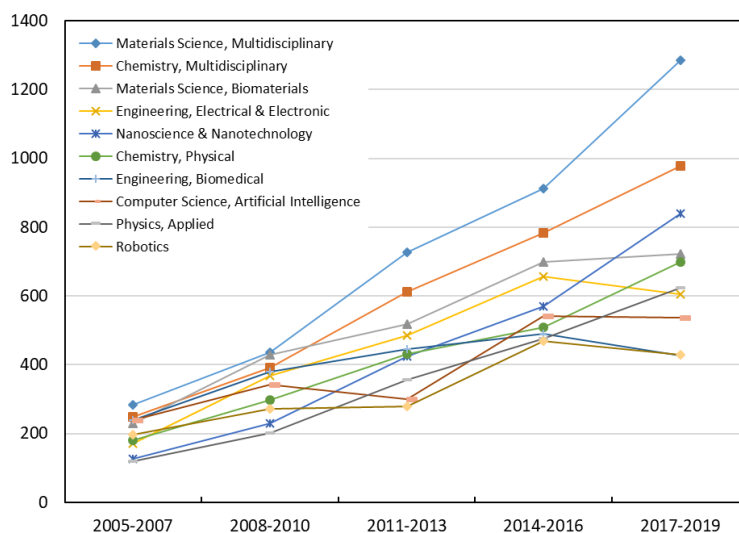

Figure S1: Dynamics of the number of documents of the top 10 WoS categories by 3-year periods from 2005 to 2019.

The dynamics of the next 10 WoS categories (ranked 11 to 20 in terms of documents) reveals similar evolution (Figure S2). The number of documents related to 'Engineering, Multidisciplinary' and ' Multidisciplinary Sciences' and 'Physics Condensed Matter' are progressing in the most important and remarkable way while "Computer Science. Theory & Methods" and "Automation & Control system" are categories for which a sharp decrease in the number of documents took place between 2016 and 2019.
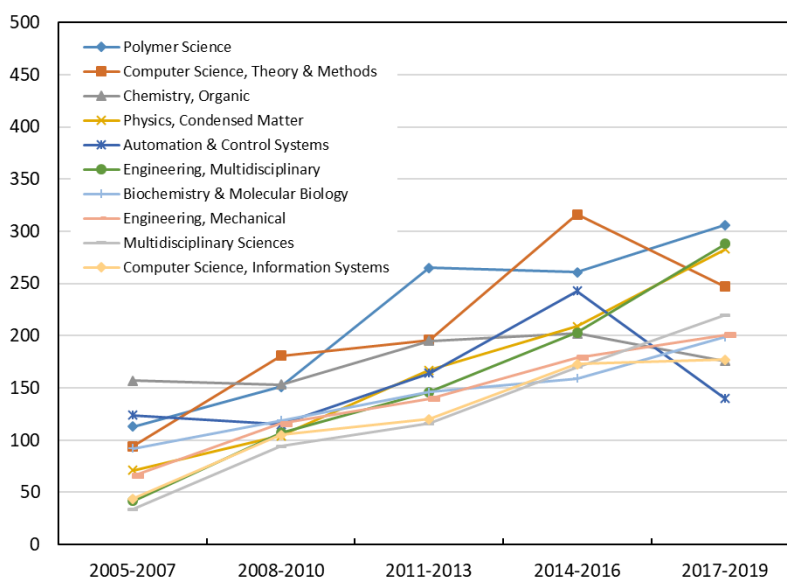

Figure S2: Evolution of the number of documents of the 11th to 20th WoS categories over the period 2005-2019

These figures are supplemented in table S1 with the evolution rate of change defined as the difference in the number of documents between 2005-2011 and 2012-2019 divided by the average number of documents over 2005-2011 for the NIE corpus (ER_NIE) or by the average number of documents over 2005-2011 at WoS scale (ER_WoS).

The methodology for calculating the values in the table is the following, with p1 = 2005-2011 and p2=2012-2019:

NmP(p) NIE: average number of documents over a given 'p' period in the NIE corpus

NmP(p) WoS: average number of documents over a given 'p' period in the full WoS database

ER_NIE (p1.p2) =[NmP(p2) NIE - NmP(p1) NIE] / NmP(p1) NIE: document number evolution rate between period p1 and p2 for NIE corpus.

ER_WoS (p1.p2) =[NmP(p2) WoS - NmP(p1) WoS] / NmP(p1) WoS : document number evolution rate between period p1 and p2 in the full WoS database.

ER_NIE/ER_WoS= Tx Acc. (p1.p2) NIE / Tx Acc. (p1.p2) WoS ratio of the evolution rates NIE / WoS

Table S1: Evolution rate of the first 20 WoS categories based on the number of documents for the period 2005-2011 compared to that of 2012-2019.

WoS Categories ranked by documents number in the NIE corpus	ER_NIE evolution rate in NIE corpus	ER_WoS evolution rate in full WoS database	ER_NIE/ER_WoS
Materials_Science_Multidisciplinary	148%	65%	2.3
Chemistry_Multidisciplinary	134%	77%	1.7
Materials_Science_Biomaterials	90%	88%	1.0
Engineering_Electrical_&_Electronic	104%	56%	1.8
Nanoscience_&_Nanotechnology	205%	77%	2.7
Chemistry_Physical	112%	40%	2.7
Engineering_Biomedical	44%	19%	2.3
Computer_Science_Artificial_Intelligence	66%	8%	8.1
Physics_Applied	188%	34%	5.5
Robotics	78%	41%	1.9
Polymer_Science	89%	33%	2.7
Computer_Science_Theory_&_Methods	78%	30%	2.6
Chemistry_Organic	20%	1%	20.3
Physics_Condensed_Matter	158%	2%	68.4
Automation_&_Control_Systems	62%	40%	1.5
Engineering_Multidisciplinary	146%	147%	1.0
Biochemistry_&_Molecular_Biology	51%	13%	3.8
Engineering_Mechanical	85%	58%	1.5
Multidisciplinary_Sciences	179%	250%	0.7
Computer_Science_Information_Systems	93%	45%	2.0

The evolution rates displayed above confirm the increase reported in the figures S1 and S2but add information relative to the evolution of the NIE corpus with respect to the full WoS database. For 18 of the first 20 WoS categories, the evolution rate of the NIE corpus is higher than the evolution rate of all WoS documents assigned to the WoS category. The two exceptions concern 'Engineering_Multidisciplinary' with identical evolution rates (146%) and 'Multidisciplinary_Sciences' with a higher increase in the number of documents for the WoS category as a whole than in the NIE corpus (179 against 250%). The ratio of the evolution rates described above thus varies between 0.7 and 68, with values mostly between 2 and 10. 'Computer_Science_Artificial_Intelligence' and 'Physics_Applied' have values of ratio between 5 and 10; the analysis of the dynamics of documents in the "Chemistry_Organic" category corresponds to a ratio of 20 but with an evolution which remains very small overall over the period. The category with the strongest growth momentum by far is 'Physics_Condensed_Matter' with a ratio of 68.

2 Annex 2 – Publishing countries dynamics

Table S2 shows the number of documents split by geographic areas. Beforehand, it should be noted that the total number of documents mentioned in this table (27,903) is greater than the total of 21,858 initially listed. This is due to the co-signatures by scientists of various origins and counted in multiple ways.

Table S2: Articles identified in the NIE corpus literature by geographic area, including

Geographic area	Number of document	% of the NIE corpus
Asia	10006	45.8%
Europe	9318	42.6%
North America	5843	26.7%
Middle East	1023	4.7%
Oceania	693	3.2%
South America	619	2.8%
Africa	401	1.8%

The next figures S3 and S4 display the time evolution of the number of documents over the period 2005-2019 for the 15 most publishing countries.
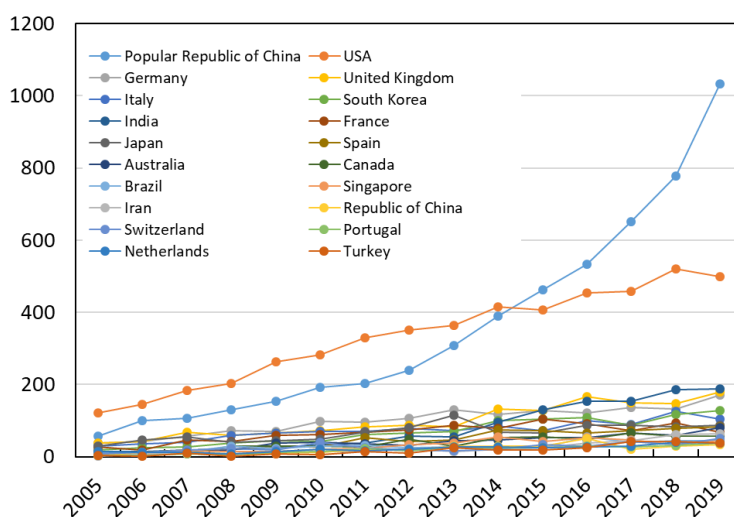
Figure S3: Number of documents over the period 2005-2019 for the 20 most publishing countries.

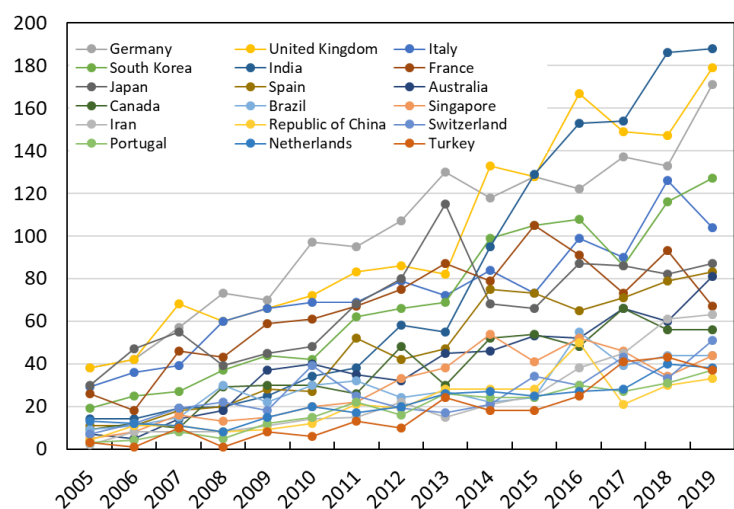**Figure S4**: Number of documents over the period 2005-2019 for the 18 most publishing countries, excluding both Popular Republic of China and the USA.

There is a very strong contrast between the countries with the hyper representation of the USA and Popular Republic of China in terms of the total number of documents belonging to the NIE corpus. We note that

Popular Republic of China passed the USA in 2015, still in terms of the total number of documents. Figure 9 zooms in on the 18 other countries in the top 20 publishers.

The annual number of documents has increased overall for the 13 countries concerned. Countries like India and Germany show a significant increase in the number of documents, especially in the second half of the period. India and Germany rank third and fourth among the top publishing countries in 2019. Growth is not all linear over the period: the number of documents from Japanese centers in 2019 is equal to that of 2012, in Italy a recent dropout was observed and in France the maximum number of documents (196) was reached in 2015, reduced in 2019 to 125.

3 Annex 3 – World top 100 institutions

Table S3: The top 100 institutions ranked by number of documents

Institutions	Nb. documents.				
chinese acad sci	869	univ manchester	93	univ calif santa barbara	73
jilin univ	279	univ bologna	93	northeastern univ	71
zhejiang univ	255	sun yat sen univ	92	ucl	71
MIT	223	southeast univ	90	virginia tech	70
nanyang technol univ	210	stanford univ	90	tech univ denmark	68
natl univ singapore	200	ohio state univ	89	yonsei univ	67
univ chinese acad sci	191	univ hong kong	89	soochow univ	67
beihang univ	188	mcgill univ	89	univ florida	67
shanghai jiao tong univ	187	xi an jiao tong univ	89	scuola super sant anna	67
sichuan univ	178	donghua univ	88	univ toronto	67
tsinghua univ	177	penn state univ	88	delft univ technol	66
tianjin univ	166	univ calif los angeles	88	nanjing univ aeronaut & astronaut	66
huazhong univ sci & technol	150	univ cambridge	87	eth	65
seoul natl univ	139	purdue univ	86	s china univ technol	65
harvard univ	137	univ minho	85	univ seville	65
univ michigan	135	texas a&m univ	84	univ connecticut	64
univ calif berkeley	133	univ freiburg	84	univ twente	64
harbin inst technol	132	osaka univ	83	south china univ technol	64
cnrs	131	univ maryland	82	johns hopkins univ	64
univ calif san diego	129	beijing inst technol	82	univ basel	63
georgia inst technol	128	fudan univ	80	tongji univ	63
peking univ	128	nanjing univ	80	univ leeds	63
univ illinois	127	tech univ dresden	79	cairo univ	62
korea adv inst sci & technol	125	max planck inst colloids & interface	78	univ washington	61
cnr	121	univ oxford	78	csic	61
northwestern univ	119	univ tehran	77	univ queensland	61
univ bristol	114	univ wisconsin	76	tech univ munich	61
ecole polytech fed lausanne	113	natl taiwan univ	76	univ sydney	61
univ sci & technol china	110	russian acad sci	75	hanyang univ	60
indian inst technol	109	univ erlangen nurnberg	75	islamic azad univ	60
univ tokyo	101	hong kong polytech univ	74	case western reserve univ	60
univ sao paulo	99	univ london imperial coll sci techno	74	hubei univ	59
		dalian univ technol	73	univ sheffield	59
		wuhan univ	73	tohoku univ	59

There is a great diversity of research institutes in this field. We logically note that Chinese institutions are in the first three positions of the podium, with the Chinese acad sci far ahead of the others. totaling 869 documents while the second has only 279 (Jilin Univ). Some American institutions are also at the top of this ranking, with MIT ranked 4th and being the top institution in the United States with 223 documents. If we ignore the Chinese Academy of Sciences, the following institutions are very similar in terms of number of documents. The first two non-Chinese and non-American institutions are respectively Seoul Nat Univ (South Korea) and CNRS (France) at ranks 14 and 19. The academic institution at the end of this top 100 is Tohoku univ with 59 documents in the period 2005-2019.

4 Annex 4 – Top institutions per country

The main institutions up to five for the 15 countries having published the most over the period 2005-2019 are detailed in table S4. Let us make the remark that in this table, we have regrouped the French universities by university pole, since Paris has more than 10 different institutions.

Table S4: Main institutes in the 15 most publishing countries

Country	Institutions
Popular Republic of China (5448)	chinese acad sci (869) jilin univ (279) zhejiang univ (255) univ chinese acad sci (191) beihang univ (188)
USA (5051)	MIT (223) harvard univ (137) univ michigan (135) univ calif berkeley (133) univ calif san diego (129)
Germany (1545)	univ freiburg (84) tech univ dresden (79) max planck inst colloids & interface (78) univ erlangen nurnberg (75) tech univ munich (61)
UK (1523)	univ bristol (114) univ manchester (93) univ cambridge (87) univ oxford (78) univ london imperial coll sci techno (74)
Italy (1113)	cnr (117) univ bologna (93) scuola super sant anna (67) politecn torino (58) univ genoa (49)
South_korea (1052)	seoul natl univ (139) korea adv inst sci & technol (125) yonsei univ (67) hanyang univ (60) konkuk univ (56)
India (1221)	indian inst technol (109) indian inst sci (44) csir (37)
France (1007)	cnrs (131) sorbonne Univ (90) univ grenoble (67) univ de paris (65) PSL univ paris (61)
Japan (1017)	univ tokyo (101) osaka univ (83) tohoku univ (59) natl inst adv ind sci & tech (55) kyoto univ (48)
Spain (721)	univ seville (65) csic (61)s univ granada (55) univ politecn madrid (46) univ politecn cataluna (32)
Australia (606)	univ sydney (61) univ queensland (61) univ adelaide (47) monash univ (44) queensland univ technol (38)
Canada (567)	mcgill univ (89) univ toronto (67) univ alberta (47) univ waterloo (44) univ ottawa (29)
Brazil (401)	univ sao paulo (99) univ estadual campinas (34) univ fed santa catarina (33)
Singapore (452)	nanyang technol univ (210) natl univ singapore (200)
Iran (374)	univ tehran (77) islamic azad univ (60) amirkabir univ technol (41) univ tehran med sci (23)

5 Annex 5 – Frequent terms du corpus

Table S5: Most frequent top 100 terms from the Title and Keyword Fields in the NIE Corpus.

Terms	variants	occurrences	nb. distinct documents
model	model|&|models|&|modeling|&|modelling	1690	1397
materials	materials|&|material	1230	1074
surface	surface|&|surfaces	1163	976
biomimetic synthesis	biomimetic synthesis|&|synthesis of biomimetic	1159	1034
nature	nature	1146	1026
design	design|&|designs|&|designer	1049	923
robot	robot|&|robotics|&|robots	924	721
control	control|&|controller|&|controllers|&|controls	886	701
scaffold	scaffold|&|scaffolds	839	664
synthesis	synthesis	813	744
hydroxyapatite	hydroxyapatite|&|hydroxyapatites	780	597
optimization	optimization|&|optimizer|&|optimized|&|optimality|&|optimizers	767	625
polymer	polymer|&|polymers	764	627
complexes	complexes|&|complex|&|complexity|&|complexation	751	629
algorithm	algorithm|&|algorithms	739	581
tissue engineering	tissue engineering|&|tissue engineered	714	603
nanoparticles	nanoparticles|&|nanoparticle	705	566
membrane	membrane|&|membranes	703	538
hydrogel	hydrogel|&|hydrogels	701	513
coatings	coatings|&|coat|&|coating	693	559
protein	protein|&|proteins	680	522
networks	networks|&|network	676	506
sensor	sensor|&|sensors	650	506
inspired algorithms	inspired algorithms|&|inspired algorithm	616	554
Human	human	606	495
oxidation	oxidation|&|oxide|&|oxidative|&|oxides|&|oxidations|&|oxidants |&|oxidant	594	478
dynamics	dynamics|&|dynamic	585	467
analysis	analysis	575	503
water	water|&|waters	553	441
engineering	engineering|&|engine|&|engineer|&|engines	545	480
properties	properties|&|property	531	502
detection	detection	514	404
method	method|&|methods	496	456
approach	approach|&|approaches	492	481
adhesion	adhesion|&|adhesives|&|adhesions	477	366
3d	3d	464	380
actuator	actuator|&|actuators|&|actuation	446	345
nanocomposite	nanocomposite|&|nanocomposites	425	342
bone	bone|&|bones	424	332
adaptive	adaptive|&|adaptation|&|adaptability|&|adaption|&|adaptations	419	327
films	films|&|film	414	356
fabrication	fabrication|&|fabric|&|fabrics	411	374
chitosan	chitosan	409	268
activity	activity|&|activation|&|activities|&|activator|&|activators	402	354
wings	wings|&|wing	380	248
function	function|&|functionalization|&|functions|&|functionality|&|functionalities	379	360
fiber	fiber|&|fibers	375	270
bio-inspired algorithms	bio-inspired algorithms|&|bio-inspired algorithm	362	331
superhydrophobic	superhydrophobic|&|superhydrophobicity	356	273
reaction	reaction|&|reactions	347	292
mechanical properties	mechanical properties|&|mechanical property	342	293
biomimetic mineralization	biomimetic mineralization|&|biomimetic minerals|&|biomimetic mineralized	326	271
flow	flow|&|flows	321	248
iron	iron	317	242
calcium phosphate	calcium phosphate|&|calcium phosphates	316	257

ligands	ligands|&|ligand	311	251
enzyme	enzyme|&|enzymes	303	263
characterization	characterization|&|characterizations	298	279
microstructure	microstructure|&|microstructures	298	258
electron	electron|&|electronics|&|electronic	297	234
silica	silica|&|silicas	294	217
simulation	simulation|&|simulations|&|simulator	288	254
phase	phase|&|phases	286	235
neural network	neural network|&|neural networks	285	223
apatite	apatite|&|apatites	281	223
biomimetic membranes	biomimetic membranes|&|biomimetic membrane|&|membrane biomimetic	281	247
ion	ion|&|ions	281	229
bone tissue engineering	bone tissue engineering|&|tissue engineered bone|&|tissue engineering bone	279	222
motion	motion|&|motions	274	224
array	array|&|arrays	273	219
carbon	carbon|&|carbonate|&|carbonic|&|carbonates|&|carbonation|&|carbons	271	212
genetic algorithm	genetic algorithm|&|genetic algorithms|&|algorithms genetic	268	232
formation	formation|&|formate	260	244
device	device|&|devices	256	223
inspired design	inspired design|&|inspired designs|&|design inspired	254	234
stability	stability|&|stabilization|&|stabilizer|&|stabilizers|&|stabilities	253	207
substrate	substrate|&|substrates	248	233
data	data	247	186
locomotion	locomotion	247	201
copper	copper	245	186
bio-inspired robotics	bio-inspired robotics|&|bio-inspired robot|&|bio-inspired robots|&|bio-inspired robotic	245	235
generation	generation|&|generator|&|generators|&|generative|&|generic	245	205
object	object|&|objects|&|objective	238	173
platform	platform|&|platforms	235	222
scales	scales|&|scale	235	205
biomimetic scaffold	biomimetic scaffold|&|biomimetic scaffolds	227	209
review	review	226	217
tissue	tissue|&|tissues	224	194
nature-inspired algorithms	nature-inspired algorithms|&|nature-inspired algorithm	223	206
particle	particle|&|particles	219	183
swarm intelligence	swarm intelligence	218	201
matrix	matrix	217	194
porphyrin	porphyrin|&|porphyrins|&|porphyrinic	214	160
total synthesis	total synthesis	211	171
biomimetic surface	biomimetic surface|&|biomimetic surfaces	210	187
natural products	natural products|&|natural product	210	189
microfluidics	microfluidics|&|microfluidic	206	164
biomimetic coatings	biomimetic coatings|&|biomimetic coating|&|coatings biomimetic	204	178
extracellular matrix	extracellular matrix	202	173
recognition	recognition	202	164

6 Annex 6 – About the display of terms in the temporal evolution of clusters

Terms displayed in the temporal map of each cluster based on their average age in the corpus, which is computed as Sum (Ni x PYi) /Sum Ni, with Ni the number of occurrences of term i and PYi the publishing year of the article containing term i (in title, abstract, author's keywords fields).

The figure S6 displays the occurrence of selected terms in the cluster D/Applied Physics/ over the period 2005-2019.
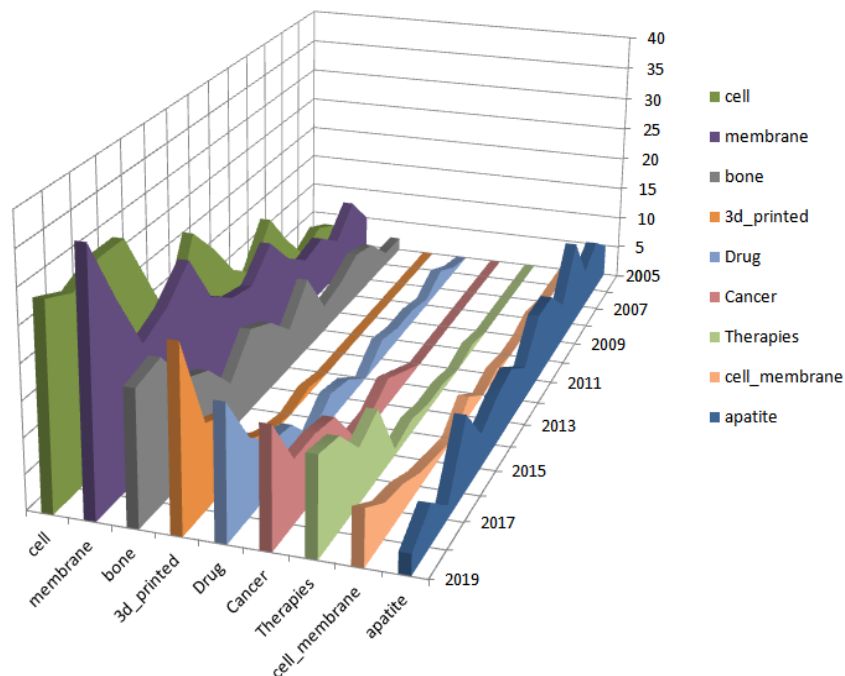

Figure S6: Occurrence of selected terms in the cluster D/Applied Physics/

Despite the large number of documents in the cluster D/Applied physics/, only '3D-printing' is displayd for year 2019. However, the figure XX show that many other terms, like 'cell', 'membrane', 'bone', 'drug', etc.. are equally important in terms of occurrence. But, the average year of these terms is lower than 2019, especially for recurrent terms like 'membrane' or 'cell'. On the other hand, '3D-printing' is a new term, which concentrates more than 50% of its occurrences in year 2019, thus 2019 is its average year where it is displayed.