Characterizing interdisciplinarity of Nobel laureates' key publications

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To know whether greater or smaller interdisciplinarity benefits high-quality scientific outputs, two indicators, the Brillouin's (BI) and Hill-type (HI) indices, are applied to characterize interdisciplinarity of key publications of Nobel laureates from 2001 to 2010. Both BI and HI indicate that smaller interdisciplinarity benefits the creative works of these Nobel laureates. The results show high concordance between BI and HI, with high correlation (>0.8). Although all values, with BI < 1 and HI < 12, show that the interdisciplinarity is always small in the sample, the study also shows that interdisciplinary studies are more widely distributed in the field of physiology or medicine than that in physics.

Keywords: Interdisciplinarity, interdisciplinary measure, Nobel laureates' key publications.

SINCE Brillouin[1] introduced an index, now called the Brillouin's index (BI), for measuring interdisciplinarity in 1956, the interdisciplinary studies have been developed[2]. In 1985, Porter and Chubin[3] introduced another indicator called Citation Outside Category (COC), which is defined as the sum of the number of citations in fields other than studying fields divided by the total sum of the citations in all studying as well as other fields. After 2000, research regarding interdisciplinarity became a popular topic. Several workers developed new indicators for measuring interdisciplinarity and tried various applications. Stirling[4] proposed a measurement framework of diversity using three dimensions: variety, balance and disparity. Rafols and Meyer[5] then combined diversity and coherence for measuring interdisciplinarity. In 2016, a new indicator, true diversity, was introduced[6].

Leydesdorff et al.[7] studied the interdisciplinarity of journals, by improving the citation-based interdisciplinary indicators at the journal level[8], and proposed the global mapping methodology[9]. In some fields, there were special discussions, including interdisciplinarity in environmental science[10], as well as in information science and library science[11–13].

However, although the indicators have become increasingly complicated, there is a research gap in the value orientation and measurement direction of interdisciplinary studies. Although a few relations between interdisciplinarity and citation impact were studied[14–18], we do not know whether greater or smaller interdisciplinarity is better. Larivière and Gingras[19] did not find a clear correlation between the interdisciplinarity and the citations received by analysing all articles collected in the Web of Science (WoS) in 2000; they found that there was an optimal level of interdisciplinarity in most fields, except biomedical sciences. Zhang et al.[6] found that the average number of citations of articles in *Nature* and *Science* increased at first and then eventually decreased by increasing interdisciplinarity, while the average number of citations of articles in *Bioinformatics* decreased by increasing interdisciplinarity. Based on the question of whether greater or smaller interdisciplinarity benefits high-quality scientific outputs, we explored a small special dataset using interdisciplinary measurements.

Methods

The methods focus on interdisciplinary measurements, i.e. indicators.

BI is used as the first indicator for measuring interdisciplinarity, considering integrated samples and disciplinary distribution of samples[10], and employed to represent the level of interdisciplinarity as an interdisciplinarity degree as

$$BI = \frac{\log N! - \sum_i \log N_i!}{N} \in [0, +\infty), \tag{1}$$

where N denotes the number of samples and N_i shows the number of samples in field i. In analysing the references (for both bibliographic coupling and co-citation analysis), N refers to the number of references and N_i refers to the number of references in field i.

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The Hill-Type Index (HI) was a revolutionary indicator, which originated from McIntosh[20] and Hill[21], and was improved by Jost[22,23], with its formula as

$$\text{HI} = \left(\sum_{j=1}^{n} p_j^q \right)^{1/(1-q)}, \tag{2}$$

where q is parameter and $j = 0 \ldots \infty$ denotes sensitivity parameter in ecology. When $q = 2$, it becomes

$$\text{HI} = 1 / \sum_{j=1}^{n} p_j^2 \in [1, +\infty). \tag{3}$$

When Stirling[4] considered that diversity included variety, balance and disparity, the following formula was introduced for measuring diversity

$$D_{\alpha,\beta} = \sum_{i,j=1; i \neq j}^{n} (d_{i,j})^\alpha (p_i p_j)^\beta, \tag{4}$$

where N donates the numbers of cells, p_i and p_j are proportions of items in cells i and j respectively, and d_{ij} is degree of disparity between the elements i and j; α and β are positive exponents.

Based on the above, an improved indicator[6] is suggested as

$$^q D_{\alpha\beta}^S = \left(\sum_{i=1}^{n} p_i^\alpha (Sp_j)^\beta \right)^{1/(1-q)}. \tag{5}$$

Supposing $\alpha = 1$ and $\beta = q - 1$, 'true diversity'[6] is stated as

$$^q D^S = \left(\sum_{i=1}^{n} p_i \left(\sum_{j=1}^{n} S_{ij} p_j \right)_i^{q-1} \right)^{1/(1-q)}. \tag{6}$$

Therefore, the original BI and HI are two key indicators. Considering both computing simplification and data availability, our computation is based on BI and HI, i.e. eqs (1) and (3). If the measurements of BI and HI indicate similar results, we have concordant conclusions.

Data

The value orientation of this study focuses not only on high impact, but also on high quality. As high quality cannot be quantified, we can select articles with high quality credited by peer review, where we choose the key publications of Nobel laureates.

The key publications (KPs) of Nobel laureates are defined as the publications existing in the references of their Nobel lectures (PDF). After collecting all the KPs, we had a key publication set, we could then study the interdisciplinarity using the references of these publications. Considering that interdisciplinary studies have become more popular with the turn of century, and data in the natural sciences remain more structured, we analysed data from 2001 to 2010, in the fields of physics (PHYS), chemistry (CHEM), and physiology or medicine (MED). All original data were sourced from Nobel website (nobelprize.org), and the citation data are searched from WoS. As a few Nobel laureates did not provide PDFs and some PDFs had no references, we keep effective data by dispelling KPs without reference and references of KPs with incomplete information and no SC in WoS. The statistical review is shown in Table 1.

In physics, there are no references in Nobel lecture PDFs of Hugh David Politzer (2004) and Willard S. Boyle (2009). In chemistry, there is no record on references from Nobel lecture PDF of Koichi Tanaka (2002) in WoS and there is no reference in Nobel lecture PDF of Richard F. Heck (2010). In physiology or medicine, data is complete.

By using BI and HI, we can measure the interdisciplinarity of Nobel KPs, in which the fields are based on SC of WoS. SC is a broader subject classification in WoS database, which represents the research direction of each paper. As the KPs of Nobel laureates mean high quality, our measurement could reveal the interdisciplinary characteristics of high qualitative publications and answer whether greater or smaller interdisciplinarity benefited high-quality scientific outputs.

Results

The distribution range of related parameters is shown in Table 2, where minimum and maximum values are set in (min, max).

In Table 2, the field of chemistry shows the widest distribution of number of SCs in references of KPs (max 497), and the field of physics does the least types of SCs in references of KPs (max 13). Both BI and HI show small values, where BI never exceeds 1 and HI does under 12. As BI can distribute from 0 to infinity and HI can do from 1 to infinity, we see that the interdisciplinarity of Nobel laureates' KPs is smaller.

Distribution and correlation of BI and HI

Figures 1–3 illustrate the distribution of BI and HI in the fields of physics, chemistry, physiology or medicine respectively, where the horizontal coordinate denotes the number of KPs, the left vertical coordinate indicates BI and the right vertical coordinate indicates HI, where BI = 0 corresponds to HI = 1.

Table 1. A review of the statistical data

Field: effective data/total data	PHYS	CHEM	MED
Number of laureates	25/27	23/25	24/24
Number of key publications	236/276	577/577	353/357
Number of references	5073/8064	22821/25175	11614/12780

Table 2. Distribution range of related parameters

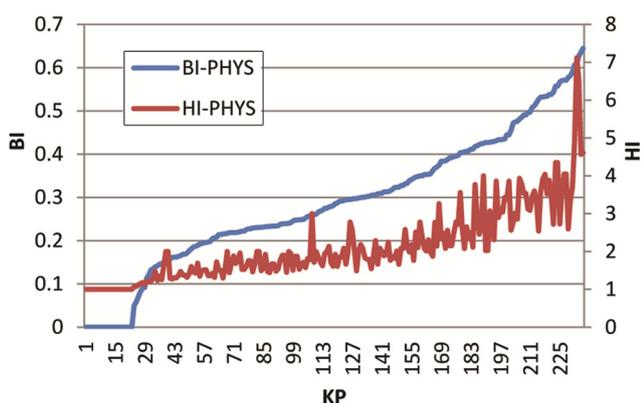| Field: (min, max)	PHYS	CHEM	MED
Number of key publications for each laureate	(1, 33)	(3, 82)	(2, 45)
Number of references in each key publication	(1, 292)	(3, 469)	(2, 184)
Number of SCs in each KPs references	(1, 362)	(3, 497)	(2, 272)
Types of SCs in each KPs references	(1, 13)	(1, 23)	(1, 23)
BI	(0, 0.6446)	(0, 0.9766)	(0, 0.9801)
HI	(1, 7.1176)	(1, 11.7122)	(1, 11.6364)

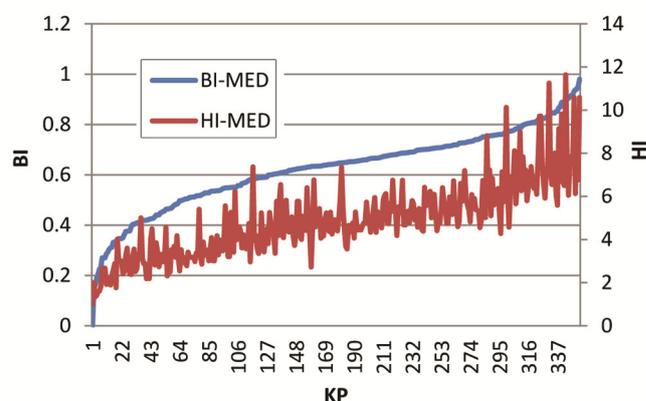**Figure 1.** Interdisciplinary distribution of key publications in physics.

Figure 2. Interdisciplinary distribution of key publications in chemistry.

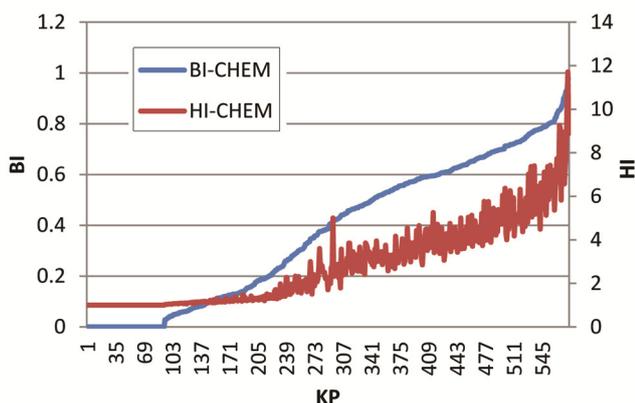**Figure 3.** Interdisciplinary distribution of key publications in physiology or medicine.

The correlations are significant in terms of both Pearson and Spearman coefficients, as shown in Table 3.

Thus, all figures and the correlations in different fields conclude of high concordance, i.e. both BI and HI have small values distributing in similar patterns, and the two measures have high correlation (>0.8), in the KPs of Nobel laureates.

Distribution and types of SCs

As different SCs mean different research directions, the complete distribution of SCs could show research information in detail. Figure 4 gives the distribution of SCs of KPs in the fields of physics, chemistry, physiology or medicine respectively, where the top 3 SCs can be clearly seen.
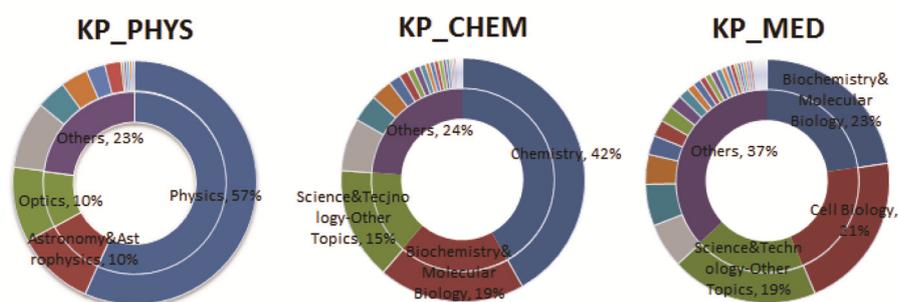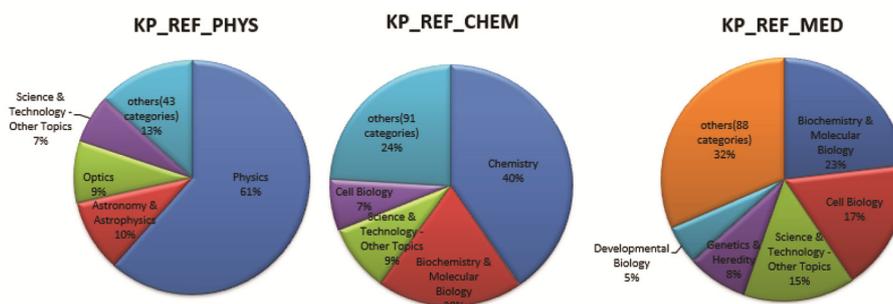
Figure 4 illustrates that the greatest types of SCs is in the field of physiology or medicine, and the lowest number in the field of physics. The top related SC remains physics and chemistry in the field of physics and chemistry, with portions 56.63% and 41.94% respectively, while the top SC in the field of physiology or medicine is biochemistry and molecular biology, with a portion of 22.62%. Although the interdisciplinarities in these three fields are small, physiology or medicine has greater interdisciplinarity, followed by chemistry, and then physics. We can conclude this information from BI and HI values, or from the types of SCs of KPs of Nobel laureates in their respective fields.

The characteristics similar to distribution of SCs of KPs are also reflected in the SCs' distribution of KPs'

Table 3. Pearson and Spearman correlations between BI and HI

		Spearman (sig. (2-tailed))					
Correlations		BI_PHYS	BI_CHEM	BI_MED	HI_PHYS	HI_CHEM	HI_MED
Pearson (sig. (2-tailed))	BI_PHYS	1	–	–	0.932**	–	–
	BI_CHEM	–	1	–	–	0.985**	–
	BI_MED	–	–	1	–	–	0.873**
	HI_PHYS	0.869**	–	–	1	–	–
	HI_CHEM	–	0.927**	–	–	1	–
	HI_MED	–	–	0.836**	–	–	1

**Significance at level 0.01 (sig. (2-tailed)).

Figure 4. Distribution of SCs in different KPs of fields.

Figure 5. Distributed types of SCs in references of KPs.

references. In Figure 5, the distribution information of the top few SCs and corresponding proportions for references of KPs in physics (KP-REF_PHYS), chemistry (KP-REF_CHEM) and physiology or medicine (KP-REF_MED) is shown respectively.

All the information on the distribution and types of SCs reveals, under the same conditions of small BI and HI, that there is wider distribution of SCs in the field of physiology or medicine, meaning that interdisciplinarity has more obvious expression in physiology or medicine. In all fields considered, physics pays more attention to its own subjects, with less interdisciplinarity.

Discussion

The above results, based on the key publications of Nobel laureates, show two important features on interdisciplinarity.

(1) As the representatives of Nobel laureates represent the publications of high quality, and the interdisciplinarity can be measured by BI and HI, our results reveal that the interdisciplinarity of publications with high quality has small index values, meaning that the Nobel laureates tend to do highly specialized research.

(2) Although there are small values of BI and HI in all three fields, physics maintains smaller interdisciplinarity whereas physiology or medicine trends towards greater interdisciplinarity with wider SCs distribution of KPs and references of KPs.

The research sample also presents certain limitations. Generally, most key publications of Nobel laureates published many years ago, which could not represent the developing tendency after 2000. Since the start of century, perhaps interdisciplinary research and multidisciplinary collaboration are becoming a new tendency in sciences, which presents an opportunity for further research.

Conclusion

Using interdisciplinary indicators, such as BI and HI, we conclude that interdisciplinarity is small in key publications of Nobel laureates during 2001–2010. Both BI and HI indicate that less interdisciplinarity benefits the work of Nobel laureates, with high concordance and high correlation (>0.8). It is also shown that interdisciplinary studies distribute wider in the field of physiology or medicine, than that of physics; although all the interdisciplinarity indices have smaller values, with $BI < 1$ and $HI < 12$. Thus, the result suggests that smaller interdisciplinarity may benefit high-quality scientific research and publications.

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