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# A Nobel opportunity for interdisciplinarity

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**Despite the growing interdisciplinarity of research, the Nobel Prize consolidates the traditional disciplinary categorization of science. There is, in fact, an opportunity for the most revered scientific reward to mirror the current research landscape.**

Chemists stir flasks, physicists solve complicated equations on blackboards and physicians, in white coats with a stethoscope around their neck, race against the clock to save patients. These enduring stereotypes are just as common as they are outdated. Today, scientists from different disciplines work increasingly together on complex and previously intractable problems. Interdisciplinary collaborations now span many fields across the natural and life sciences in order to tackle the world's most challenging problems[1]. Yet the scientific enterprise continues to be dominated by old stereotypes: interdisciplinary science is less likely to receive funding[2] and is discriminated at institutional levels[1]. To alleviate this, several solutions have been suggested to funders, institutions and publishers[3]. However, the most visible form of scientific credit, our reward system, has so far been ignored. How interdisciplinary is it? To address this question, we explore interdisciplinarity in arguably the most prestigious award in science: the Nobel Prize.

In the early 1980s, Dan Shechtman discovered the quasicrystal[4], a regular but not periodic solid. The discovery that matter could organize itself in disallowed symmetries caused an enormous excitement[5], and Shechtman eventually received the Nobel Prize 27 years later. Yet the award he won was the Nobel Prize in Chemistry, despite the fact that the discovery of the quasicrystal was published in a physics journal, *Physical Review Letters*, and had its largest long-term impact in physics[6]. Indeed, Shechtman's Nobel Prize-winning work has been cited over 3,000 times, with 52% of the citing papers published in physics journals, 27% in engineering and only 10% in chemistry (Fig. 1a and Supplementary Information). Does this mean that Shechtman's discovery was underappreciated by chemists? The answer is no: normalizing for the total size of the chemistry literature after 1984, the citations from chemistry were in fact slightly higher than expected by chance. However, the normalized impacts on physics and engineering were around six and two times higher. Shechtman's paper is therefore a prime example for an interdisciplinary discovery that had a big impact in several disciplines.

As crystallography is on the border of physics and chemistry, Shechtman's interdisciplinary impact is not surprising. However, it makes us wonder: is Shechtman's award an anomaly, deviating from the expectation that a Nobel Prize should be awarded in the discipline that produced it? To answer this question, we analysed the interdisciplinary impact of 108 Nobel Prize-winning papers[7] by looking at all the 59,305 papers that cited them, as recorded by Thomson Reuters Web of Science (Supplementary Information). These Nobel Prize-winning papers consist of 25 papers in physiology/medicine (2006–2017), 43 in chemistry (1998–2017) and 40 in physics (1995–2017), covering all papers since the Nobel committee started offering a detailed explanation with references for the prize[7]. Note that the choices of these years follow from the limitation of the data source; a more far-reaching set of Nobel Prize papers or comparable time periods would have been preferred but was not available.

We find that 60 Nobel Prize discoveries generated very little interest outside of their awarded field. Consider, for example, Schwarz et al.'s 1985 paper on the role of the human papillomavirus in cancer[8], acknowledged with a Nobel Prize in Physiology or Medicine in 2008. The paper received only 41 of its 1,134 total citations from outside of the life sciences (Fig. 1b). However, we do find 35 interdisciplinary discoveries—namely papers that had a big impact in both the awarded and in at least another field. The remaining 13 Nobel Prize-winning papers, all awarded in chemistry, are special as they had only limited impact in chemistry. The prime example is Dixon et al.'s 1986 paper on cell receptors[9], the winner of the chemistry prize in 2012, which received 832 of its 984 citations from the life sciences; only 17 came from chemistry-focused journals (Fig. 1c).

Today, the Nobel Prize in Chemistry plays a bridging role in the natural sciences, celebrating discoveries that either make an impact in chemistry only, that impact both physics and chemistry, or have an impact mostly in the life sciences[10]. Interestingly, most of these cross-disciplinary papers were published after 1980, reflecting the transformation in the field's major research goals from traditional analytical chemistry towards biochemistry[11,12] and the emergence of interdisciplinary teams[13,14]. But what about physics and life sciences? Although in the past few decades these fields have fundamentally changed too—for example, through increasing interdisciplinary efforts in biological physics—the Nobel Prize in these areas remained deeply disciplinary, as we show below. To understand the degree of interdisciplinarity in the Nobel Prizes, we plot each winning paper along a triangle (Fig. 2a). A publication is placed on the bottom corner if all the citations of the corresponding paper came from chemistry; likewise, the top-right corner corresponds to exclusive impact in physics, and the top-left corner to life sciences. Whenever a paper receives citations from several fields, the paper is placed between the corners, its position reflecting the relative mix of citations. For example, a paper would be at the centre of the triangle if it received an equal number of citations from all three fields.

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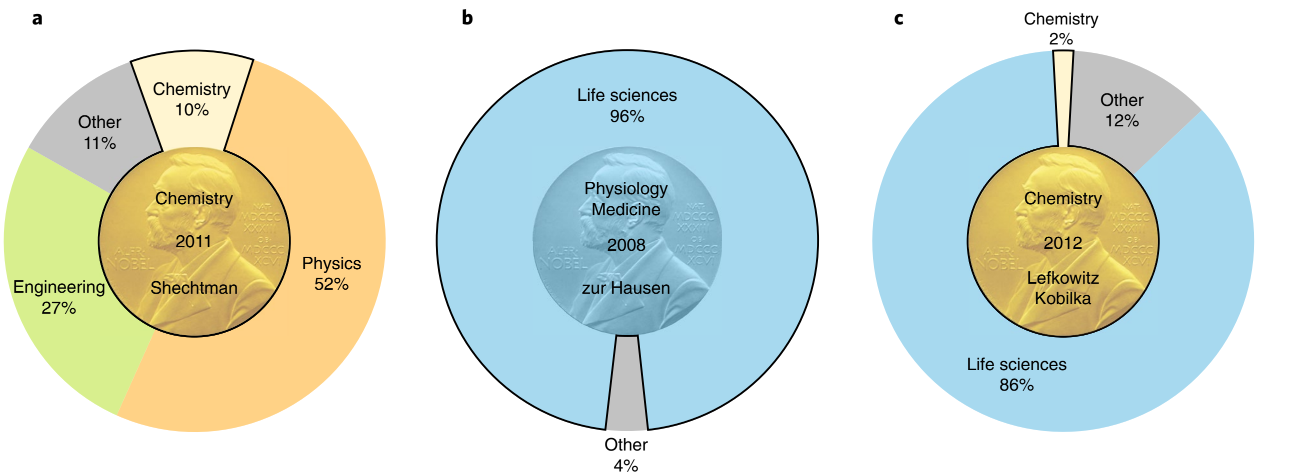


**Fig. 1 | The disciplinary/interdisciplinary impact of Nobel Prize-winning discoveries.** Distribution of citations to Nobel Prize-winning papers according to the disciplines of the citing journals based on the Web of Science subject categories. **a**, Shechtman's 1984 paper on quasicrystals[4], awarded with the Nobel Prize in Chemistry in 2011, had a largely interdisciplinary impact, being cited significantly by papers from physics and engineering as well as its own field. **b**, In contrast to chemistry, the impact of Nobel Prize papers in physiology/medicine is highly limited to one field—citations almost exclusively come from the life sciences. A typical example is Schwarz et al.'s 1985 paper on the papillomavirus[8], which led to zur Hausen's 2008 Nobel Prize in Physiology or Medicine. **c**, Dixon et al.'s 1986 paper on cell receptors[9], which earned Lefkowitz and Kobilka the 2012 Nobel Prize in Chemistry, is one whose impact is almost exclusively outside of chemistry. The paper has been mostly cited by the life sciences.

On the basis of our analysis, we make several observations: papers associated with a Nobel Prize in Chemistry (yellow discs) are spread along the chemistry–physics and chemistry–life sciences edges on the triangle, confirming quantitatively the effort by the chemistry prize in rewarding research that has impact beyond chemistry. In contrast, physiology/medicine Nobel Prize-winning papers are all clustered in the narrow vicinity of the life sciences corner, indicating that they have no impact beyond that area. Similarly, most physics prize-winning papers fall in the narrow vicinity of the physics corner. All Nobel Prize-winning papers are located in a narrow band that connects the physics–chemistry and the chemistry–life sciences border. No Nobel Prize has been awarded to articles that fall within the shaded area, representing ideas outside this narrow band. In other words, there has been no award for work that has had impact on all three disciplines. In particular, there is evidence for a lack of prizes at the physics–life sciences border.

Could it simply be that there are no high-impact discoveries relevant for both physics and life sciences or to all three disciplines? To answer this question, we plotted the top 10,000 papers in Web of Science in terms of citations after ten years (Fig. 2b). While the Nobel Prize is not given merely for citations[15–18], the distribution of the top 10,000 papers captures the diversity of ideas important across all fields of science. Indeed, the majority of Nobel Prize-winning papers can be found in this top 10,000 list. The plot does confirm the exceptional number of high-impact papers at the physics–chemistry and the life sciences–chemistry border, areas regularly awarded by the chemistry prizes. It also shows, however, that 220 out of 10,000 papers are located inside the interdisciplinary shaded area, documenting the existence of high-impact interdisciplinary discoveries[19] of direct relevance to physics, chemistry and the life sciences, in line with the global structure of science[10]. Some of these high-impact papers fall onto the physics–life sciences axis, reflecting mostly recent, highly active interdisciplinary areas (Fig. 2c) in artificial intelligence (16 papers), network science (18 papers), geology (15 papers) and signal processing (11 papers). Furthermore, we found a cluster of ten interdisciplinary papers on quantum dots. These fields capture some of the highest-impact interdisciplinary areas not yet embraced by the Nobel Prize.

Taken together, Fig. 2 gives a snapshot of science that is disappointing on two levels. First, despite the understanding that interdisciplinary research is unavoidable in addressing the most challenging problems in current science and society, the vast majority of research is still highly disciplinary. Second, our most prestigious system of scientific recognitions, the Nobel Prize, is reflecting—and possibly cementing—this reality. Finding that a still relatively small body of interdisciplinary work has not been rewarded by the prize is statistically not surprising. However, having only the chemistry prize reaching out towards interdisciplinary subjects flies in the face of the interdisciplinary impact of an increasing fraction of recent high-impact discoveries[19,20]—particularly between physics and the life sciences.

Measuring the interdisciplinarity of papers from the top 10,000 list over time unveils a silver lining. Since the mid-1990s, research that makes a more balanced impact in different fields has been steadily increasing (Fig. 3), and the time for the Nobel Prize to catch up with this reality has just arrived. We are now 23 years after 1995, the moment when the amount of interdisciplinary high-impact papers started to rise. And today, the average delay between publication of a discovery and its reward with a Nobel Prize is around 20 years[21]. We have thus reached the critical point in time where the issue of recognizing outstanding interdisciplinary research has become pressing (Supplementary Information).

Before concluding, we investigate if the analysed papers are truly monodisciplinary, or if we can detect multidisciplinary nuances, by increasing the granularity of subject categories[22]. Doing so indeed identifies multidisciplinary impact within disciplines—for example, showing that most of the Nobel papers in the life sciences have been cited within both immunology and cell biology (Supplementary Fig. 3). This observation reveals what could be expected: the narrower the sub-fields that we consider, the more likely we find impact in multiple ones. In other words, the concept of multidisciplinary impact is resolution-dependent. However, this does not affect our main point: on the relevant and least-granular level of the Nobel Prize categories, only discoveries in clear-cut fields receive an award.

The Nobel Prize was founded to acknowledge advances in a specific discipline. Given that these prizes are disciplinary by definition, shouldn't we just leave them alone? We argue that the answer should either be 'sure, but then let us create new, up-to-date prizes', or it should

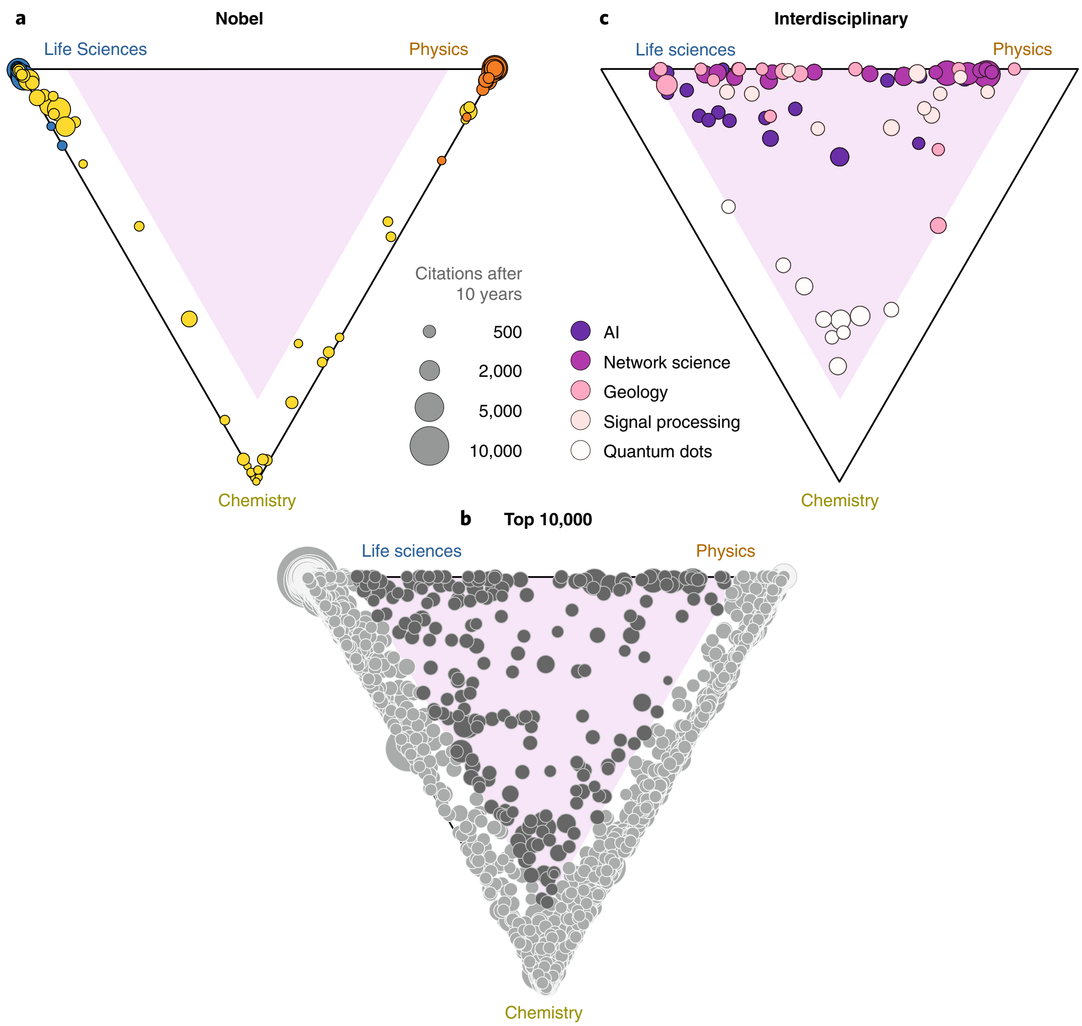


**Fig. 2 | The intellectual space of Nobel Prizes.** An interactive version of this is available at https://mszell.github.io/nobelplot/nobelplot.html. **a**, The position of the 108 Nobel Prize-winning papers[7] in the physics–chemistry–life sciences triangle is determined by how many relative citations each paper received from the respective community. For example, a paper at the centre of the triangle received an equal number of citations from all three fields, while a corner position is reserved for papers whose citations came only from one field. Size denotes number of citations after ten years[6], and colour denotes field of award: orange, physics; yellow, chemistry; blue, physiology/medicine. The Nobel Prize-winning papers are all in a narrow band on the physics–chemistry and the chemistry–life sciences borders. No Nobel Prize is awarded to papers in the shaded interdisciplinary area, especially on the physics–life sciences axis. **b**, Among the top 10,000 papers in terms of citations after ten years, only 220 show a high degree of interdisciplinary impact, falling into the shaded, interdisciplinary area. **c**, Of the 220 interdisciplinary impact papers in the shaded area we identify the largest groups by subject: artificial intelligence (AI; 16 papers), network science (18 papers), geology (15 papers), signal processing (11 papers) and quantum dots (10 papers).

be 'no'. First, the Nobel Prize is special, having come to represent to the world science at its best. The few Nobel Prize categories made sense when the prize was established in 1895[23]; science, however, has fundamentally changed since then. Second, the rules of the Nobel Prize have already been generously bent—to reward multiple scientists and not just one, and not just for a discovery 'during the preceding year' as originally stated[24]. Why not adapt the prize even further?

The possible unintended consequence of prestigious award systems, such as the venerable Nobel Prize, in amplifying structural biases, prompts us to wonder: why not create an up-to-date award system that simply recognizes the best research, rather than pigeonholing findings into specific disciplines[25]? After all, high-impact science is increasingly achieved through the combination of ideas coming from different disciplines[12,20,26]. In many ways, interdisciplinary research is happening despite the current reward and support structures that artificially maintain the disciplinary borders within the current scientific enterprise. A renewed system that recognizes research that crosses the artificial and traditional boundaries and disciplines could thus significantly spur innovation towards relatively uncharted territories, like the shaded triangle of the studied impact space. To be clear, our point is not that previous Nobel Prizes, or other discipline-focused prizes, were in any way undeserved or should have been awarded to other discoveries. Our point is more general: whatever the specific selection processes behind our most prestigious awards may be, they have become out of sync with reality and may be holding back long-needed developments[27]. Moving science into the twenty-first century will only be possible by rethinking the traditional boundaries between disciplines, or even by upending the concept of disciplines itself[28,29]—making sure that our scientific recognition and credit system is timely[21], open-minded[7] and quantitatively justified[30].

## Data availability

All data generated or analysed during this study are included in the supplementary information files of this published article.

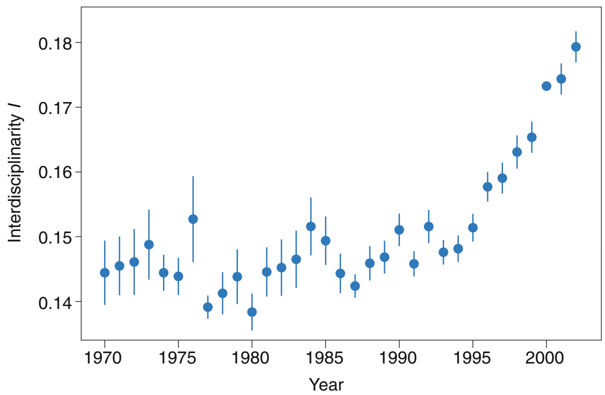


**Fig. 3 | Interdisciplinary research is on the rise.** We define a measure of interdisciplinary impact, $I = 1 - G$, using the Gini coefficient $G$, a standard measure for inequality, applied to the number of citations from different fields (Supplementary Information). The value of $I$ ranges from 0 to 1. If a paper has $I = 1$, then it received an equal amount of citations from each discipline; if $I = 0$, it received citations only from one field. The plot shows the evolution of $I$ of the top 10,000 papers from Fig. 2b over time, averaged over all papers published each year. Error bars denote standard error of the mean. Interdisciplinarity of these high-impact papers was approximately constant for over two decades but began to rise steadily from the mid-1990s.

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## Additional information

**Supplementary information** is available for this paper at https://doi.org/10.1038/s41567-018-0314-6.

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