RESEARCH ARTICLE SUMMARY

SCIENCE COMMUNITY

Quantifying the evolution of individual scientific impact

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INTRODUCTION: In most areas of human performance, from sport to engineering, the path to a major accomplishment requires a steep learning curve and long practice. Science is not that different: outstanding discoveries are often preceded by publications of less memorable impact. However, despite the increasing desire to identify early promising scientists, the temporal career patterns that characterize the emergence of scientific excellence remain unknown.

RATIONALE: How do impact and productivity change over a scientific career? Does impact, arguably the most relevant performance measure, follow predictable patterns? Can we predict the timing of a scientist's outstanding achievement? Can we model, in quantitative and predictive terms, scientific careers? Driven by these questions, here we quantify the evolution of impact and productivity throughout thousands of scientific careers. We do so by reconstructing the publication record of scientists from seven disciplines, associating to each paper its long-term impact on the scientific community, as quantified by citation metrics.

RESULTS: We find that the highest-impact work in a scientist's career is randomly distributed within her body of work. That is, the highest-impact work can be, with the same probability, anywhere in the sequence of papers published by a scientist—it could be the first publication, could appear mid-career, or could be a scientist's last publication. This random impact rule holds for scientists in different disciplines, with different career lengths, working in different decades and publishing solo or with teams, and whether credit is assigned uniformly or unevenly among collaborators.

The random impact rule allows us to develop a quantitative model, which systematically untangles the role of productivity and luck in each scientific career. The model assumes that each scientist selects a project with a random potential p and improves on it with a factor Q_i, resulting in a publication of impact $Q_i p$. The parameter Q_i captures the ability of scientist's i to take advantage of the available knowledge in a way that enhances ($Q_i > 1$) or diminishes ($Q_i < 1$) the potential impact p of a paper. The model predicts that truly high-impact discoveries require a combination of high Q and luck (p) and that increased productivity alone cannot substantially enhance the chance of a very high impact work. We also show that a scientist's Q, capturing her sustained ability to publish high-impact papers, is independent of her career stage. This is in contrast with all current metrics of excellence, from the total number of citations to the h-index, which increase with time. The Q model provides an analytical expression of these traditional impact metrics and allows us to predict their future time evolution for each individual scientist, being also predictive of independent recognitions, like Nobel prizes.

CONCLUSIONS: The random impact rule and the Q parameter, representing two fundamental characteristics of a scientific career, offer a rigorous quantitative framework to explore the evolution of individual careers and understand the emergence of scientific excellence. Such understanding could help us better gauge scientific performance and offers a path toward nurturing high-impact scientists, potentially informing future policy decisions. ■

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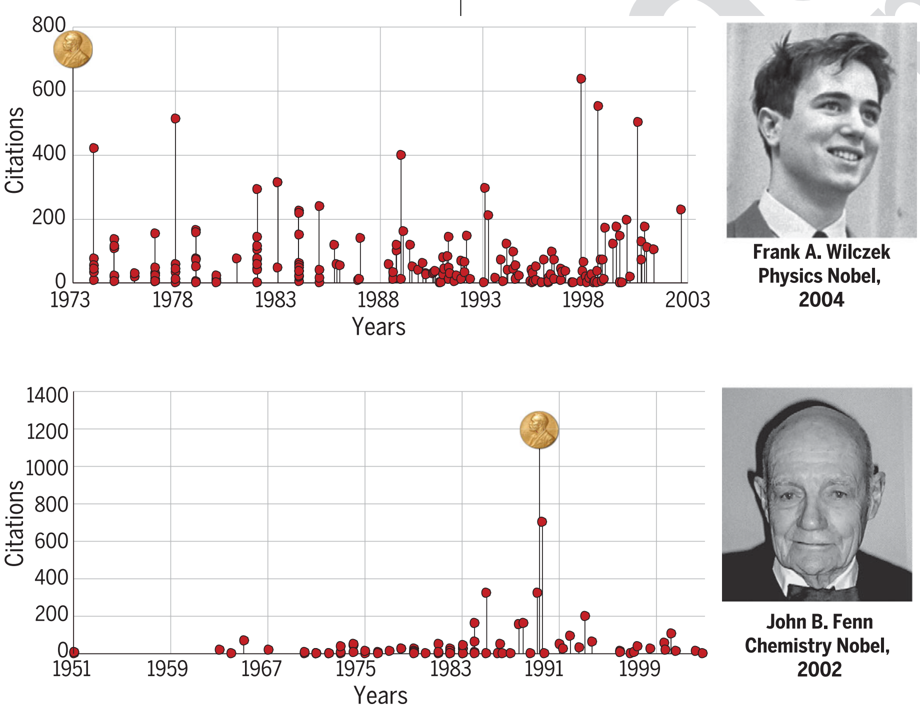

Random impact rule. The publication history of two Nobel laureates, Frank A. Wilczek (Nobel Prize in Physics, 2004) and John B. Fenn (Nobel Prize in Chemistry, 2002), illustrating that the highest-impact work can be, with the same probability, anywhere in the sequence of papers published by a scientist. Each vertical line corresponds to a research paper. The height of each line corresponds to paper impact, quantified with the number of citations the paper received after 10 years. Wilczek won the Nobel Prize for the very first paper he published, whereas Fenn published his Nobel-awarded work late in his career, after he was forcefully retired by Yale. Image of Frank A. Wilczek is courtesy of www.societyforscience.org. Image of John B. Fenn is available for public domain use on Wikipedia.org.

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Cite this article as R. Sinatra *et al.*, *Science* **354**, aaf5239 (2016).
DOI: 10.1126/science.aaf5239

MS no: RAaaf5239/HJ/