Interdisciplinary Scientists are More Innovative than Interdisciplinary Teams

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Significance Statement (Maximum: 120 words)

Modern science is built on specialization and teamwork, under the assumption that complex knowledge can be divided across experts and recombined to produce innovation. Our findings challenge this assumption. Analyzing millions of scientific publications, we show that scientists who integrate knowledge across fields produce more innovative work than teams of specialists covering the same breadth of fields. At the same time, such generalists are becoming increasingly rare, as they collaborate less and publish more slowly. These results reveal a limit to the division of labor in scientific discovery: some breakthroughs require integration rather than coordination. Supporting generalist researchers may therefore be essential for sustaining innovation.

Abstract (Maximum: 250 words)

Scientific work has become increasingly specialized and team-based, reflecting the belief that complex knowledge can be divided across experts and recombined through collaboration. We test this idea by comparing two forms of interdisciplinarity: knowledge integrated within scientists and knowledge distributed across teams. Using 49 million publications by 3 million scientists from 1900 to 2020, we identify scientists who publish across multiple fields, indicating integration of knowledge across domains, and compare their work to that of teams of specialists covering the same breadth of fields. We find that these scientists produce more innovative research than such teams, as measured by both disruption and atypicality. This advantage persists after accounting for team size, publication year, and field differences. At the same time, such scientists are becoming increasingly rare. Their share declines over time, and they are more likely to work in small teams or alone. They also publish more slowly and are less likely to repeatedly cite the same core references. Together, these findings show that interdisciplinarity is not equivalent across levels: it is most effective when integrated within a single scientist rather than distributed across teams. Scientific innovation may therefore depend not only on combining expertise, but also on sustaining researchers who can bridge fields themselves.

Introduction

Scientific work has become increasingly specialized and team-based (1, 2). As knowledge expands, researchers focus on narrower domains, while collaboration enables complex problems to be addressed by dividing effort across individuals (3). This organization of science rests on a central assumption: complex knowledge can be decomposed into components and coordinated across contributors, allowing teams to accomplish tasks beyond the reach of individuals.

A growing body of research highlights the benefits of this division of labor within scientific teams (4). At the same time, prior work shows that combining ideas from different fields can produce more novel and impactful discoveries (5, 6). However, this literature largely treats interdisciplinarity as a team-level property, emphasizing how knowledge is distributed across collaborators. Far less attention has been paid to an alternative form: the integration of knowledge within individual scientists (7). Whether these two forms—knowledge integrated within individuals and knowledge distributed across teams—are equivalent in their capacity to generate innovation remains an open question (8).

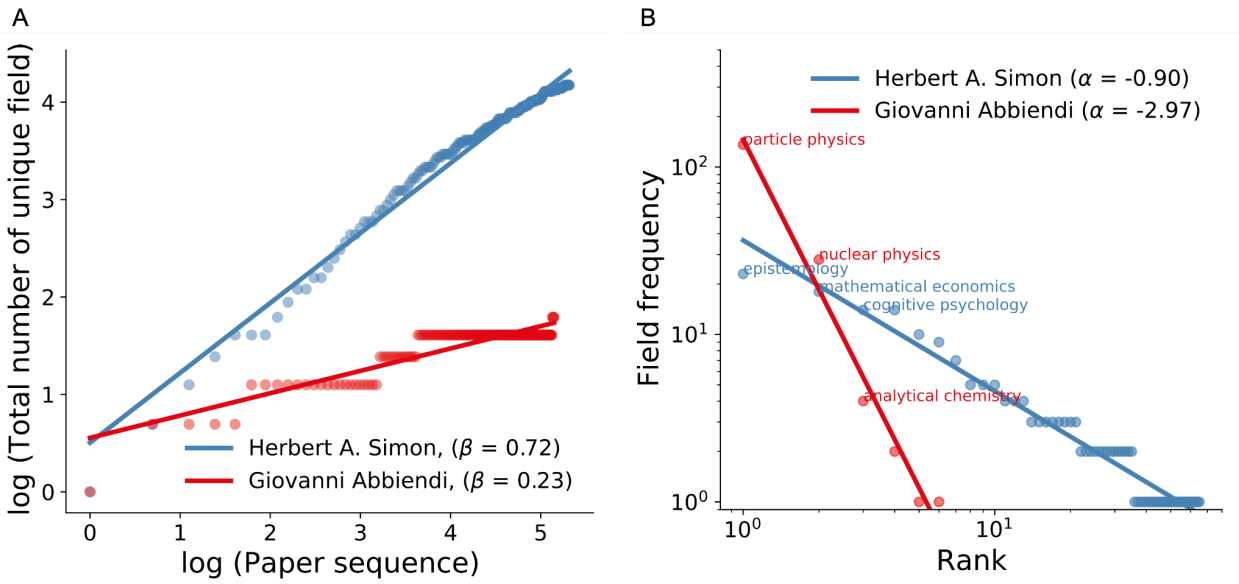
This distinction is consequential. In organizational settings, diversity within units and diversity across units often produce different outcomes, indicating that integration and coordination are not interchangeable (9). In science, however, the prevailing view assumes that distributing expertise across collaborators can substitute for integrating knowledge within individuals. If this assumption holds, then the increasing division of labor should have accelerated innovation. But if integrating knowledge within scientists plays a distinct role, organizing knowledge across people may not fully substitute for integration within individuals. This possibility is consistent with recent evidence that scientific productivity continues to rise while breakthrough innovation appears to slow (10–12).

Here, we test this idea by comparing two forms of interdisciplinarity: knowledge integrated within scientists and knowledge distributed across teams. Using 49 million publications by 3 million scientists from 1900 to 2020, we identify scientists who publish across multiple fields as a measure of cross-domain integration, and compare their work to that of teams of specialists spanning the same breadth of fields. This design isolates how the locus of integration—within individuals versus across collaborators—shapes scientific outcomes, while accounting for differences in knowledge diversity, publication year, field, and team size. We find that these two forms of interdisciplinarity are not equivalent: scientists who integrate knowledge across fields produce more innovative research than teams that distribute the same knowledge across specialists.

Beyond this central comparison, we document a paradox in the organization of modern science. Scientists who integrate knowledge across fields are becoming increasingly rare, and their behavior departs from the dominant model of science, which favors large-scale collaboration and rapid publication. These scientists are more likely to work in small teams or alone, publish more slowly, and rely less on repeatedly cited core references, consistent with the greater learning costs required to integrate knowledge across domains. Together, these findings indicate that scientific innovation depends not only on combining expertise, but also on sustaining researchers who integrate knowledge across domains—an increasingly disfavored mode of scientific work.

Interdisciplinary Scientists Expand Across Fields More Rapidly

To characterize how scientists engage with multiple fields over the course of their careers, we examine how the number of distinct fields F grows with cumulative publications N. We find that the number of unique fields increases with the number of publications according to a power-law relationship, $F \sim N^{\beta}$, where the exponent β captures the rate at which scientists expand into new fields. This scaling pattern provides a simple way to distinguish interdisciplinary scientists from specialists. Interdisciplinary scientists exhibit substantially higher exponents than specialists, indicating that each additional publication is more likely to involve a new field, whereas specialists tend to remain within familiar fields.



For example, Herbert A. Simon, widely recognized for contributions spanning political science, computer science, and psychology, exhibits a high exponent (β=0.72), consistent with rapid cross-field expansion. In contrast, Giovanni Abbiendi, whose work is concentrated within physics, shows a much lower exponent (β=0.23; Fig. 1A).

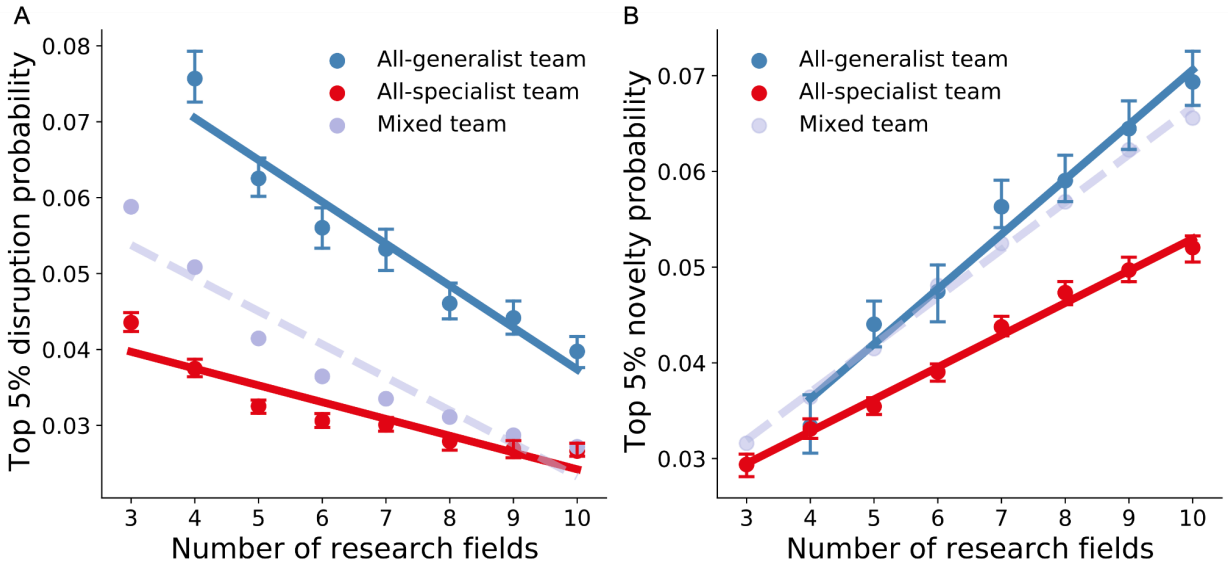
This growth pattern is not arbitrary: it is consistent with the Zipf-like distribution of publications across fields, suggesting a common scaling structure underlying how scientists allocate effort across domains. While all scientists exhibit a long-tailed distribution of publications across fields, interdisciplinary scientists maintain a more even distribution, whereas specialists concentrate heavily on a small number of core domains (Fig. 1B). This difference is reflected in the decay exponent α, with smaller values indicating broader engagement across fields.

Together, these results establish a key distinction between the two groups: interdisciplinary scientists do not simply span more fields than specialists, but expand into new fields more rapidly and distribute their work more evenly across fields. Importantly, because β is estimated from a growth process, it is independent of career length or total productivity. This distinguishes our approach from prior measures based on diversity indices of paper references, which are sensitive to the number of papers and vary across career stages (6, 7, 13). Instead, the scaling

exponent captures a long-term, stable behavioral pattern of how scientists navigate across fields, providing a foundation for comparing the innovative performance of generalists and specialists.

Interdisciplinary Scientists Produce More Innovative Work Than Teams

We next examine whether integrating knowledge within individual scientists leads to different innovative outcomes than distributing the same breadth of knowledge across teams. To do so, we compare the innovative performance of interdisciplinary scientists to that of teams of specialists that collectively span the same number of fields. This comparison isolates the effect of how knowledge is organized—within individuals versus across collaborators—while holding constant the breadth of knowledge involved.



We measure innovation using both disruption and novelty. Disruption captures the extent to which a paper displaces prior work, as indicated by subsequent citations (14, 15), whereas novelty captures the surprise of reference combinations within a paper (5). These two measures reflect distinct dimensions of innovation—novelty captures the recombination of ideas, whereas disruption captures the creative destruction of ideas—and are known to behave differently (16). Across both measures, we find a consistent pattern: interdisciplinary scientists who integrate knowledge across fields produce more innovative work than teams that distribute the same knowledge across specialists (Fig. 2A–B). This advantage persists after accounting for differences in team size, career age, publication year, and field (see SI Appendix).

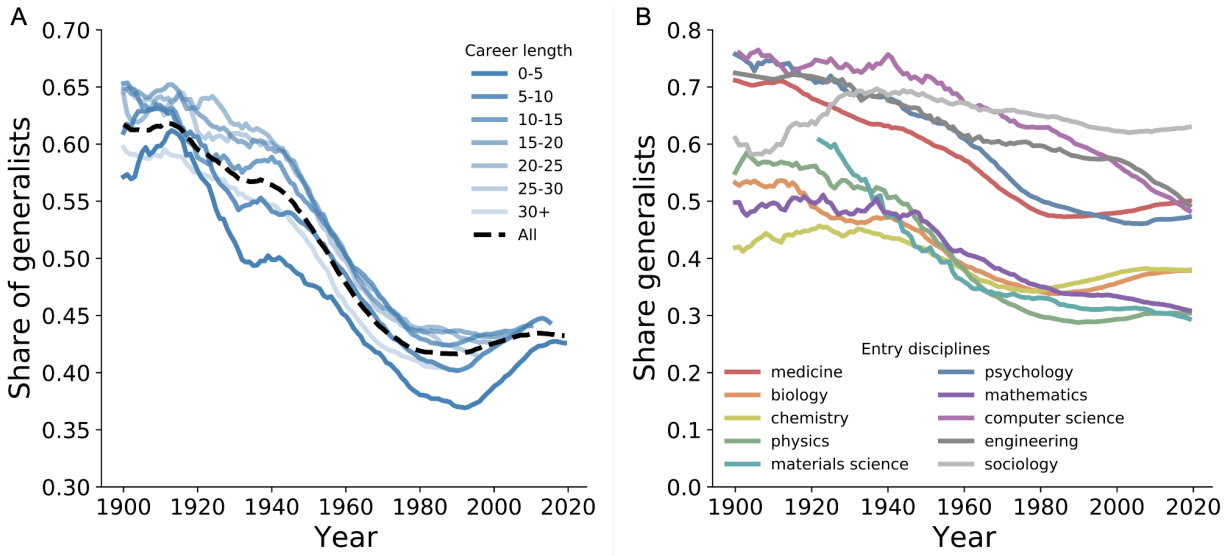
These findings show that interdisciplinarity is not equivalent across levels. Integrating knowledge within a single scientist produces different—and more innovative—outcomes than distributing the same knowledge across a team. This result suggests that the advantage of integration is not driven by differences in knowledge diversity, but by how that knowledge is organized and challenges the assumption that teams can fully substitute for individuals in combining expertise.

Interdisciplinary Scientists Are Declining

Although interdisciplinary scientists produce more innovative work, their prevalence has declined over time. The share of scientists who actively expand into new fields, quantified by a

scaling exponent capturing how rapidly scientists enter new fields with additional publications and exceeding 0.72, has steadily decreased over the past century. This pattern holds across different career lengths, indicating that the decline is not driven by shorter careers but reflects a broader shift in research behavior (Fig. 3A).

Importantly, this decline is not confined to specific domains. Using the field of a scientist's first publication as their entry field, we examine the share of interdisciplinary scientists within each cohort. Across nearly all fields, the fraction of scientists with high scaling exponents declines substantially over time, despite differences in baseline levels of interdisciplinarity scientists across fields. This consistency suggests that the observed decline reflects a system-wide shift in the organization of scientific work rather than changes in field composition.



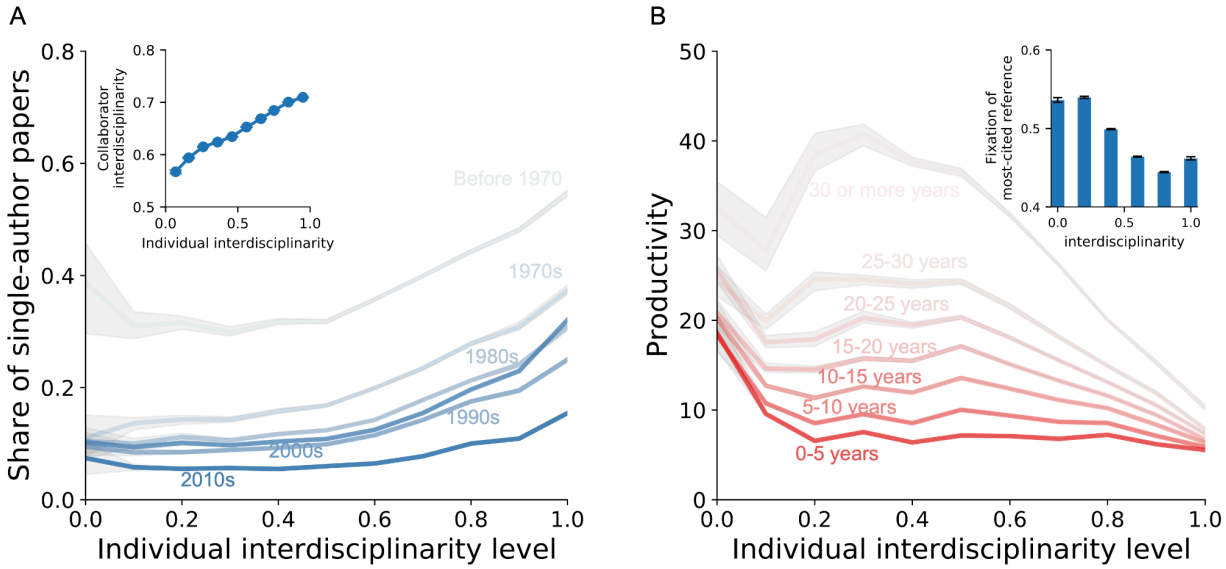
Interdisciplinary Scientists Work More Independently and Publish Less

We next examine how the work patterns of interdisciplinary scientists differ from those of specialists. Scientists with higher scaling exponents—those who expand more rapidly across fields—tend to work alone or in smaller teams. This relationship holds consistently across entry cohorts, indicating that it is not driven by temporal changes in team size but reflects a stable association between individual research style and collaboration patterns (Fig. 4A). When they do collaborate, they tend to work with others who share a similar research style—other interdisciplinary scientists rather than specialists—as indicated by the positive association between a scientist's scaling exponent and that of their collaborators (Fig. 4A, inset).

However, these collaboration patterns are linked to lower research productivity. At the individual level, the scaling exponent is negatively associated with the total number of papers, controlling for career length (Fig. 4B), entry cohort, first-paper discipline, and average team size (see SI Appendix). This pattern suggests that integrating knowledge across fields is associated with lower productivity (6).

To better understand the source of this difference, we examine how scientists rely on prior knowledge. Prior work shows that scientists repeatedly draw on a small set of core references

over their careers: although most references are cited only once, a single most-cited reference often recurs across many publications (17). Using this measure as an indicator of reliance on established knowledge, we find that the share of citations to a scientist's most frequently cited reference declines with the scaling exponent (Fig. 4B, inset). Interdisciplinary scientists therefore rely less on canonical prior work, indicating that they engage more broadly with new literature rather than repeatedly building on a stable core.



Taken together, these results suggest that integrating knowledge across fields requires more effort. Interdisciplinary scientists work in smaller teams, produce fewer outputs, and rely less on established knowledge. These patterns are consistent with the greater effort required to learn, combine, and contribute across multiple domains, helping explain why such scientists are both more innovative and increasingly rare.

Discussion

Our findings show that interdisciplinarity is not equivalent across levels. While prior work emphasizes the benefits of combining knowledge across fields (5, 6, 13), we show that how such knowledge is organized matters: integrating knowledge within individual scientists produces more innovative outcomes than distributing the same breadth of knowledge across teams. This result challenges a central assumption in the organization of modern science—that teams of specialists can substitute for individuals who span multiple domains.

At the same time, we document a paradox: despite their stronger innovative performance, interdisciplinary scientists are becoming less common. Our results suggest that this decline reflects the costs of interdisciplinary work. These scientists tend to work in smaller teams, rely less on established knowledge, and publish fewer papers. In a system that rewards productivity and collaboration, such costs may discourage interdisciplinary research at the individual level, even if it remains valuable for innovation.

These findings have implications for the evaluation and support of scientific research. Current incentive structures may disproportionately reward specialization and collaboration while

undervaluing integrative work (18). If major scientific advances depend on integrating knowledge within a single mind, supporting such researchers may be essential for generating transformative ideas.

Our analysis is observational and based on publication data, and therefore has limitations. Although we control for key factors, unobserved differences may influence both research style and outcomes. In addition, our measure captures realized interdisciplinarity rather than underlying cognitive processes. Future work could examine how individuals integrate knowledge and how institutional contexts shape these dynamics (19).

Materials and Methods

We analyze large-scale publication data to examine how knowledge is integrated within individuals and distributed across teams. Our dataset is based on the OpenAlex corpus, comprising approximately 49 million journal articles published between 1900 and 2020 and linked to 3 million disambiguated scientists. For each scientist, we reconstruct career trajectories by ordering publications over time.

To quantify interdisciplinarity at the individual level, we measure how the number of distinct fields F grows with cumulative publications N. We model this relationship using a power-law relationship, $F \sim N^{\beta}$, where the exponent β captures the rate at which a scientist expands into new fields. Higher values of β indicate more rapid cross-field expansion and are used to identify interdisciplinary scientists. Fields are assigned to publications using the Microsoft Academic Graph scientific taxonomy (20), and each scientist's field coverage and productivity profile is constructed from the distribution of their publications across fields.

We evaluate innovation using two complementary measures. Disruption is defined based on subsequent citation patterns and captures the extent to which a paper displaces prior work (21). Novelty is measured as the atypicality of reference combinations within a paper, reflecting the extent to which it recombines knowledge from distant fields (5). These measures capture distinct dimensions of innovation (16) and are analyzed jointly throughout the study.

To compare knowledge integration within individuals to its distribution across teams, we construct matched sets of scientists and teams that span the same breadth of fields. Teams are defined based on coauthorship, and field coverage is measured at the paper level. This design allows us to isolate how knowledge is organized—within individuals versus across collaborators—while holding constant the breadth of knowledge involved. Additional paper-level metadata, including publication year, team size, and field assignments, are used as controls in the analysis.

To examine how scientists rely on prior knowledge, we identify each scientist's most frequently cited reference across their publications and measure the share of citations to this reference as an indicator of reliance on established knowledge. Additional robustness checks and alternative specifications are reported in the SI Appendix.

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