Essays on the Organization of Science and Innovation

by *Robert Ward*

This talk

~25 mins of slides

Please hold
questions until
the end

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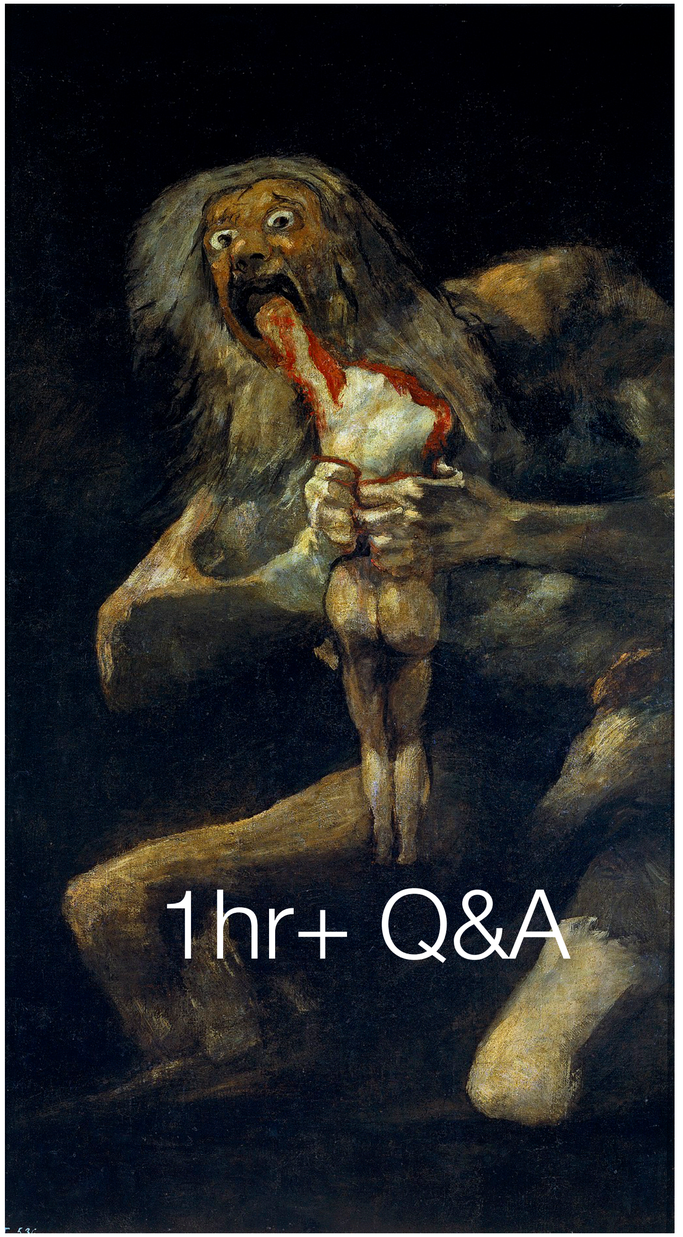

How should we organize people and information to produce good ideas?

Chapter One
Products

Chapter Two
Teams

Chapter Three
Ecosystems

Chapter One — Products
Interdisciplinarity and Reception

We promote interdisciplinary research to produce more useful scientific knowledge

But have little theory, methods, evidence to support that claim

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How are interdisciplinary publications received by the scientific community?

Interdisciplinary research

> “integrates perspectives, information, data, techniques, tools, concepts, and/or theories from two or more disciplines” NASEM, 2005

Current approach

Articles are bags of disciplinary knowledge with varying diversity

The problem

Impossible to distinguish more and less integrated texts

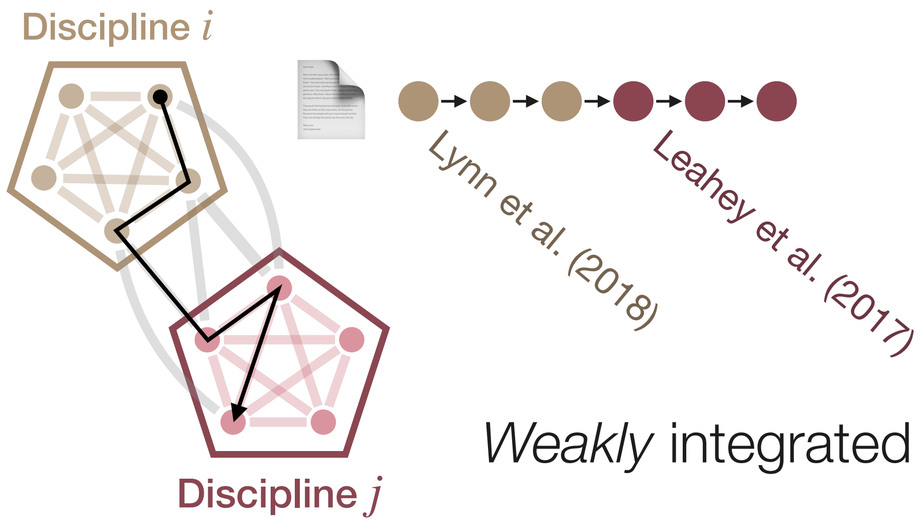
Current approach

Articles are bags of disciplinary knowledge with varying diversity

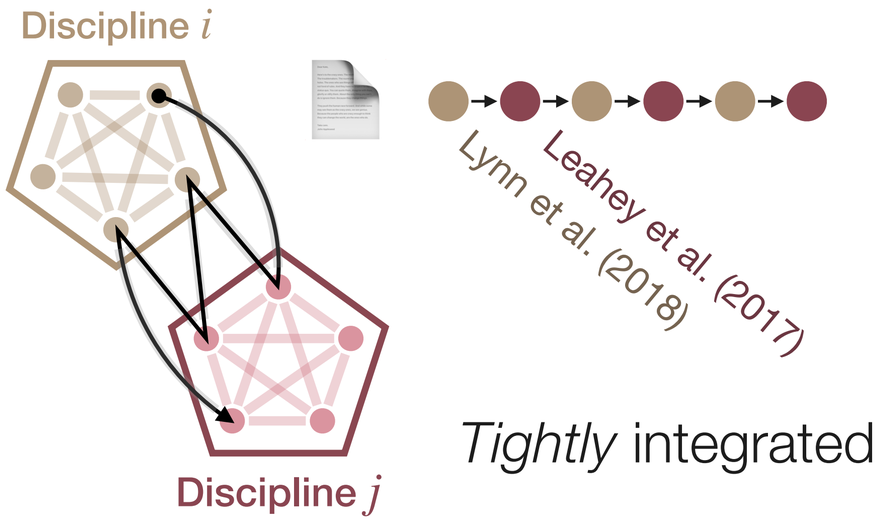
The problem

Impossible to distinguish more and less integrated texts

Same combination, varying interdisciplinarity



Weakly integrated



Tightly integrated

More interdisciplinary

Quantifying interdisciplinarity

How disordered or surprising is the text relative to the disciplinary structure of science?

$$\langle S \rangle = \sum_i p_i \sum_j p_{ij} \log_2 \frac{1}{\phi_{ij}}$$

Units are bits

$\langle S \rangle$ can be decomposed into a combinatorial and an integrative dimension

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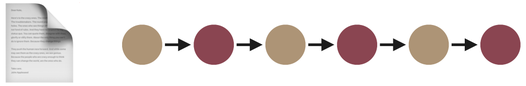

Article-specific probabilities
Describe the first-order random walk parsed from its text

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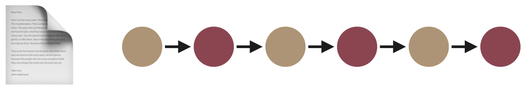

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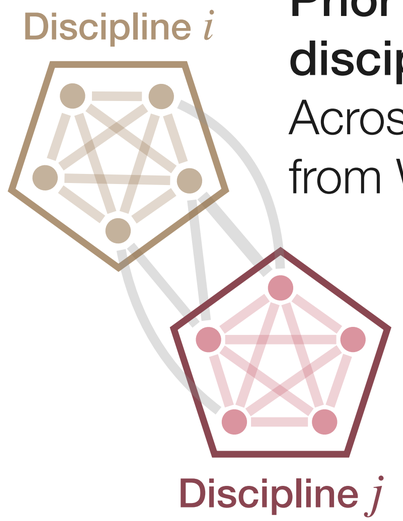


Prior probability of disciplinary connection
Across 66 million articles from WoS (1980-2019)

$\langle S \rangle$ can be decomposed into a combinatorial and an integrative dimension

Effects on Reception

Two main predictions

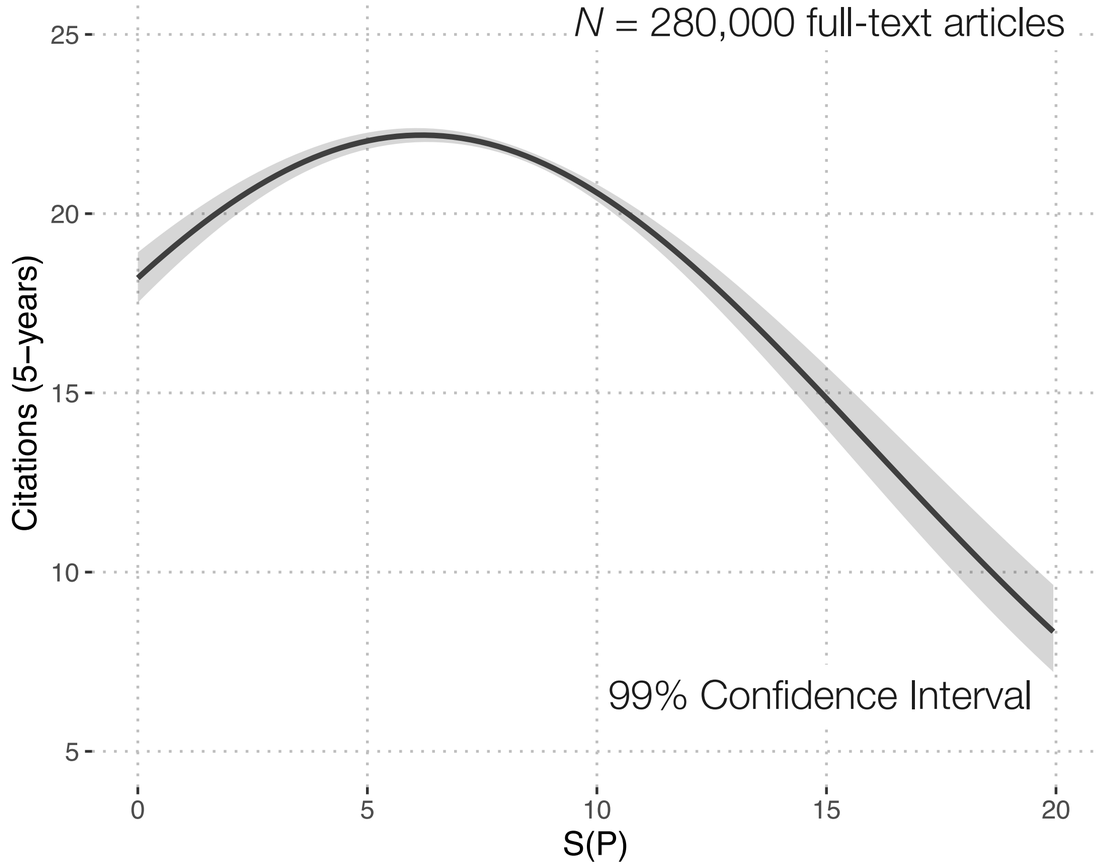
I. Highly interdisciplinary articles are more readily discarded but provoke deeper engagement

II. Integration functions to moderate perception of combination

Citation Counts	Citation Depth	Citation Breadth
Number of citations within 5yrs of publication	Probability of multiple referencing within citing articles	Entropy of citing disciplines and journals

Preliminary results

Interdisciplinarity and Citation Counts*



Additional results

I. Comparisons to previous methods
II. Citation Breadth
III. Citation Depth
IV. Decomposed results for (*, II,III)

Citation behavior is consistent with experimental evidence on human information processing

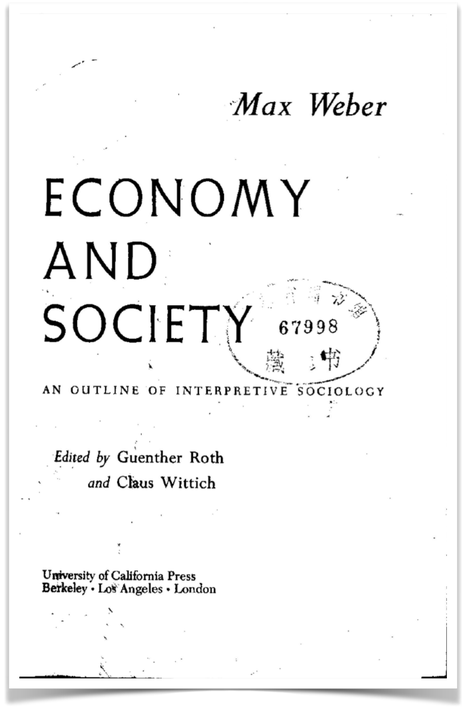
Contributions

I. New measures of interdisciplinarity and its components
    I. Increased validity Wang and Schneider, 2020; Zwanenburg et al., 2022
    II. Cognitive grounding Aslin et al. 2012; Lynn and Bassett, 2018
II. New outcomes and evidence
III. Transportable to other category systems Rosch 1978; Hannan et al. 2019

Chapter Two — Teams

Endogenous Division of Labor

Managed



Max Weber

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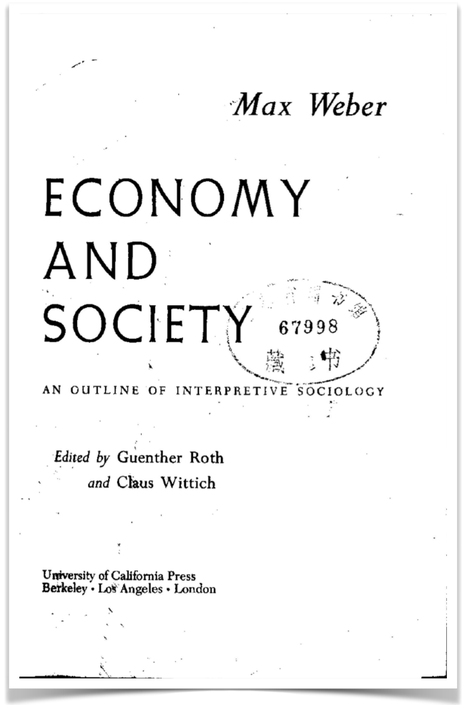
Division of Labor 亚 You

Managed



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Division of Labor ⫫ You

Self-Organized

Fig. 3-1 Method to working without a boss

step 1. Come up with a bright idea
step 2. Tell a coworker about it
step 3. Work on it together
step 4. Ship it!

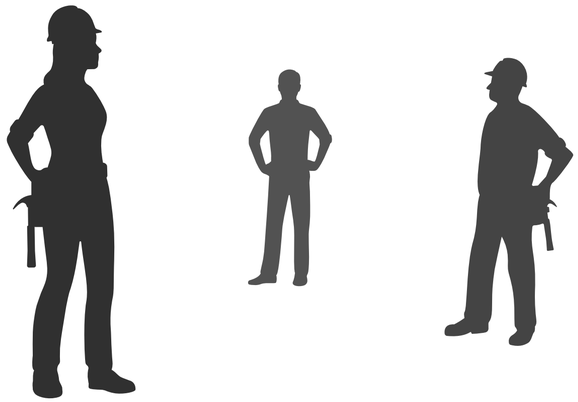
VALVE | METHOD DIAG. 3

You → Division of Labor

How does team composition affect task allocation and innovation?

Endogenous Division of Labor

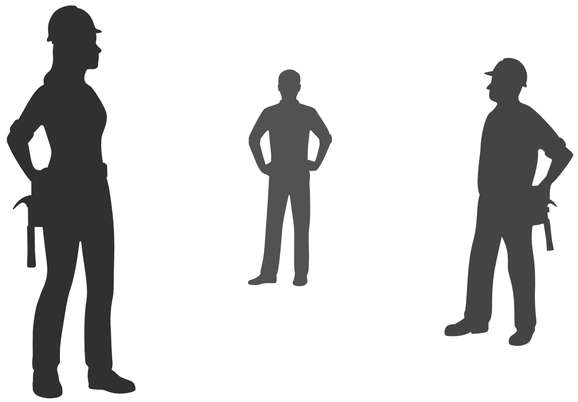
Team Composition



Familiarity	Who do you know?
Similarity	Who are you like?
Skills	What can you do?
Preferences	What do you want to do?

Endogenous Division of Labor

Team Composition



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Joint Task Allocation

$$\Pr\left[\text{task}_i = \text{task}_j \mid X_{ij}\right]$$

- ↑ with dyadic familiarity
- ↑ with dyadic similarity
- ↓ with task interdependence
- ↓ with distrust

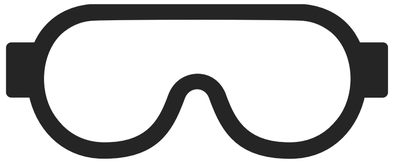
Effects of Familiarity/Similarity on Task Performance

Teams perform tasks with distinct information processing requirements

Generation

↷ Novelty

↓ σ^2 Quality



Implementation

⇊ Novelty

↑ Quality

Coordination

⇊ Novelty

↑ Quality

Research Design

Datasets

I. **Articles** (Nature, Science, PNAS, PLoS) — 95,000 teams, 5.8 million dyads
contribution statements, author histories, inferred demographics, citation outcomes

II. **iGEM Projects** — 114 teams, 3,900 dyads
survey + administrative + digital trace data

II. Effects of composition on structure

Predictors: familiarity, similarity

Outcome: probability of dyadic task performance

Estimator(s): Multilayer-ERGM, Dyadic Regression

III. Joint effects of composition and structure on innovation

Predictor: superfamily based on multilayer motif expression

Outcomes: novelty and usefulness/quality

Estimator(s): QMLE-Poisson, OLS

Contributions

I. Theory of self-organization in teams Puranam et al., 2014; Lee and Edmondson, 2017; Kleinbaum et al., 2013

II. Clarify mechanisms by which team composition affects innovation Guimera et al., 2005; Vedres and Cserpes, 2021

Chapter Three — Ecosystems

Unintended Consequences in Network Interventions

Research

Interorganizational networks known to affect innovation

Practice

Interventions that try to induce beneficial relationships often fail.

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Interorganizational networks known to affect innovation

Practice

Interventions that try to induce beneficial relationships often fail.

How should we design network interventions?

Constraints on network interventions

The networks we want to change are endogenous and evolving

I. Limited controllability → hard to force teams to interact

II. Induced homophily → can't independently change *composition* or *structure*

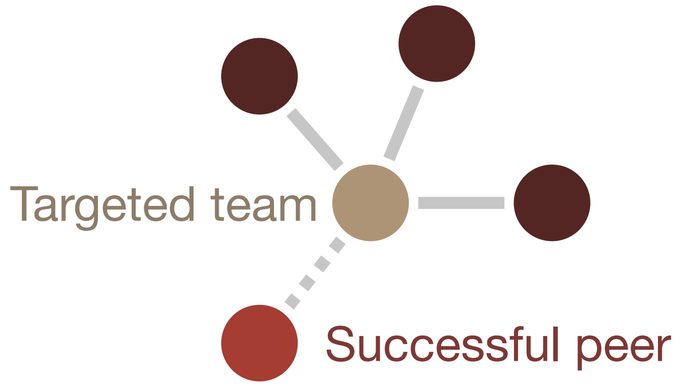
Policymakers often focus on changing either *composition* or *structure*

I. Increasing connectivity across fragmented groups (healthcare, science)
II. Inducing connections to peers with specific attributes (entrepreneurship, education)

Imagine two alternate worlds

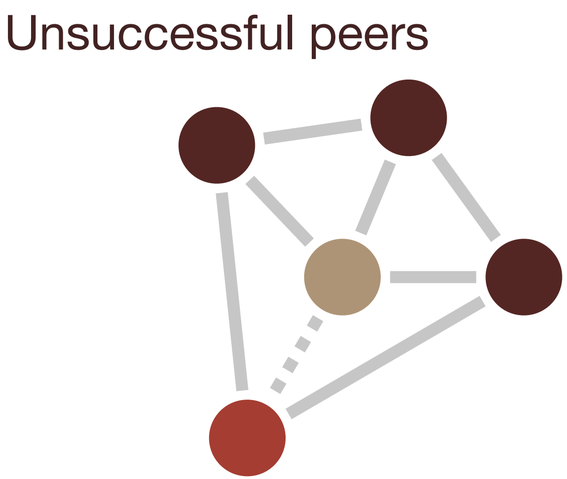
Both treat the targeted team with a successful peer, predicting ↑ innovation

I.



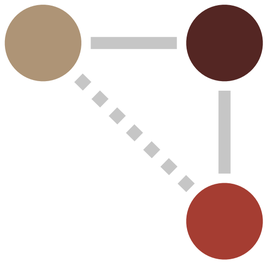
Low clustering, predicting ↑ **innovation**

II.



Dense clustering, predicting ↓ **innovation**

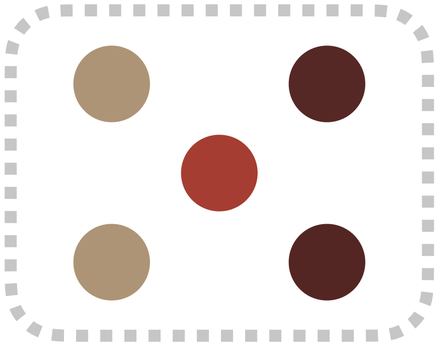
Families of network interventions



Local search through alters

↑ Clustering

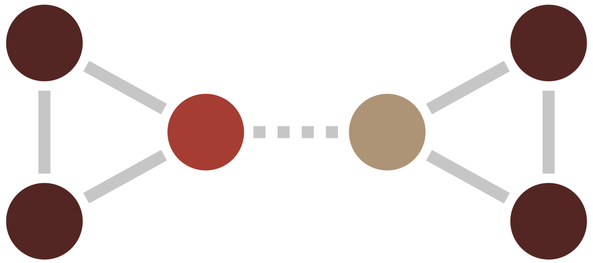
High Efficacy



Local search through colocation

↗ Clustering

Medium Efficacy



Distant search multiple mechanisms

↓ Clustering

Low Efficacy

Research Design

To understand how the design of network interventions affects their success

I. **Estimate average causal effect of local networks on team innovation**

   Data: 10-year panel of iGEM teams

   Treatment: 1 ≤ successful peer; local clustering coefficient

   Outcome: Probability of successful innovation

   Estimator: Exponential Random Graph-IPTW-Logit

II. **Simulate effect of each intervention under different initial conditions**

   Newman-Watts network (size, composition, global clustering coefficient)

   Interventions are rules about network change w/ stochastic compliance

   Payoffs calculated using parameters from (**I.**)

Contributions

I. New estimator Shalizi and Rinaldo, 2013; Eckles and Bakshy, 2021
II. Identify causal effect of local clustering on innovation Ahuja, 2000; Uzzi, 2005
III. Connects evidence on network dynamics to intervention problems Asikainen et al., 2020; Funk and Park, 2023

Timeline

Chapter One
Status: refining
Submit: Spring 2024
Target: Science

Chapter Two
Status: data cleaning
Submit: Fall 2025
Target: ASQ

Chapter Three
Status: analysis
Submit: Fall 2024
Target: PNAS / OrgSci

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Thank you!