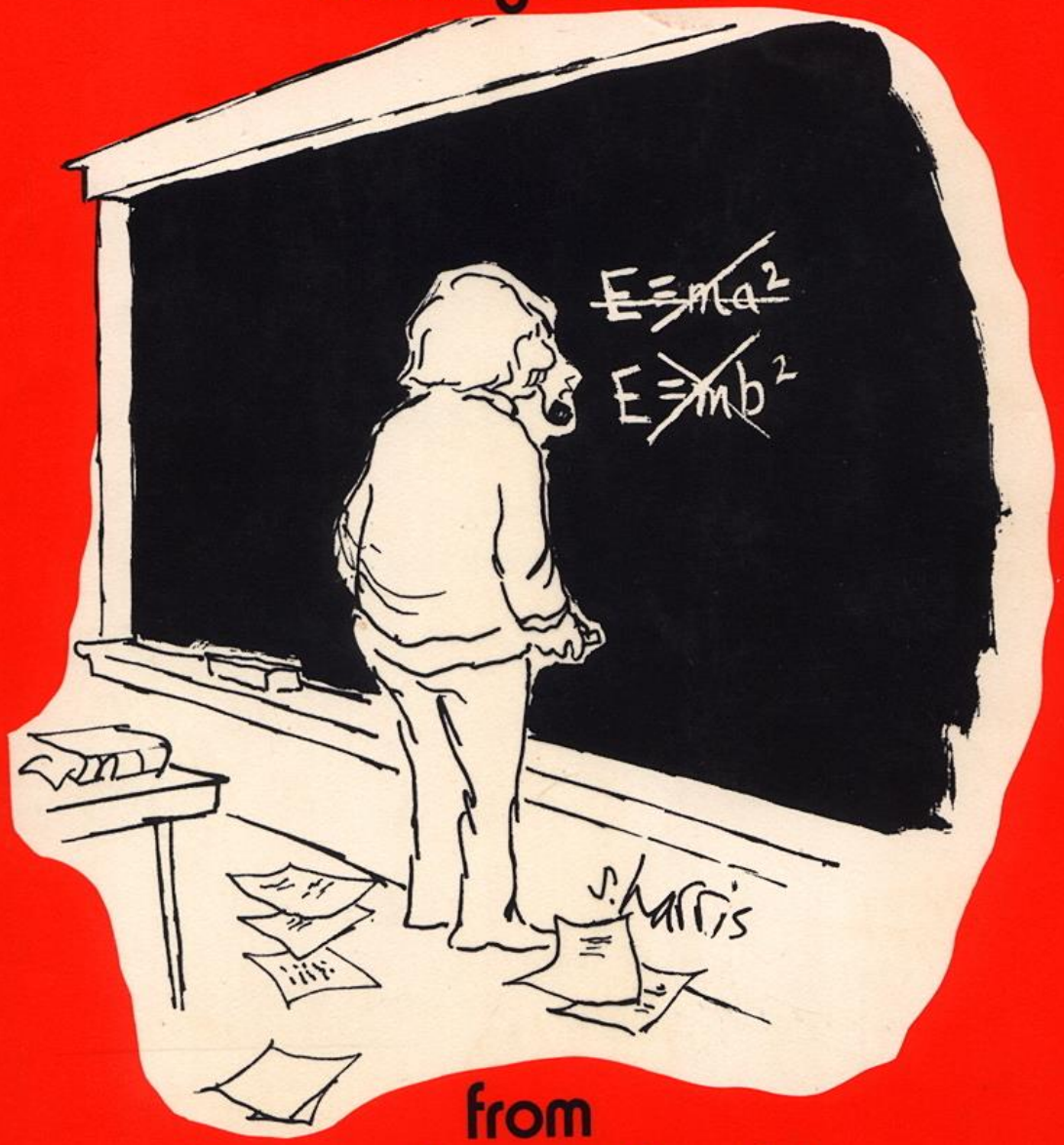
cartoons by

Sidney Harris



from

American Scientist

Scientific Creativity, Logic, and Chance:

The Integration of Product, Person, and Process Research Traditions

Introduction

- The Metasciences
  - History of Science
  - Philosophy of Science
  - Sociology of Science
  - Psychology of Science

The Two Psychologies of Science

- Experimental
  - The Process of Scientific Discovery
  - Creativity as Logical Problem Solving
- Correlational
  - The Person of the Creative Scientist
  - Creativity as Personal Attribute

Potential Integration?

- Third Point of Attack
- The Product
- Behavioral rather than Experimental or Psychometric
- *in vivo* rather than *in vitro* (Dunbar)

Creative Products

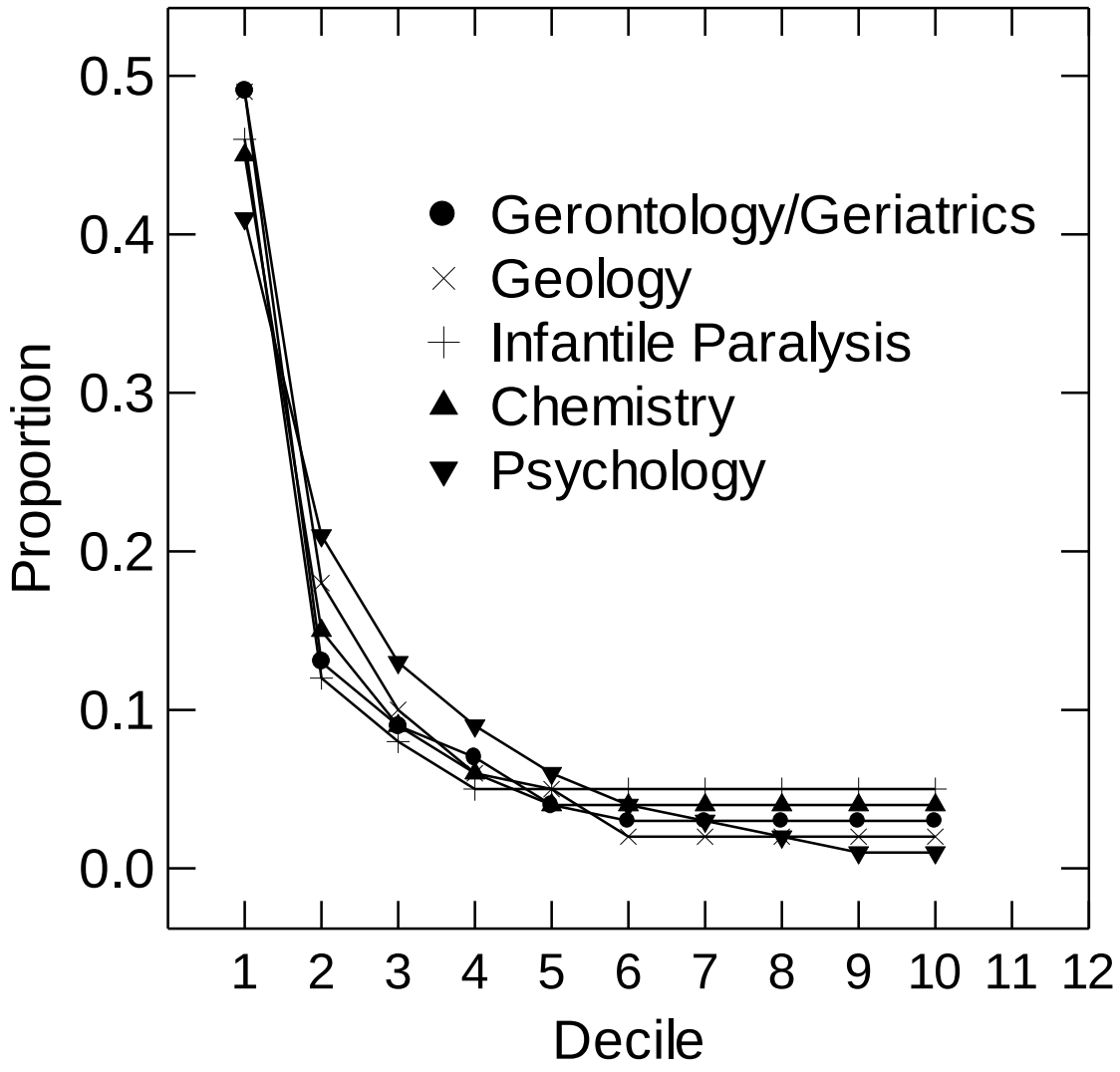
- Scientific Careers:
  - Publications
- Scientific Communities:
  - Multiples

Publications

- Individual Variation
- Longitudinal Change

Individual Variation

- Skewed Cross-sectional Distribution


0.5
0.4
0.3
0.2
0.1
0.0
Proportion
1
2
3
4
5
6
7
8
9
10
11
12
Decile
Gerontology/Geriatrics
Geology
Infantile Paralysis
Chemistry
Psychology

Individual Variation

- Skewed Cross-sectional Distribution
  - Lotka's Law

Individual Variation

- Skewed Cross-sectional Distribution
  - Lotka's Law
  - Price's Law

Individual Variation

- Skewed Cross-sectional Distribution
  - Lotka's Law
  - Price's Law
- Quantity-Quality Relation

Individual Variation

- Skewed Cross-sectional Distribution
  - Lotka's Law
  - Price's Law
- Quantity-Quality Relation
  - Mass Producers and Perfectionists?

Individual Variation

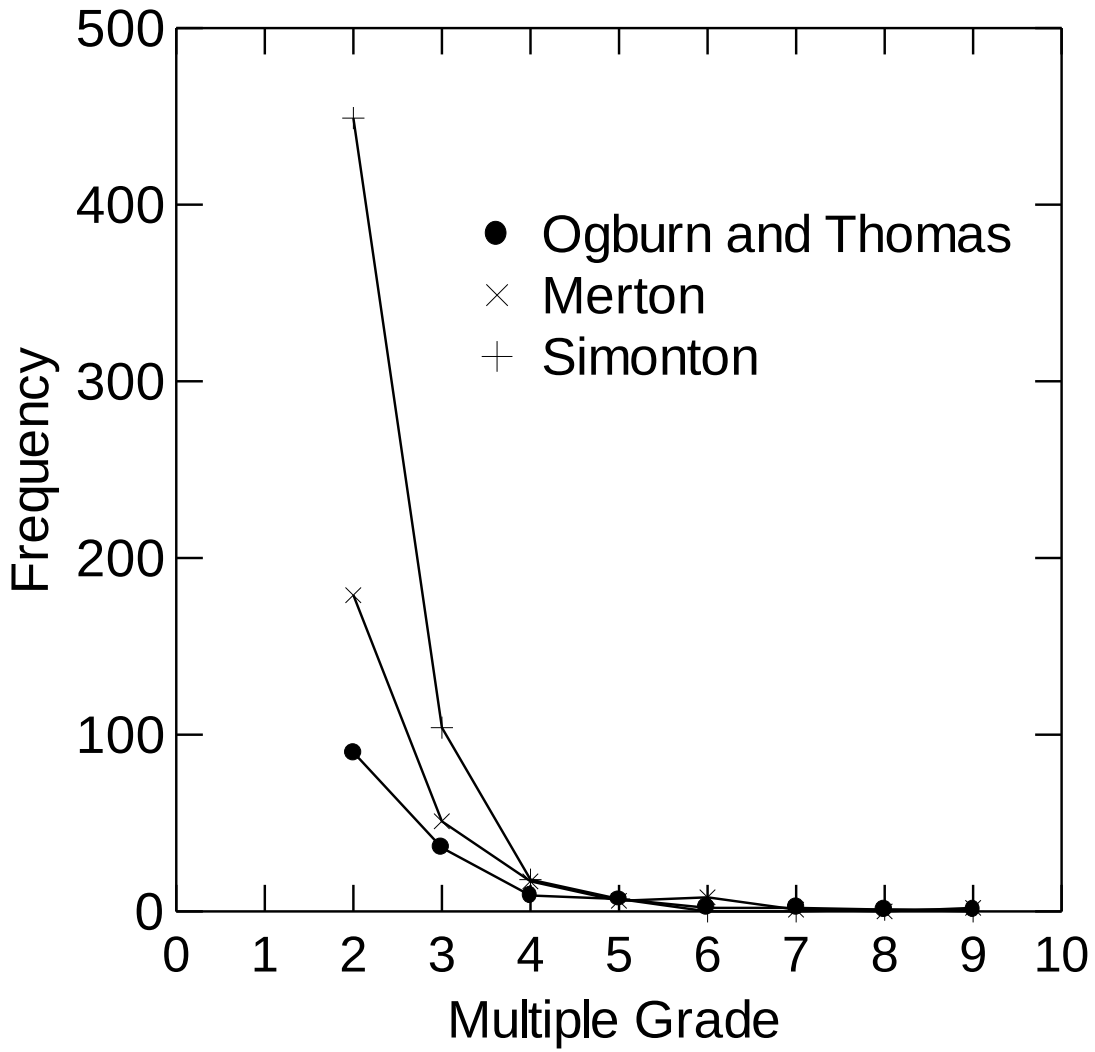
- Skewed Cross-sectional Distribution
  - Lotka's Law
  - Price's Law
- Quantity-Quality Relation
  - Mass Producers and Perfectionists?
  - No … the Equal-Odds Rule
  - Continuum Connecting the Silent and the Prolific

Longitudinal Change

- Randomness of Career-Wise Output
  - No “runs”
  - Poisson Distribution
- Quantity-Quality Relation
  - Random Fluctuation Around Quality Ratio Baseline
  - Hence, the Equal-Odds Rule

Multiples

- Distribution of Multiple Grades


500
400
300
200
100
0
Frequency
0
1
2
3
4
5
6
7
8
9
10
Multiple Grade
Ogburn and Thomas
Merton
Simonton

Multiples

- Distribution of Multiple Grades
- Temporal Separation of Multiple Discoveries

Multiples

- Distribution of Multiple Grades
- Temporal Separation of Multiple Discoveries
- Individual Variation in Multiple Participation

Multiples

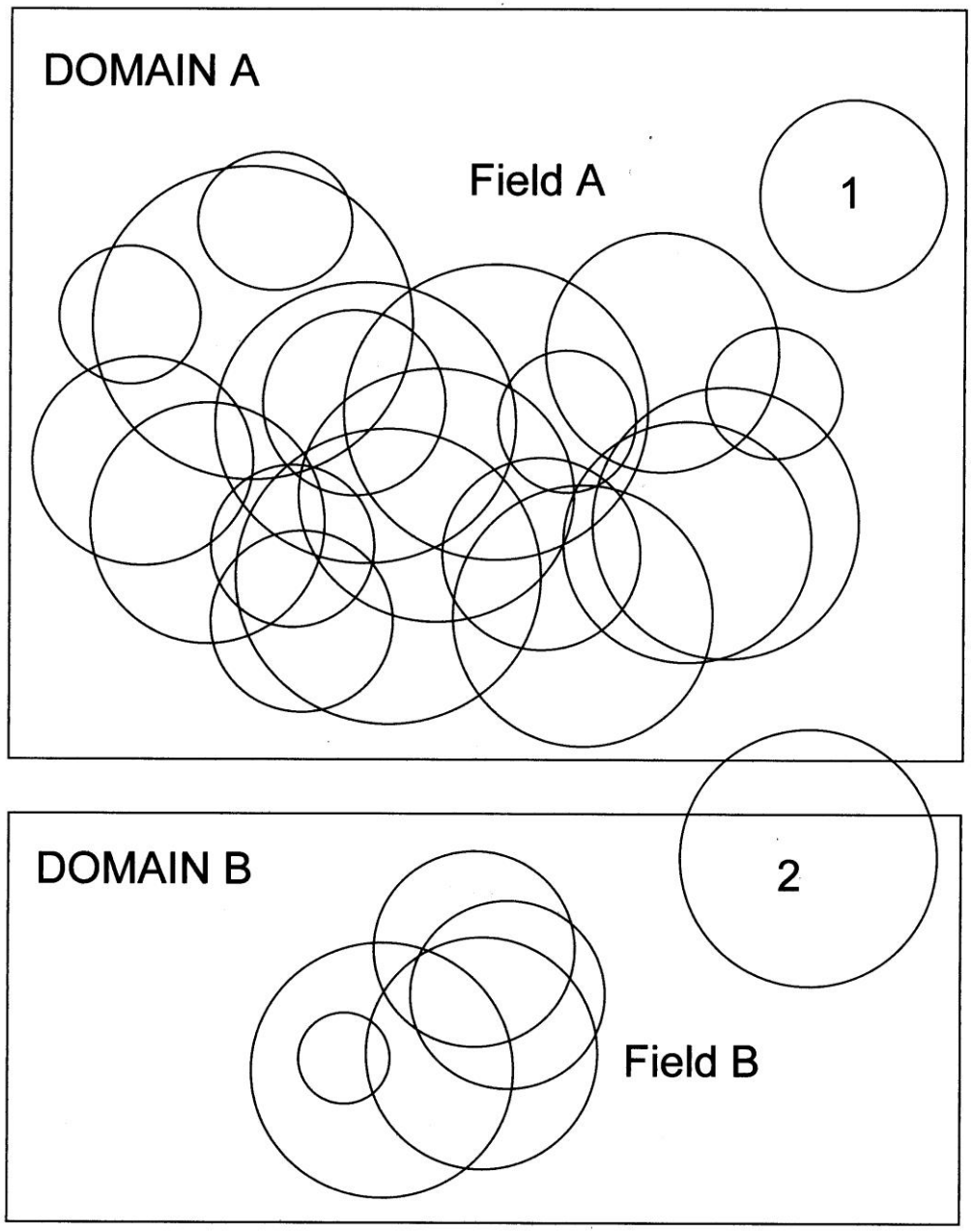
- Distribution of Multiple Grades
- Temporal Separation of Multiple Discoveries
- Individual Variation in Multiple Participation
- Degree of Multiple Identity

Combinatorial Processes

- Definitions
- Assumptions
- Implications
- Elaboration
- Objections

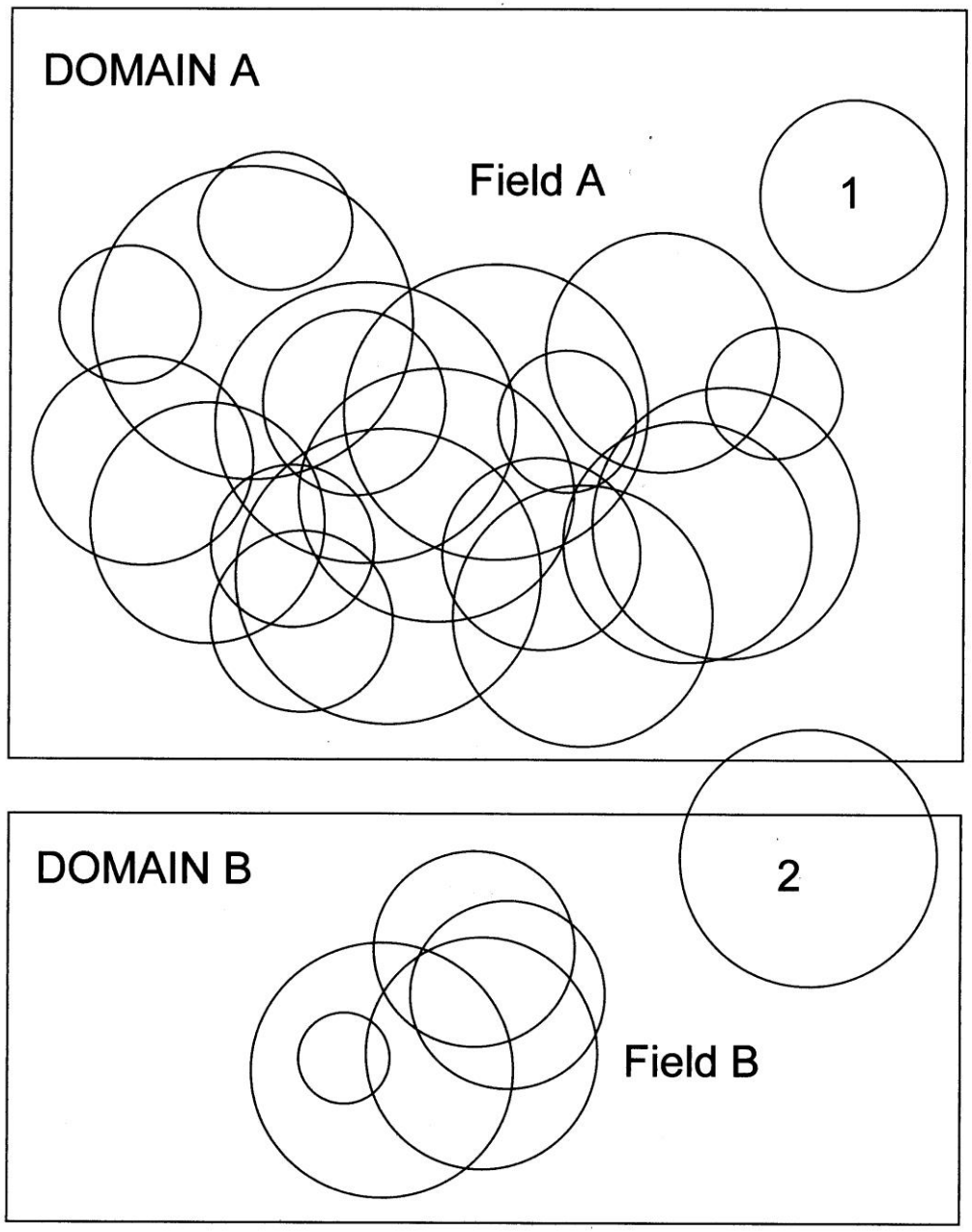
Definitions

- Individual
- Domain
- Field


DOMAIN A
Field A
1
DOMAIN B
2
Field B

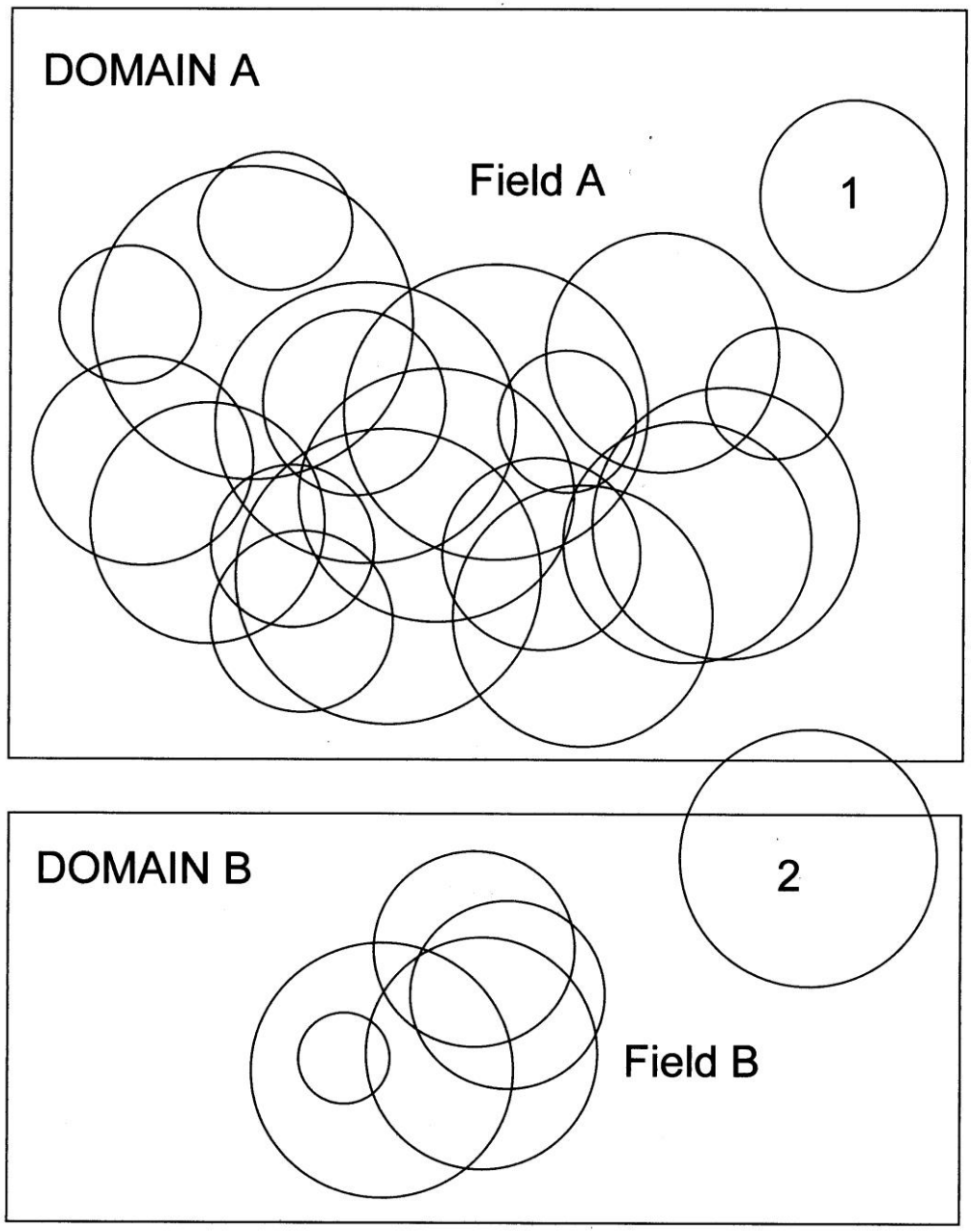
Assumptions

- Individual Samples from Domain Ideas


DOMAIN A
Field A
1
DOMAIN B
2
Field B

Assumptions

- Individual Samples from Domain Ideas
- Within-Field Variation in Sample Size


DOMAIN A
Field A
1
DOMAIN B
2
Field B

Assumptions

- Individual Samples from Domain Ideas
- Within-Field Variation in Sample Size
- Quasi-Random Combination of Ideas

Henri Poincaré (1921):
Ideas rose in crowds; I felt them collide until pairs interlocked, so to speak, making a stable combination.

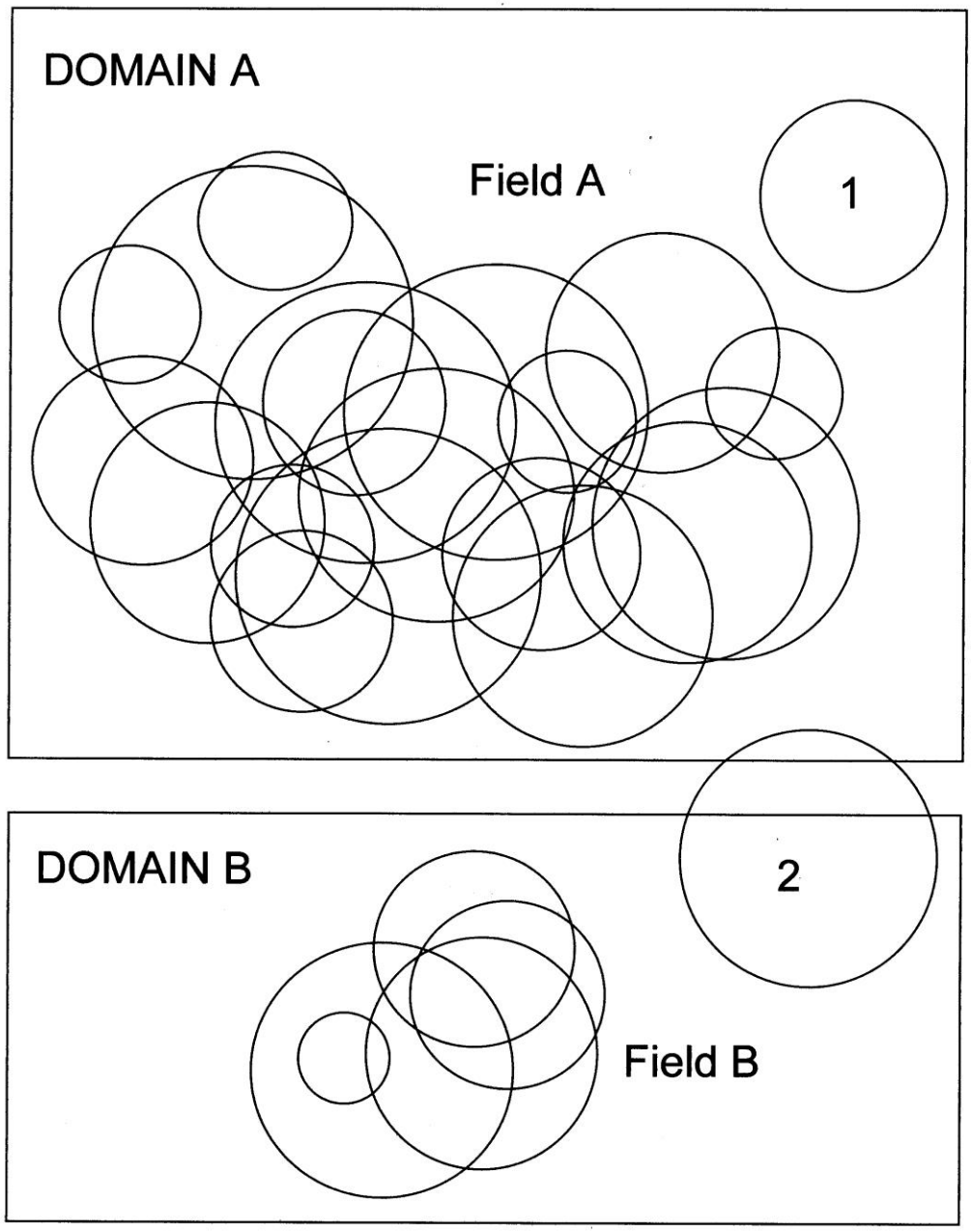
[These ideas are like] *the hooked atoms of Epicurus* [that collide] *like the molecules of gas in the kinematic theory of gases* [so that] *their mutual impacts may produce new combinations.*

Assumptions

- Individual Samples from Domain Ideas
- Within-Field Variation in Sample Size
- Quasi-Random Combination of Ideas
- Variation in Quality of Combinations

Assumptions

- Individual Samples from Domain Ideas
- Within-Field Variation in Sample Size
- Quasi-Random Combination of Ideas
- Variation in Quality of Combinations
- Variation in Size of Fields

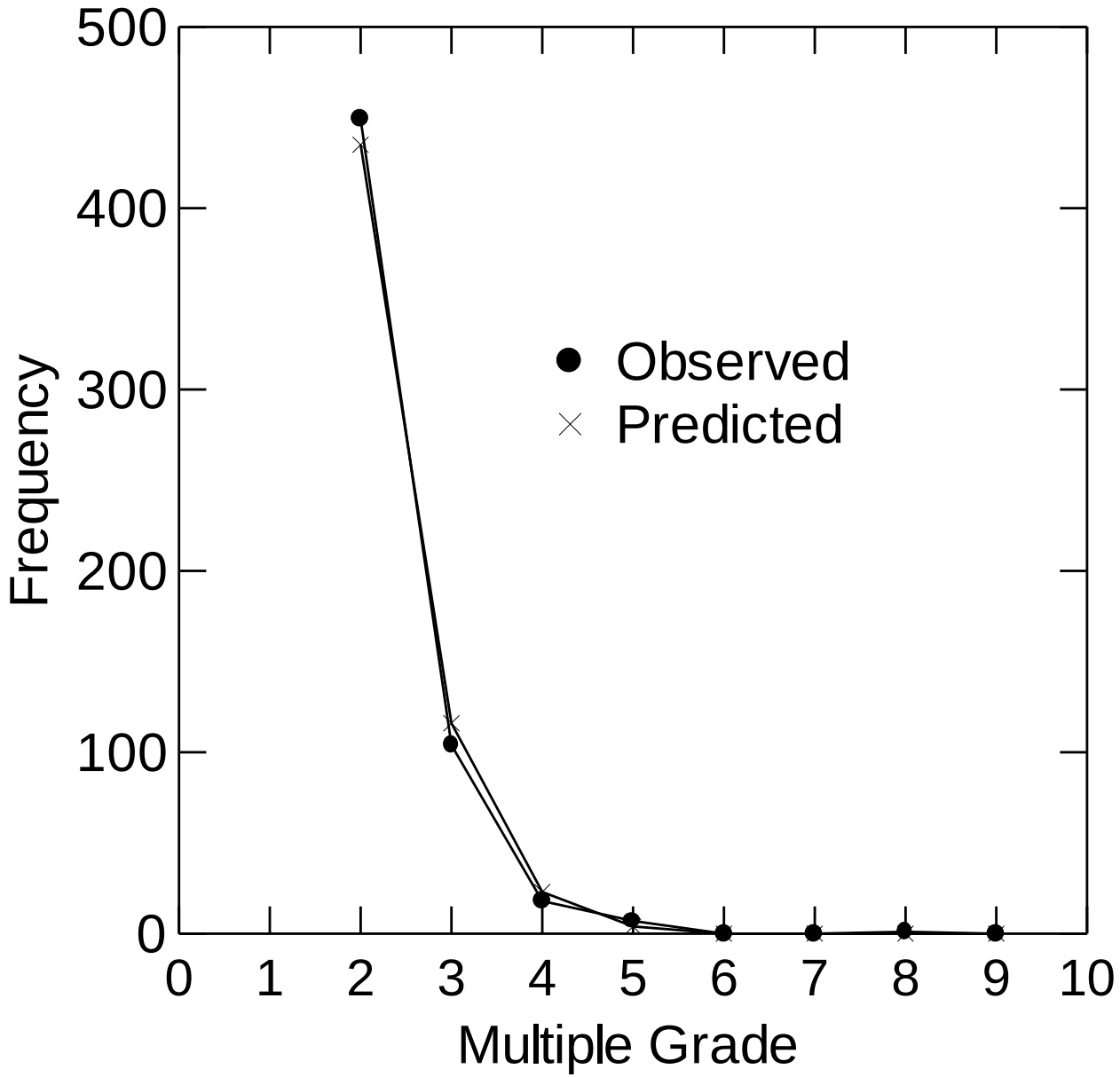

DOMAIN A
Field A
1
DOMAIN B
2
Field B

Assumptions

- Individual Samples from Domain Ideas
- Within-Field Variation in Sample Size
- Quasi-Random Combination of Ideas
- Variation in Quality of Combinations
- Variation in Size of Fields
- Communication of Ideational Combinations

Implications

- Research Publications
  - Cross-sectional Variation
  - Longitudinal Change
- Multiple Discoveries
  - Multiple Grades


500
400
300
200
100
0
Frequency
Observed
Predicted
0
1
2
3
4
5
6
7
8
9
10
Multiple Grade

Implications

- Research Publications
  - Cross-sectional Variation
  - Longitudinal Change
- Multiple Discoveries
  - Multiple Grades
  - Temporal Separation

Implications

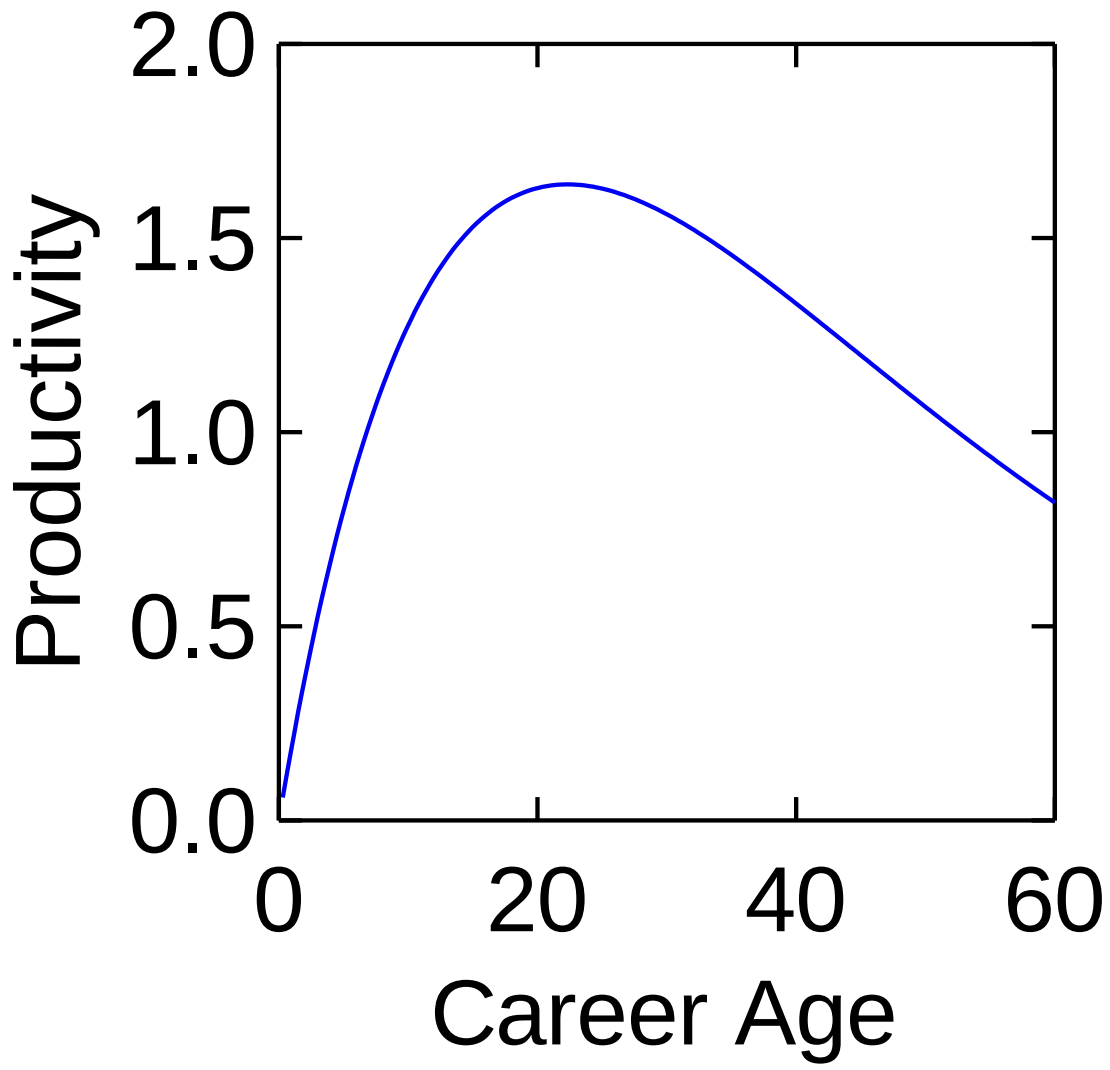
- Research Publications
  - Cross-sectional Variation
  - Longitudinal Change
- Multiple Discoveries
  - Multiple Grades
  - Temporal Separation
  - Multiples Participation

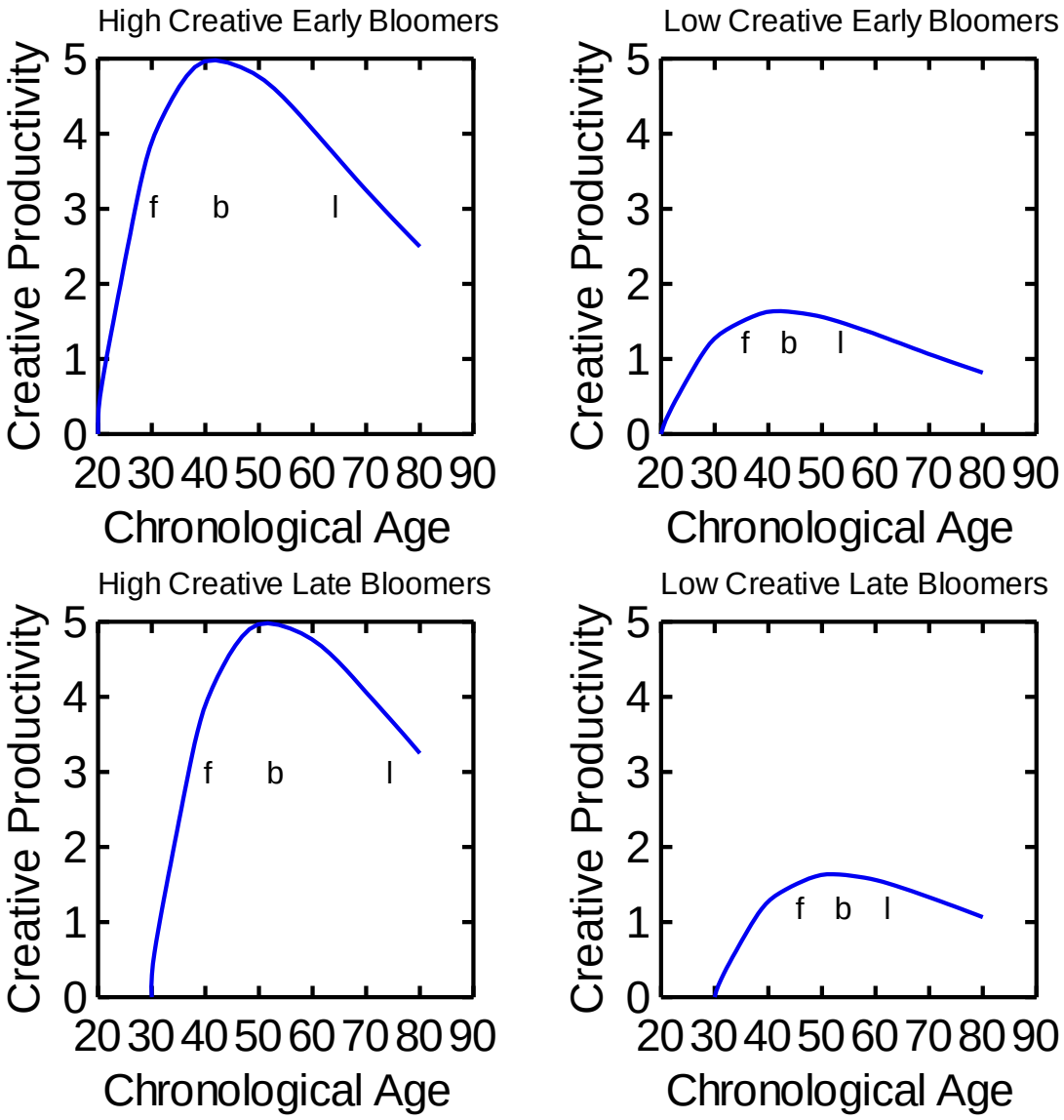
Implications

- Research Publications
  - Cross-sectional Variation
  - Longitudinal Change
- Multiple Discoveries
  - Multiple Grades
  - Temporal Separation
  - Multiples Participation
  - Multiple Identity

Elaboration

- Aggregated Data on Career Output
  - Aggregated Across Time Units
  - Aggregated Across Scientists
- Cognitive Combinatorial Model
  - Longitudinal Submodel
  - Individual-Differences Submodel
  - Integrated Model


2.0
1.5
1.0
0.5
0.0
Productivity
0
20
40
60
Career Age


High Creative Early Bloomers
Creative Productivity
0
1
2
3
4
5
f
b
l
20 30 40 50 60 70 80 90
Chronological Age
Low Creative Early Bloomers
Creative Productivity
0
1
2
3
4
5
f
b
l
20 30 40 50 60 70 80 90
Chronological Age
High Creative Late Bloomers
Creative Productivity
0
1
2
3
4
5
f
b
l
20 30 40 50 60 70 80 90
Chronological Age
Low Creative Late Bloomers
Creative Productivity
0
1
2
3
4
5
f
b
l
20 30 40 50 60 70 80 90
Chronological Age

Objections

- Alternative Explanations?
  - Multiplicative Models?
  - Cumulative Advantage?
- Explanatory Limitations?
  - Too Abstract?
  - Yes, so ...

Scientific Activity

- Individuals: Research Programs
- Fields: Peer Review
- Domains: Disciplinary Zeitgeist

Individuals: Research Programs

- The Features of High-Impact Programs
- Repercussions of those Features

The Features of High-Impact Programs

- Multiple Projects
- Network of Enterprises (Gruber)
- Variability in Nature of Projects

Projects Vary According to ...

- Research Topic
- Degree of Risk
- Intrinsic Importance
- Programmatic Relevance
- Amount of Progress
- Type of Research
- Current Degree of Effort

For example:

Chronology of Darwin's Work on Evolution

1837	He opens notebook on the "transmutation of species."
1842	He produces a pencil sketch of his theory
1844	He enlarges the sketch
1854	Begins collating notes for *Origins*
1856	Begins writing in earnest
1859	He publishes *Origin of Species*

Meanwhile ...

1837-46	He studies the geology of South America
1837-42	He studies coral formation
1838-44	He studies volcanic islands and mountain chains
1838-42	He studies geological formations in Scotland and Wales
1837-45	He prepares the volumes reporting the zoological findings of the *Beagle* voyage (5 volumes on fossil mammals, mammals, birds, fish, and reptiles)
1847-54	He publishes extensive monographs on both fossil and modern cirripedes
1837-58	He publishes miscellaneous papers, notes, and reviews on topics as diverse as earthworms, mold, glacial action, erratic boulders, volcanic rocks, a rock seen on an iceberg, dust falling on ships in the Atlantic, the effects of salt water on seeds, seed vitality, the role of bees in the fertilization of Papilionaceous flowers, Waterhouse's *Natural History of the Mammalia*, and on *Rhea americana*, *Sagitta*, *Planaria*, and *Arthrobalanus*

Repercussions of those Features

- Crosstalk
- Priming Effects
- Serendipitous Events
- Stochastic Ideational Output

Poincaré:

I turned my attention to the study of some arithmetical questions apparently without much success and without a suspicion of any connection with my preceding researches. Disgusted with my failure, I went to spend a few days at the seaside, and thought of something else. One morning, walking on the bluff, the idea came to me ... that the arithmetic transformations of indeterminate ternary quadratic forms were identical with those of non-Euclidean geometry.

Fields: Peer Review

- Individuals as Members of Fields
  - Correspondence
  - Professional Meetings
  - Readings
  - Manuscript and Proposal Reviews
- Hence Arises the Peer Review Paradox

Peer Review Paradox

- Exposure to Explicit Standards for
  - Submitted Manuscripts
  - Grant Proposals
- Internalization of Those Standards
- Improvement with Practice
- Inconsistency with Equal-Odds Rule

Resolution of Paradox

- Low Reliability
- Low Predictive Validity
- Low Inferential Capacity

In fact, if anything, exposure to peer review, both as referee and as author, should render scientific activity all the more probabilistic!

Domains: Disciplinary Zeitgeist

- Two Forms of Zeitgeist
  - Sociocultural (e.g., communication systems)
  - Disciplinary (i.e., the ideational content of the domain at a particular point in time)
- Yet Neither Can Ensure Deterministic Inevitability

Two Implications

- Creative Ideas the Joint Product of
  - The Size of the Field
  - The Richness of the Domain
- Variation in Individual Output Increases with Size of Field

Creative Scientists

- Premise: Dispositional Characteristics and Developmental Experiences Should Correspond with the Hypothesized Combinatorial Process
- However: Domain Contrasts in Degree of Constraint Imposed on Creativity
  - Scientific versus Artistic Creativity
  - Revolutionary versus Normal Science

Creative Scientists

- Hence, NSC > RSC > AC Regarding Degree of Constraint

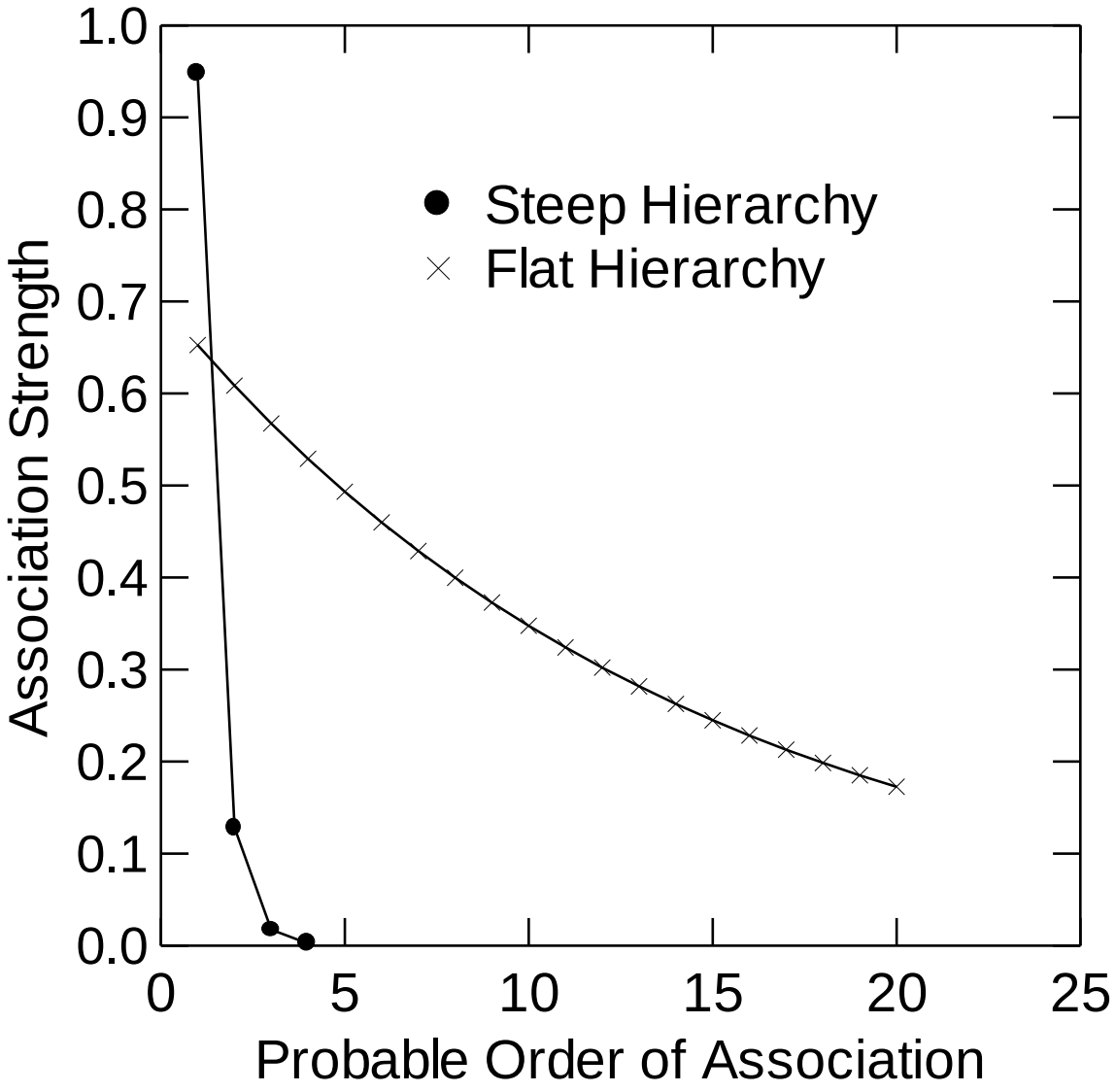
Creative Scientists

- Hence, NSC > RSC > AC Regarding Degree of Constraint
- With Corresponding Expectations Regarding Disposition and Development

Disposition

- Intellectual Capacity
  - Intelligence Sufficient for Domain Mastery
  - Associative Richness for Combinatorial Capacity

Ernst Mach:
[Although a scientist must have] a powerfully developed *mechanical* memory, which recalls vividly and faithfully old situations ... more is required for the development of *inventions*. More extensive chains of images are necessary here, the excitation by mutual contact of widely different trains of ideas, a more powerful, more manifold, and richer connection of the contents of memory, a more powerful and impressionable psychical life, heightened by use. ... [F]rom the teeming, swelling host of fancies which a free and high-flown imagination calls forth, suddenly that particular form arises to the light which harmonises perfectly with the ruling idea, mood, or design.


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Association Strength
Steep Hierarchy
Flat Hierarchy
0
5
10
15
20
25
Probable Order of Association

Disposition

- Intellectual Capacity
  - Intelligence Sufficient for Domain Mastery
  - Associative Richness for Combinatorial Capacity
- Personal Qualities

Disposition

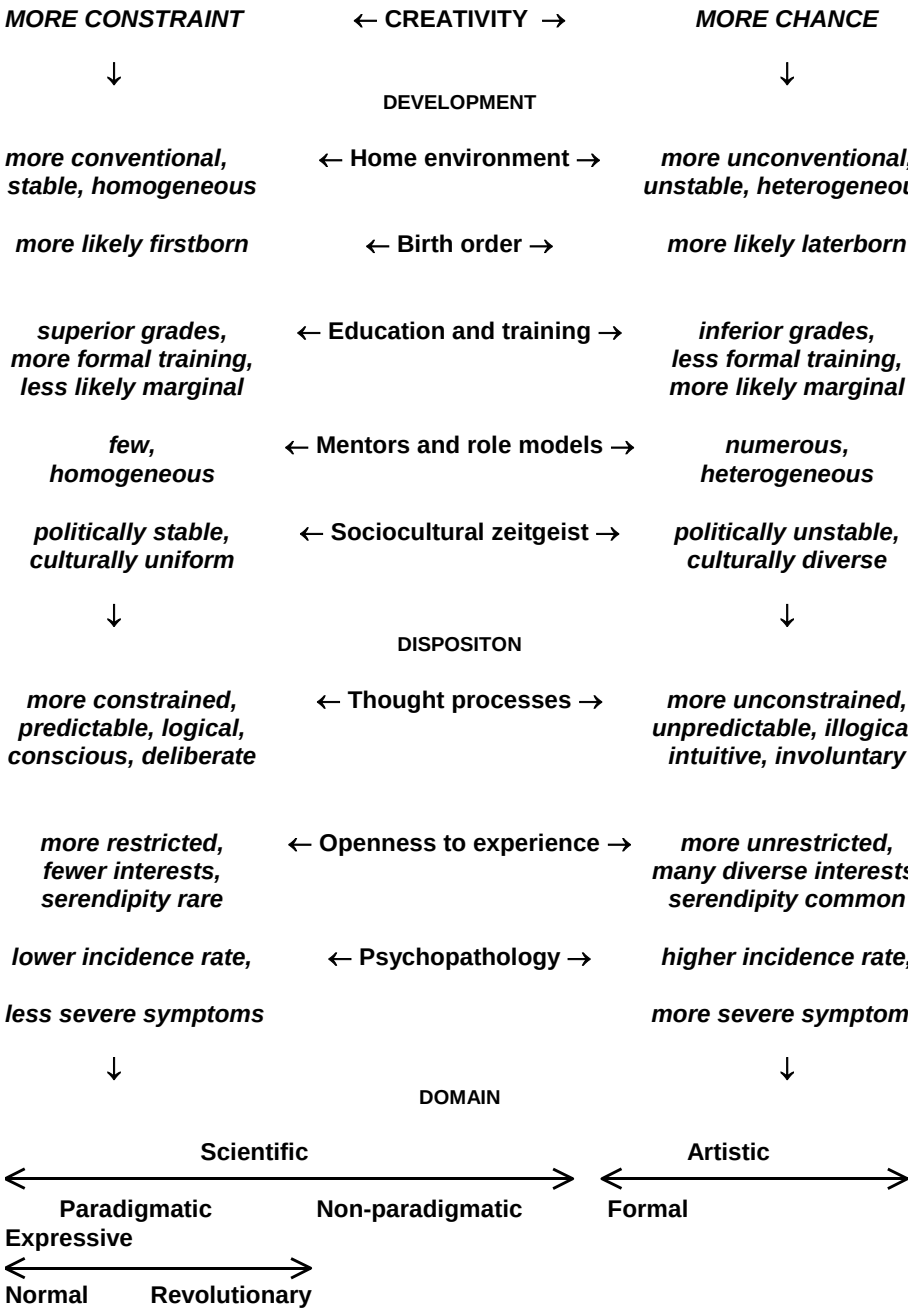
- Intellectual Capacity
  - Intelligence Sufficient for Domain Mastery
  - Associative Richness for Combinatorial Capacity
- Personal Qualities
  - Openness to Experience

Disposition

- Intellectual Capacity
  - Intelligence Sufficient for Domain Mastery
  - Associative Richness for Combinatorial Capacity
- Personal Qualities
  - Openness to Experience
  - Psychopathology

Development

- Home Environment
  - Shared Effects
  - Nonshared Effects
- Education and Training
  - Scholastic Performance
  - Level of Formal Education
  - Mentoring
- Sociocultural Context


MORE CONSTRAINT
← CREATIVITY →
MORE CHANCE
DEVELOPMENT
more conventional, stable, homogeneous
← Home environment →
more unconventional, unstable, heterogeneou
more likely firstborn
← Birth order →
more likely laterborn
superior grades, more formal training, less likely marginal
← Education and training →
inferior grades, less formal training, more likely marginal
few, homogeneous
← Mentors and role models →
numerous, heterogeneous
politically stable, culturally uniform
← Sociocultural zeitgeist →
politically unstable, culturally diverse
DISPOSITON
more constrained, predictable, logical, conscious, deliberate
← Thought processes →
more unconstrained, unpredictable, illogica intuitive, involuntary
more restricted, fewer interests, serendipity rare
← Openness to experience →
more unrestricted, many diverse interest serendipity common
lower incidence rate, less severe symptoms
← Psychopathology →
higher incidence rate, more severe symptom
DOMAIN
Scientific
Artistic
Paradigmatic
Non-paradigmatic
Formal
Expressive
Normal
Revolutionary

Scientific Discovery

- Logical Processes:
  - The Newell-Simon Paradigm
  - Limitations of the Paradigm
- Chance Processes
  - Insight Problems
  - Creative Production
  - Computer Problem Solving
  - Group Creativity

Conclusion: Scientific Creativity

- The Three Alternative Perspectives:
  - Experimental Studies of the Discovery Process
  - Psychometric Studies of Creative Scientists
  - Behavioral Studies of Actual Creative Behavior in Science
- Can Be Successfully Integrated
- Using a Combinatorial Model

The importance of the proposed integration may be illustrated by elaborating upon the expression “not to see the forest for the trees.”

The person- and process-oriented psychologists are comparable to scientists who investigate singular trees.

The person-oriented psychologists are botanists who focus on how trees vary in a diversity of morphological traits, such as how firs differ from pines with respect to leaves, cones, branches, bark, trunk, and roots.

The process-oriented psychologists are plant physiologists who analyze trees in terms of basic mechanisms, such as the role of osmotic and capillary processes in the extraction and conveyance of water and nutrients, the genetic processes behind reproduction, and the photosynthetic processes by which trees support their metabolism.

Although both botanists and plant physiologists provide us with everything we may want to know about individual trees, they cannot provide the whole picture.

After all, a significant characteristic of most trees is that they tend to be part of ecological systems, especially forests, with distinct properties that cannot be reduced to either botany or plant physiology. These attributes include the distribution of different tree species relative to geography, rainfall, temperature, soil, flora and fauna, and other conditions.

By the same token, product-oriented psychologists scrutinize how discoveries are distributed across individual scientists (as affected by the characteristics of research programs and peer review) and scientific communities (as affected by the attributes of the domain and disciplinary communication).

As a consequence, they are studying the forest, not the trees.

Yet if you compile everything that the botanist, plant physiologist, and ecologist can tell you about their respective findings, you obtain a complete knowledge of trees, both as singular plants and as the collectives known as forests.

In the same way, the in vivo behavioral inquiries into scientific careers and communities must be integrated with in vitro studies from the two disciplines of psychology, one concentrating on the person who creates and the other on the process of creation.

To do less will only leave psychology with a fragmentary and misleading perspective on scientific creativity.