Novelty Measurement and Innovation Type Identification of Scientific Papers Based on Problem-Method Combinations (Postprint)

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Abstract

[Purpose/Significance] The novelty measurement of scientific papers constitutes an important component of scientific achievement evaluation. This paper proposes a novelty measurement method and innovation type identification approach for scientific papers based on problem-method combinations, starting from the core elements of scientific papers, namely problems and methods. [Method/Process] Based on the word frequency principle, we respectively calculate the problem novelty, method novelty, and problem-method combination novelty of scientific papers, and then compute the overall novelty of the paper through weight assignment. Simultaneously, grounded in combinatorial innovation theory and from the perspective of problem-method combinations in scientific papers, we propose four innovation types and a method for determining the innovation type of an article based on its novelty value. [Results/Conclusion] An empirical study was conducted on over 200,000 ACM papers from 1951-2018, demonstrating that the proposed novelty measurement method and innovation category identification approach for scientific papers are scientific, reasonable, and operable.

Full Text

Novelty Measurement and Innovation Type Identification of Scientific Papers Based on Problem-Method Combinations

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Abstract: [Purpose/Significance] The novelty measurement of scientific papers constitutes an important component of scientific achievement evaluation.

This paper proposes a method for measuring novelty and identifying innovation types based on the core elements of scientific papers—problems and methods. [Method/Process] Based on the word frequency principle, we calculate the novelty of problems, methods, and problem-method combinations separately, then compute the overall novelty of a paper through weighted assignment. Simultaneously, grounded in combination innovation theory, we propose four innovation types from the perspective of problem-method combinations and a method to determine the innovation type based on the paper's novelty value. [Result/Conclusion] An empirical study of over 200,000 ACM papers from 1951–2018 demonstrates that the proposed novelty measurement method and innovation category identification method are scientific, reasonable, and operable.

Keywords: scientific paper; novelty measurement; combination innovation; problem-method combination

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1 Introduction

Innovation is "the soul of national progress," as President Xi Jinping has stated. The *Proposal of the Central Committee of the Communist Party of China for Formulating the 14th Five-Year Plan for National Economic and Social Development and the Long-Range Objectives Through the Year 2035* places "adhering to innovation" as the foremost among twelve key areas of work for the next five years, emphasizing the strengthening of national strategic scientific and technological capabilities, stimulating talent innovation vitality, and improving scientific and technological innovation systems and mechanisms. The document calls for resolutely eliminating the "four-only" phenomenon (sole emphasis on academic credentials, professional titles, educational background, and awards), making the evaluation of scientific and technological achievements a critical task. As the primary carrier of scientific achievements, scientific papers embody innovation, with novelty being a key characteristic of innovativeness that is indispensable to innovation evaluation.

Innovative achievements rarely emerge from nothing; combination lies at the core of innovation, a principle supported by numerous scholars. I. Nonaka argues that combination represents the primary pathway for organizations to utilize explicit knowledge for knowledge creation. L. Fleming suggests that both recombination of existing knowledge and combination of new knowledge can lead to innovation. B. Uzzi et al. propose that atypical combinations of existing knowledge may generate innovation across all disciplines. S. Mishra et al., in exploring the relationship between MeSH terms and paper novelty, demonstrate that term combinations in biomedicine can reflect article novelty, with the most impactful articles often introducing novel combinations based on typical ones. Thus, measuring combination novelty offers a theoretically grounded approach to assessing scientific paper novelty.

In scientific novelty checks, innovativeness manifests as the absence of prior publication of the project's scientific and technical content before the commission date. In patent applications, it requires that the invention or utility model differs from prior art. For academic papers, Chen Jianqing defines "innovation" as establishing or developing valuable new theories, methods, or technologies within a relevant academic field, or deriving new significance from previous research through processing, organization, and excavation, such as proposing new conclusions. This highlights that novelty is essential for papers to contribute to scientific development, making innovation evaluation of scientific papers highly valuable for scientific assessment and research funding allocation.

Problems and methods constitute the two core elements of scientific achievements. Each scientific paper represents a cross-combination of old and new problems with old and new methods. Recombination of problems and methods, as well as combinations of new problems and new methods, can all generate innovation. Therefore, calculating the combination novelty of problem-method pairs can measure paper novelty to a certain extent. However, limited by the difficulty of extracting problems and methods, previous studies rarely measure novelty from these perspectives. Instead, they compute keyword frequency or similarity without distinguishing semantic functions, leading to certain biases. For example, when a technical method is studied as a research object in its early stages and later applied to other problems, its application articles also exhibit high novelty. Yet, indiscriminate calculation of word frequency or similarity would reduce the novelty value of the latter due to the influence of the former as a research object. Lu Wei et al. constructed a rule-based data annotation method using over 120,000 papers from computer science and information science journals published between 2009–2018, employing BERT pre-trained models for vectorization and LSTM networks to automatically identify problem and method keywords. Building on this research, this paper proposes a novelty measurement method based on problem-method combination co-occurrence rates.

Furthermore, based on combination innovation theory, we propose four innovation types from the perspective of problem-method combinations and a method to identify the innovation type according to article novelty values.

2 Related Research

2.1 Novelty Measurement of Scientific Papers Current methods for evaluating single-paper novelty fall into three categories. The first is peer review, the most common subjective qualitative evaluation method in academia, which relies on domain experts' personal judgment. While simple to implement, it suffers from issues of injustice, non-objectivity, and irrationality due to individual cognitive biases.

The second category calculates novelty based on citation relationships, grounded in the theory that academic impact manifests through citations. Some scholars have explored the relationship between citation count and novelty. For instance, Shen Lü argues that scientific innovation is proportional to citation rate—higher citation rates indicate greater innovation. Lu Wanhui et al. conducted statistical analysis on novelty and citations of library and information science papers in China, finding significant positive correlation between topic novelty and citations. While citation analysis can reflect novelty characteristics, its limitation lies in evaluating novelty through external features rather than content-level measurement.

The third category measures topic novelty based on keyword frequency or similarity. Yang Jianlin et al. proposed a time-stamped keyword pair inverse document frequency approach to quantify document novelty, finding that important core journals publish papers with higher average topic novelty. Ren Haiying et al. calculated novel combination rates based on co-occurrence networks of subject terms, considering articles innovative when rates exceed thresholds. Yang Jing et al. used Jaccard coefficients to compute keyword overlap, arguing that higher overlap indicates lower topic novelty. Xu Dan et al. extracted subject terms and calculated their inverse document frequency to measure novelty. Lu Wanhui et al. employed Doc2Vec and Hidden Markov Models (HMM) for vectorization and similarity calculation. Qian Lingfei et al. argued that greater interdisciplinary degree indicates higher potential innovation, defining metrics like keyword crossover rate.

While these methods can evaluate novelty to some extent, they ignore semantic function information. For example, "genetic programming" appears as a research problem in *Multi-chromosomal genetic programming (2005)* but as a method in *Genetic programming for shader simplification (2011)*. Indiscriminate calculation mixes problems and methods, reducing the latter's novelty value despite its high novelty as a new technology applied to problems. Our method uses deep learning models to identify problem and method terms, measuring novelty through problem-method co-occurrence rates while strictly distinguishing between problem and method terms, avoiding mutual interference. Additionally, we calculate both combination frequency and individual term frequencies, as combinations of new problem + new method, new problem + old method, and old problem + new method all have zero co-occurrence frequency initially. Considering only combination frequency would assign novelty value 1 to all, yet new problem + new method is typically considered more novel than other combinations. Moreover, higher individual frequencies of old problems or methods indicate lower novelty.

2.2 Innovation Type Identification of Scientific Papers The concept of innovation was first proposed by economist Schumpeter in 1912 and has since been continuously researched. Regarding innovation classification, R. Garcia et al. categorize innovation into radical, incremental, and moderate types. R. M. Henderson et al. classify innovation into incremental, architectural, modular, and radical types, suggesting new knowledge may strengthen or destroy existing knowledge. J. L. Bower et al. distinguish between sustaining and disruptive innovation based on value networks. Song Ziliang categorizes innovation into theoretical, methodological, and interdisciplinary types. Despite numerous classification methods, most remain theoretical without operational identification approaches. This paper proposes four innovation types from the problem-method combination perspective and a concrete identification method based on novelty values.

3 Novelty Measurement and Innovation Type Identification Based on Problem-Method Combinations

3.1 Novelty Measurement Based on Problem-Method Combination Co-occurrence Single-paper problem-method pairs represent cross-combinations of old and new problems with old and new methods, specifically: new problem + new method, new problem + old method, old problem + new method, and old problem + old method (Figure 1 [Figure 1: see original paper]). Generally, papers containing new problem + new method are considered most novel, followed by new problem + old method or old problem + new method, with old problem + old method being least novel. However, old problem + old method combinations can still be novel, such as new combinations of old problems and methods. Additionally, earlier publication of a problem-method pair indicates higher novelty. Overall, problem-method combinations can reflect paper novelty.

Academic papers with high-frequency problems and methods often reflect research hotspots, while low-frequency terms may indicate novelty, such as new problems or methods. Paper novelty decreases as the pre-publication frequency of its problems and methods increases. Based on this principle, we propose formulas for calculating problem novelty, method novelty, and problem-method pair novelty:

$$\mathrm{nov}(Q) = \ln(n(Q_i)) + 1 \quad (1)$$
$$\mathrm{nov}(M) = \ln(n(M_j)) + 1 \quad (2)$$
$$\mathrm{nov}(Q, M) = \frac{\ln(n(Q_i, M_j)) + 1}{|Q||W|} \quad (3)$$

Where Q and M are the problem and method term sets of document D, $\mathrm{nov}(Q)$ denotes problem novelty, $\mathrm{nov}(M)$ denotes method novelty, and $\mathrm{nov}(Q, M)$ denotes problem-method pair novelty. $|Q|$ represents the number of problems in document D, and $|M|$ represents the number of methods. Q_i and M_j denote the i-th problem term and j-th method term in D. $n(Q_i)$ indicates the frequency of problem Q_i in the field before D's publication, $n(M_j)$ indicates the frequency of method M_j, and $n(Q_i, M_j)$ indicates the co-occurrence frequency of problem-method pair (Q_i, M_j) (including document D). The natural logarithm slows the novelty decline rate to avoid excessively low values while preserving the novelty ranking.

We then compute the weighted average of problem novelty, method novelty, and problem-method pair novelty as the overall paper novelty, denoted $\text{nov}(D)$:

$$\text{nov}(D) = k_1\text{nov}(Q) + k_2\text{nov}(M) + k_3\text{nov}(Q, M) \quad (4)$$

Where k_1, k_2, k_3 ($k_1 + k_2 + k_3 = 1$, $k_1, k_2, k_3 \geq 0$) are weights reflecting the domain-specific importance of problems, methods, and their combinations. These should be determined based on the knowledge update characteristics of the field. Since individual term frequencies always exceed or equal combination frequencies, we have $\text{nov}(Q, M) \geq \text{nov}(Q)$, $\text{nov}(Q, M) \geq \text{nov}(M)$, and $\text{nov}(D) \leq \text{nov}(Q, M)$. When a paper's novelty exceeds a threshold, its problem-method pair novelty also exceeds that threshold.

3.2 Innovation Type Identification Based on Problem-Method Combination Novelty Novelty is the essential attribute of academic innovation. When a paper's novelty exceeds a threshold, it can be considered highly innovative, with innovation types classified according to novelty values. If both problem and method novelty values exceed their respective thresholds, the paper exhibits "new problem + new method" combination innovation. The specific classification rules are:

- If $\text{nov}(Q) \geq T_q$ and $\text{nov}(M) \geq T_m$: "New problem + new method" combination innovation
- If $\text{nov}(Q) \geq T_q$ and $\text{nov}(M) \leq T_m$: "New problem + old method" combination innovation
- If $\text{nov}(Q) \leq T_q$ and $\text{nov}(M) \geq T_m$: "Old problem + new method" combination innovation
- If $\text{nov}(Q) \leq T_q$ and $\text{nov}(M) \leq T_m$: "Old problem + old method" combination innovation

Where T_d is the overall innovation threshold, T_q is the problem innovation threshold, and T_m is the method innovation threshold. Figure 2 [Figure 2: see original paper] illustrates the classification process.

4 Empirical Study

4.1 Dataset Construction We collected ACM (Association for Computing Machinery) papers from 1951–2018, extracting titles and abstracts. Using Lu Wei et al.'s problem-method extraction model, we identified problem and method terms. We stored each paper's DOI, title, abstract, problem terms, method terms, publication date, and citation count (through December 2018) in a MySQL database, totaling 204,310 valid records. The annual distribution is shown in Figure 4 [Figure 4: see original paper]. We then calculated novelty values for all papers.

4.2 Novelty Value Calculation Each paper's novelty was measured at its publication time by substituting pre-publication frequencies into our formulas. Figure 5 [Figure 5: see original paper] shows the distribution of problem, method, and problem-method pair novelty values, with problem novelty primarily in the 0.2–0.6 and 1.0 ranges, and method novelty showing similar patterns, indicating comparable update rates. Based on this distribution, we set weights in formula (4) to $k_1 = 0.25$, $k_2 = 0.25$, and $k_3 = 0.5$. Using 0.6 as the innovation threshold (considering that new combinations of old problems and methods also exhibit high innovation), we visualized results in Figure 5, where dots represent high-innovation papers and triangles represent low-innovation papers.

When overall novelty exceeds the threshold, papers can be classified into four types based on problem and method novelty values. Using median values as thresholds for problem and method innovation, we found that "new problem + new method" accounts for 49.22% of high-novelty papers, "old problem + new method" for 21.72%, "new problem + old method" for 20.93%, and "old problem + old method" for 8.13%. This distribution reflects that most ACM papers represent cutting-edge research with problem or method innovation.

4.3 Case Analysis Given the dataset size (over 200,000 papers), we randomly selected 10 papers (2 from each category) for analysis to validate our method's reasonableness and interpretability (Table 1).

"New problem + new method" examples: - *R-trees: a dynamic index structure for spatial searching* (1984): Proposed a novel data structure for high-dimensional spatial data. - *XGBoost: A Scalable Tree Boosting System* (2016): Introduced a scalable end-to-end tree boosting system. Both papers were highly novel at publication and received extensive citations.

"Old problem + new method" examples: - *Cross-domain sentiment classification via spectral feature alignment* (2010): Applied spectral feature alignment to cross-domain sentiment classification. - *RAP: an associative processor for database management* (1975): Introduced the RAP associative processor for databases. Both combined established problems with novel methods.

"New problem + old method" examples: - *Invetter: Locating Insecure Input Validations in Android Services* (2017): Used machine learning to identify insecure input validations in Android. - *A Genetic Algorithm-Based Solver for Very Large Jigsaw Puzzles* (2018): Applied genetic algorithms to large-scale jigsaw puzzles. Both addressed new problems with established methods.

"Old problem + old method" examples: - *Experiments with Convolutional Neural Network Models for Answer Selection* (2016): Applied CNNs to answer selection. - *What do concurrency developers ask about?* (2018): Studied concurrency issues using LDA topic modeling. These combined established problems and methods in novel ways.

Low-novelty examples: - *Matrix and Tensor Decomposition in Recommender*

Systems and *Automatically evolving difficult benchmark feature selection datasets with genetic programming* had lower novelty as their problems, methods, and combinations had appeared frequently.

This case analysis demonstrates our method's reasonableness and interpretability.

4.4 Analysis of Novelty and Citation Count The relationship between novelty and citations has attracted scholarly attention. Lu Wanhui et al. found that papers with higher topic novelty typically receive more citations. Our analysis (Figure 6 [Figure 6: see original paper]) shows that highly cited papers generally have high novelty values (>0.6), and high-novelty papers tend to receive more citations, consistent with previous research. However, the relationship is not perfectly linear, primarily because: (1) citation counts increase over time, making recent papers' true impact not yet fully realized, and (2) paper influence depends on factors beyond novelty, such as research field popularity.

5 Conclusion and Discussion

As core elements of scientific papers, problem-method combinations can reflect paper novelty to a considerable extent. These combinations include new problem + new method, new problem + old method, old problem + new method, and old problem + old method (with the latter including both old combinations and new combinations of old elements). Constrained by extraction difficulties, previous studies often ignored semantic functions when calculating keyword frequencies, obscuring the novelty of applying old methods to new problems, new methods to old problems, or creating new combinations of old elements.

Based on an existing problem-method extraction model, this paper proposes a novelty measurement method using problem-method co-occurrence rates, calculating problem novelty, method novelty, combination novelty, and overall novelty. Grounded in combination innovation theory, we propose four innovation types and an identification method based on novelty values. Our empirical study of over 200,000 ACM papers demonstrates the method's scientific validity, reasonableness, operability, and interpretability.

Limitations include focusing only on problems and methods while ignoring other dimensions like new viewpoints or conclusions. Future work could extend the approach by first identifying sentences expressing viewpoints and conclusions (often appearing in abstracts and opening/closing sections) and incorporating them into the calculation for more comprehensive novelty measurement.

References

[1] Xinhua News Agency. Xi Jinping: Explanations on the *Proposal of the Central Committee of the Communist Party of China for Formulating the 14th Five-Year Plan for National Economic and Social Development and*

the Long-Range Objectives Through the Year 2035 [EB/OL]. [2021-06-01]. http://m.xinhuanet.com/2020-11/03/c_{1126693341}.htm.

[2] *Science and Technology Novelty Search Tutorial* Writing Group. Science and Technology Novelty Search Tutorial [M]. Beijing: Mechanical Industry Press, 2001.

[3] Yin Xintian. Detailed Explanation of Chinese Patent Law [M]. Beijing: Intellectual Property Press, 2011.

[4] Chen Jianqing. Reflections on Evaluating the Innovativeness of Academic Papers in China [J]. Youth Journalist, 2013(18): 33-35.

[5] NONAKA I. A dynamic theory of organizational knowledge creation [J]. Organization science, 1994, 5(1): 14-37.

[6] FLEMING L. Recombinant uncertainty in technological search [J]. Management science, 2001, 47(1): 117-132.

[7] UZZI B, MUKHERJEE S, STRINGER M, et al. Atypical combinations and scientific impact [J]. Science, 2013, 342(6157): 468-472.

[8] MISHRA S, TORVIK V I. Quantifying conceptual novelty in the biomedical literature [EB/OL]. [2021-03-01]. http://hdl.handle.net/2142/90328.

[9] LU Wei, LI Pengcheng, ZHANG Guobiao, et al. Identifying lexical functions in academic texts: Automatic keyword classification based on BERT vectorization [J]. Journal of the China Society for Scientific and Technical Information, 2020, 39(12): 1320-1329.

[10] YANG Feng, LIANG Ye, GOU Qinglong, et al. The root causes of peer review system defects and improvement mechanisms [J]. Studies in Science of Science, 2008, 26(3): 569-572.

[11] SHEN Lü. The general equilibrium theory of scientific and technological innovation: A scientometric analysis of scientific achievement innovation evaluation [J]. Studies in Science of Science, 2003, 21(2): 205-209.

[12] LU Wanhui, SU Jinyan, YU Qian. Research on the relationship between academic achievement topic novelty and academic citations [J]. Information and Documentation Services, 2018(6): 68-73.

[13] YANG Jianlin, QIAN Lingfei. Measuring topic novelty based on keyword pair inverse document frequency [J]. Information Studies: Theory & Application, 2013, 36(3): 99-102.

[14] REN Haiying, WANG Deying, WANG Feifei. Research on the relationship between subject term combination novelty and academic impact [J]. Information and Documentation Services, 2017, 61(9): 87-93.

[15] YANG Jing, WANG Fang, BAI Rujiang. A method for evaluating single academic paper innovation based on research topic comparison [J]. Library and Information Service, 2018, 62(17): 75-83.

[16] XU Dan, XU Shuang, CHEN Sisi, et al. Research on detecting document topic novelty based on natural language word-pair method [J]. Library and Information Service, 2018, 62(8): 130-138.

[17] LU Wanhui, TAN Zongying. Research on measuring academic achievement topic novelty: Based on Doc2Vec and HMM algorithms [J]. Data Analysis and Knowledge Discovery, 2018, 2(3): 22-29.

[18] QIAN Lingfei, YANG Jianlin, DENG Sanhong. Single-indicator evaluation of disciplinary innovation capability in humanities and social sciences [J]. Library & Information, 2013(2): 93-98.

[19] SCHUMPETER J. The Theory of Economic Development [M]. Translated by GUO Wujun, LÜ Yang. Beijing: Huaxia Publishing House, 2015.

[20] GARCIA R, CALANTONE R. A critical look at technological innovation typology and innovativeness terminology: a literature review [J]. Journal of product innovation management, 2002, 19(2): 110-132.

[21] HENDERSON R M, CLARK K B. Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms [J]. Administrative science quarterly, 1990, 35: 9-30.

[22] BOWER J L, CHRISTENSEN C M. Disruptive technologies: catching the wave [J]. Harvard business review, 1995, 73(1): 43-53.

[23] SONG Ziliang. Preliminary exploration of basic research innovation classification [J]. Science and Technology Management Research, 1995, 15(4): 27-29.

Author Contributions:
Qian Jiajia: Designed research methodology, conducted experiments and data analysis, wrote the paper.
Luo Zhuoran: Proposed research framework, revised the paper.
Lu Wei: Determined research direction, reviewed the paper.

Novelty Measurement and Innovation Type Identification of Scientific Literature Based on Question-Method Combination

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Abstract: [Purpose/significance] Novelty measurement is an important part of scientific achievement evaluation. This paper aims to propose a method for novelty measurement and innovation type identification of scientific papers based on the core elements of problems and methods. [Method/process] Based on the word frequency principle, this paper calculates question novelty, method novelty, and question-method combination novelty respectively, then calculates the overall novelty of the paper by weight assignment. In addition, based on combination innovation theory, this study proposes four types of innovation from the perspective of scientific paper question-method combination and a method to identify the type of innovation according to the novelty value. [Result/conclusion] Finally, this paper conducts an empirical study based on more than 200,000 ACM papers from 1951 to 2018, and proves that the novelty measurement method and innovation category identification method proposed in this paper are scientific, reasonable and feasible.

Keywords: scientific literature; novelty measurement; combination innovation; question-method combination

Note: Figure translations are in progress. See original paper for figures.