

Citation-Based Analysis of Development Paths in Interdisciplinary Fields: A Case Study of Eye Tracking (Postprint)

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Abstract

[Objective/Significance] Interdisciplinary research has become a crucial paradigm and inevitable trend in modern scientific innovation. Investigating the development models and evolutionary pathways of disciplines within interdisciplinary fields holds significant importance for revealing the dynamic processes of formation and development in interdisciplinary domains. [Method/Process] Taking the Eye Tracking (ET) field as a case study, we extract and discipline-annotate literature citation relationships, constructing citation networks at both the literature and discipline levels; calculate each discipline's citation-to-others ratio, cited-by-others ratio, and Price's index to analyze the interdisciplinary development models of major disciplines in the ET field from a macro perspective; examine disciplinary citation relationships within and between different developmental stages to explore the relational structures and role evolution of various disciplines throughout the interdisciplinary development process; and identify pivotal literature connecting different disciplinary relationships based on citation betweenness centrality, investigating citation relationships among pivotal literature, highly-cited literature, and their references to reveal the specific evolutionary pathways of ET field development from a micro perspective. [Results/Conclusion] The development of the ET field has undergone three stages—incubation, development, and maturity—and exhibits three disciplinary development models: independent, cross-disciplinary, and learning-oriented. Citation relationships among disciplines become progressively tighter and more evenly distributed across stages, with neurology, psychology, and clinical medicine occupying central positions in interdisciplinary development and knowledge output. The vertical development of the ET field manifests as basic theoretical innovation in independent disciplines, while horizontal development manifests as deep integration among the three types of disciplines, presenting an “independent-linear-network” developmental pathway.

Full Text

Preamble

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Analyzing the Development Path of Interdisciplinary Fields Based on Citation Analysis: A Case Study of Eye Tracking

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Abstract

[Purpose/Significance] Interdisciplinary research has become an important paradigm and inevitable trend in modern scientific innovation. Exploring the development patterns and evolutionary paths of disciplines within interdisciplinary fields is crucial for revealing the dynamic processes of interdisciplinary formation and development. **[Method/Process]** Taking the eye tracking (ET) field as an example, this study extracts and annotates citation relationships with disciplinary information to construct citation networks at both the document and discipline levels. It calculates the cross-field reference ratio, cross-field citation ratio, and Price's Index for each discipline to analyze macro-level interdisciplinary development patterns in the ET field. The study examines intra-stage and inter-stage disciplinary citation relationships to explore relationship structures and role evolution of various disciplines during interdisciplinary development. Based on betweenness centrality in citation networks, it identifies key documents connecting different disciplines and examines citation relationships among important documents, highly cited documents, and references to reveal specific evolutionary paths at the micro-level. **[Result/Conclusion]** The ET field has experienced three stages: incubation, development, and maturity, presenting three disciplinary development patterns: independent, interdisciplinary, and learning-oriented. Citation relationships among disciplines have become increasingly close and evenly distributed over time, with neuroscience, psychology, and clinical medicine occupying core positions in interdisciplinary development and knowledge output. Vertical development in the ET field manifests as basic theoretical innovation in independent disciplines, while horizontal development appears as deep integration of the three discipline types, following an "independent-linear-mesh" evolutionary path.

Keywords: citation analysis; interdisciplinary research; development pattern; evolution path; eye tracking

Disciplines represent systematic classifications of human knowledge. As scientific systems grow increasingly complex, many social and scientific problems cannot be solved by single-discipline knowledge alone, making interdisciplinary research an indispensable model for modern scientific innovation. Interdisciplinary research facilitates knowledge diffusion through citation linkages, greatly promoting collaboration, integration, and innovation across different disciplines. Analyzing interdisciplinary phenomena and dynamic processes helps reveal formation, development, and evolution patterns, identify the roles and transformations of different disciplines in field development, and uncover development patterns and specific paths in interdisciplinary fields, thereby providing references for safeguarding interdisciplinary innovation, collaborative research, and scientific output.

The concept of interdisciplinarity was first proposed by American psychologist R.S. Woodworth in 1926, referring to “inter-disciplinary” research activities that transcend disciplinary boundaries. Its essence lies in creating interdisciplinary knowledge products through cross-penetration and integration among different basic disciplines. Unlike in-depth research within a single discipline, interdisciplinary research emphasizes horizontal development, focusing on high-level cross-integration with other disciplines to address deepening scientific and technological issues and social problems, thereby exhibiting different field development patterns and cross-evolutionary processes. Currently, research on development patterns and evolutionary laws in interdisciplinary fields primarily employs keyword evolution, topic similarity calculation, author collaboration network changes, and citation network analysis. Among these, citation relationships between documents most directly reflect cross-disciplinary associations and evolutionary paths. Therefore, this paper uses bibliometric and citation network analysis methods to construct citation relationship networks at both document and discipline levels, exploring development patterns, relationship structures, role evolution, and specific evolutionary paths in interdisciplinary fields from macro, meso, and micro perspectives.

2 Related Work

As an increasingly important paradigm and trend in modern scientific innovation, interdisciplinary research has attracted numerous scholars to explore its evolutionary characteristics and patterns. Current research on interdisciplinarity can be summarized into three perspectives: interdisciplinary basic research, key technology and methodology research, and interdisciplinary knowledge mining. Investigating the “inter” disciplinary development process and patterns constitutes an important task in interdisciplinary knowledge mining. This section reviews relevant work from three aspects: interdisciplinary research based on citation analysis, development pattern and path identification in interdisciplinary fields, and evolutionary characteristic analysis of interdisciplinary fields.

2.1 Interdisciplinary Research Based on Citation Analysis

References reflect the knowledge foundation of a paper, including authors' absorption of predecessors' concepts, methods, and technologies, while citing documents reflect the impact of cited literature on subsequent research. Citations directly represent knowledge flow among documents, journals, and disciplines. Citation analysis enables exploration of interdisciplinary phenomena from macro to micro perspectives, analyzing development patterns, relationship structures, and status changes of disciplines from knowledge diffusion and exchange perspectives, thereby revealing the essential characteristics of interdisciplinary research evolution and providing support for understanding and utilizing interdisciplinary evolutionary laws.

Current interdisciplinary citation analysis can be summarized in two aspects: (1) constructing interdisciplinary measurement indicator systems based on citations to measure diversity, evenness, and disparity of disciplines in literature. Diversity indicators focus on the number and proportion of different disciplines, assuming greater interdisciplinary involvement indicates stronger interdisciplinarity. For example, A.L. Porter and D.E. Chubin proposed the classic Citations Outside Category (COC) indicator, measuring interdisciplinarity by calculating the proportion of references from other disciplines. T. Chakraborty incorporated citing documents and proposed the Citation Diversity Index (CDI) based on the proportion of other-discipline literature in citing documents. Disparity indicators focus on distance and similarity between disciplines, assuming greater knowledge diffusion across different disciplines indicates stronger interdisciplinarity. J. Wang et al. proposed the interdisciplinary distance indicator, measuring interdisciplinarity at the disparity level through average similarity among disciplines in references. Evenness indicators focus on balance of knowledge distribution across disciplines, similar to information entropy concepts—more balanced knowledge sources indicate higher interdisciplinary degree, such as Gini coefficient and Herfindahl coefficient. These indicators, primarily used in economics to measure income and industrial structure balance, were later introduced to informetrics. Among these indicators, diversity indicators like COC are simple to calculate and widely applicable, while the other two categories provide beneficial supplements.

- (2) Analyzing interdisciplinary characteristics of disciplinary fields through citation methods, including knowledge source distribution in specific fields, disciplinary differences in citation lag, and inter-field influence relationships. Liu Ting et al. used a modified Herfindahl coefficient to quantify interdisciplinary knowledge input in Chinese library and information science, finding knowledge input mainly concentrated within the discipline, with interdisciplinary knowledge primarily from computer science, economics, law, and general social sciences. E.J. Rinia et al. analyzed the average age and proportion of references in SCI-indexed papers from the UK and Germany between 1960-1992, finding intra-disciplinary citation lags significantly shorter than interdisciplinary ones. K. Karunan

et al. proposed a citation network structure-based method for quantifying interdisciplinary knowledge contribution, empirically analyzing bioenergy and nano-energy technology fields, discovering close knowledge exchange between them with more significant contributions from the former to the latter, and summarizing five network structure patterns of interdisciplinary knowledge contribution. These studies quantitatively analyze static characteristics of interdisciplinary fields from source, temporal, and directional perspectives, providing rich research entry points, but pay less attention to dynamic evolutionary features, while analyzing formation, development, and changing interrelationships in interdisciplinary fields holds significant importance.

2.2 Development Pattern and Path Identification in Interdisciplinary Fields

Exploring formation and development patterns in interdisciplinary fields has increasingly attracted scholarly attention. J. Xu et al. examined keyword evolution in the Joint Attention field across three disciplines from 1970-2014, exploring its development pattern and finding the field initially emerged within a single discipline, with participating disciplines increasing over time to form a mature interdisciplinary field, featuring dynamic roles as knowledge exporters, receivers, and hybrids. T. Chakraborty used reference and citation diversity indicators to analyze Data Mining literature from 1975-2010, finding the field initially depended heavily on other disciplines with limited knowledge output, but over time reduced external dependence and increased knowledge output, summarizing an “absorption-internalization-output” development pattern. Lü Dongqing et al. classified 23 disciplines’ interdisciplinary development patterns in Chinese humanities and social sciences into cohesive, convergent, balanced, and open types, showing low-level, high-level, violently fluctuating, and balanced fluctuating characteristics. Yue Zenghui et al. conducted descriptive statistical analysis of interdisciplinary knowledge diffusion in the social network field, including quantity, intensity, and breadth of knowledge absorption and spillover, identifying four disciplinary development patterns with conclusions similar to Lü Dongqing et al.

These studies primarily explore interdisciplinary field and disciplinary development patterns at the macro level, effectively identifying development stages and disciplinary roles, but rarely combine micro-level analysis to explain interdisciplinary development patterns. Therefore, this paper attempts to analyze dynamic evolution processes of interdisciplinary fields from macro, meso, and micro perspectives using citation analysis methods, aiming to discover development patterns and specific evolutionary paths in the eye tracking field.

2.3 Evolutionary Characteristic Analysis of Interdisciplinary Fields

To further reveal interdisciplinary development patterns, micro-level evolutionary characteristics require quantitative analysis. Research on interdisciplinary

field evolution can be roughly divided into three granularities: document-level, author-level, and topic-content-level.

Document-level analysis primarily uses scientometric methods to statistically analyze literature growth and aging in specific fields and citation-based evolutionary characteristics. M. Coccia used exponential models to fit literature growth across disciplines in interdisciplinary fields, finding early outputs mainly came from a few basic disciplines, with later applied and new sub-discipline development continuously strengthening field interdisciplinarity. Y.W. Chang and M.H. Huang observed interdisciplinary characteristics and input discipline proportion changes in the library and information science field from 1978-2007 through direct citation, bibliographic coupling, and author co-authorship perspectives, finding numerous reference source disciplines and increasing interdisciplinarity, but significantly lower interdisciplinarity in bibliographic coupling and co-authorship. Ke Qing and Zhu Tingting used JCR 2007-2014 journal citation data from library and information science to explore knowledge source diversity and evenness, finding high but stable interdisciplinarity with no stable preferences for citing other disciplines, while sociology and management showed increasing influence.

Author-level interdisciplinary research primarily uses author collaboration networks and research interest similarity analysis to reflect structural and content evolution trends. P. Liu and H. Xia studied cooperation network structure evolution in the Evolution of Cooperation field, finding network structure gradually transformed from dispersed isolation to local communities, which then connected and evolved into “small-world” structures as network density increased. Guan Peng et al. used Author-Topic models to analyze author research interest evolution in lithium-ion battery fields, finding core authors’ research interests significantly correlated with field development trajectories, leading domain research themes.

Topic-content research focuses on thematic evolution analysis using subject terms. Wei Ling et al. proposed six evolution types of disciplinary topics and empirically analyzed informatics papers, finding topic expansion, contraction, and merging as the most common evolutionary paths. B. Chen et al. used topic models to analyze topic and context changes in information retrieval, identifying stable and volatile topics and revealing several evolution patterns.

In summary, document-level interdisciplinary evolution research effectively reveals knowledge sources and disciplinary relationship evolution. Author and topic-content methods reflect participating subjects and connotation characteristics, helping understand evolution motivations and contexts. Probabilistic topic model-based evolution analysis can obtain author-topic and document-topic relationships and their evolution, but requires manual content discrimination of output topics.

Previous research provides rich practical experience in methodological indicators and perspectives, but studies combining macro and micro-level quantitative

analysis of interdisciplinary development patterns remain limited. Therefore, building on previous work, this paper proposes an interdisciplinary development pattern and path analysis method to explore main disciplines' development patterns and interrelationships at macro and meso levels, and analyze document citation relationships at the micro level to reveal interdisciplinary field development paths.

3 Interdisciplinary Development Pattern and Path Analysis Method

To explore an interdisciplinary field's development patterns, disciplinary relationships, role changes, and specific development paths over time, this paper proposes an interdisciplinary development pattern and path analysis method examining evolutionary characteristics from macro, meso, and micro levels. At the macro level, we calculate cross-field reference ratios, cross-field citation ratios, and Price's Index for major disciplines across stages to reflect disciplinary dependence and update speed, revealing different disciplinary development patterns through trend analysis and inter-disciplinary measurement differences. At the meso level, we construct inter-disciplinary citation networks based on target documents' internal citation relationships, examining intra-stage and inter-stage disciplinary citation relationships to explore relationship structures and role evolution, thereby investigating the field's lifecycle. At the micro level, we construct citation networks based on highly cited documents, examining citation relationships among important documents, highly cited documents, and references to reveal specific citation methods and motivations, and explore knowledge flow and diffusion forms to identify concrete evolutionary paths in the eye tracking field. Figure 1 [Figure 1: see original paper] illustrates this analytical framework, where results from the three levels interconnect and corroborate each other for comprehensive evolutionary characteristic analysis.

3.1 Disciplinary Development Pattern Analysis in Interdisciplinary Fields

Disciplinary development patterns in interdisciplinary fields essentially condense and summarize temporal trends of interdisciplinarity for major disciplines, using relevant measurement indicators to reflect and extract development patterns from different perspectives. A discipline's development pattern can be reflected through the quantity and activity of internal and external knowledge utilization. The quantity of internal/external knowledge utilization can be described through Cross-Same Reference Ratio (CSRR) and Cross-Same Citation Ratio (CSCR), while knowledge utilization activity can be measured using Price's Index and more detailed citation lag indicators. High cross-reference ratio indicates the discipline heavily depends on other disciplines' knowledge, while high cross-citation ratio indicates the discipline widely exports knowledge to others, and vice versa. Based on these relationships, four basic discipline types emerge: (1) Independent type (low-low): low cross-reference and cross-citation ratios, pri-

marily internal knowledge flow, showing strong independence; (2) Learning type (high-low): high cross-reference but low cross-citation ratio, mainly absorbing other disciplines' knowledge with limited output capacity; (3) Interdisciplinary type (high-high): high ratios in both dimensions, close knowledge exchange with other disciplines, showing strong openness; (4) Export type (low-high): low cross-reference but high cross-citation ratio, relying on internal knowledge while widely exporting to other disciplines.

This paper adopts T. Chakraborty's cross-reference and cross-citation ratio methods to reflect knowledge absorption and output across disciplines. The CSRR calculation is as follows:

Formula (1):

$$ratio_{reference} = \sum_{article=1}^j \left(\frac{ExtRef_{article}}{IntRef_{article}} \right) \frac{Ref_{article}}{Ref_{year}}$$

where *article* is the target document number, *ExtRef* and *IntRef* represent reference counts from other disciplines and the same discipline respectively, and *Ref_{article}* and *Ref_{year}* represent the target document's reference count and total references in the current period. The CSCR calculation follows a similar approach. Analyzing trends and inter-disciplinary differences in these ratios reveals dependence patterns across stages, thereby extracting disciplinary development patterns.

We use Price's Index and citation lag indicators to reflect knowledge utilization activity. Price's Index measures the ratio of references published within five years to total references, indicating literature aging or update speed. Higher values indicate faster new knowledge absorption. The index gradually decreasing over time suggests deepening research and entry into mature development. The calculation is:

Formula (2):

$$\frac{\text{References published within 5 years}}{\text{Total references}} \times 100\%$$

Citation lag indicators calculate average time differences between citing and cited documents within and across disciplines, finely describing disciplinary participation activity and its evolution. Shorter lags for cross-disciplinary knowledge absorption indicate stronger learning activity. By calculating Price's Index and citation lag across disciplines and analyzing their trends and inter-disciplinary differences, we can effectively reveal dynamic developmental processes and inter-disciplinary differences, supplementing disciplinary development pattern discovery.

3.2 Inter-Disciplinary Citation Relationship Analysis

Examining intra-stage and inter-stage disciplinary citation relationships reveals relationship structures and role evolution among disciplines during interdisciplinary field development, uncovering functions and significance of different disciplines. This requires extracting all citation relationships within target documents and projecting them onto inter-disciplinary citation networks based on target documents' citation relationships. We then use citation network analysis to identify key nodes and edge attributes across stages. Disciplinary annotation of target documents is the most critical step, primarily using journal classification systems or single-paper attributes. This paper employs the journal classification system approach: (1) Python crawlers collect target document set D and citing document set S , establishing relationships through WoS accession numbers; (2) We traverse all relationships to obtain common document set T and construct document-level citation networks; (3) Using journal classification systems and rule-based matching, we annotate each document in T with disciplinary attributes to obtain citing and cited documents' disciplinary classifications, converting document citation relationships into inter-disciplinary citation relationships to construct disciplinary citation networks. These directed weighted networks reflect disciplinary citation relationships with temporal continuity and acyclic structure, enabling visualization of knowledge flows and mining of underlying developmental patterns through path identification, structure, and content analysis.

3.3 Document-Level Citation Relationship Analysis

Analyzing citation networks of typical documents in interdisciplinary fields helps discover concrete knowledge flow and diffusion methods at the micro level, revealing evolutionary paths. We select the top N most cited documents from target documents to construct citation networks based on direct citation relationships between these documents and their references, then identify important documents connecting different disciplines through betweenness centrality. Betweenness Centrality measures the proportion of shortest paths between node pairs that pass through a given node. High betweenness centrality nodes often lie on paths connecting different clusters, acting as bridges or gatekeepers with privileged information transmission/modification status. Identifying such documents can verify whether they “benefit” from additional citations or advantages, and examine indirect knowledge flow between disciplines. The calculation is:

Formula (3):

$$CB(i) = \sum_{j \neq k} P_{jk}(i)$$

where $CB(i)$ is node i 's betweenness centrality, j and k are other node pairs, $P_{\{jk\}}$ represents the number of shortest paths between j and k , and $P_{\{jk\}}(i)$ represents how many of those paths pass through i .

4 Empirical Analysis

4.1 Data Acquisition and Processing

Eye tracking (ET) measures gaze points or eye movements, using monitors to record and mark eye movement trajectories and active areas to understand human subjective intentions toward external objects. Its research includes rapid eye movement sleep, eye movement mechanisms, disease treatment, human-computer interaction, and robotics, involving psychology, neuroscience, clinical medicine, computer science, engineering, and other disciplines—a typical interdisciplinary field. With technological advances, eye tracking has been widely applied in human-computer interaction, transportation, ergonomic analysis, disease treatment, and architectural site selection, showing broad prospects. Therefore, this paper selects eye tracking as the interdisciplinary research object, using keyword co-occurrence and citation analysis to analyze knowledge diffusion evolution.

Using the search query TS=“eye tracking” OR TS=“eye movement” OR TS=“gaze tracking” OR TS=“eye gaze”, we retrieved all relevant documents from 1900-2016 in the Web of Science Core Collection and obtained all citing documents using a custom Python crawler. After deduplication, we obtained 31,008 target documents, 1,281,725 references, and 672,993 citing documents.

Although original data contains WoS Categories (WC) fields, WoS’s 251 categories allow multiple classifications per document, preventing direct use. Therefore, we used ESI journal classification as the disciplinary annotation basis, matching the Publication Name (SO) field against the ESI journal list to determine disciplinary attributes. The ESI journal list contains 11,491 journals across 22 categories (Table 1).

Among 31,008 target documents, 6,188 (20%) could not be matched because their publications were not in the ESI list. Similarly, 66,608 citing records (10%) and 352,985 reference records (28%) were unmatched. For target and citing documents, we established supplementary matching rules using the Research Areas (SC) field from successfully matched records. Remaining documents were assigned to the most probable discipline based on their research areas. Finally, we manually annotated 1,681 target documents and 7,778 citing documents that still could not be classified, resulting in valid sets of 31,008 target documents, 665,215 citing documents, and 928,740 references. Disciplinary annotation revealed seven main disciplines: neuroscience (NEB), psychology (PSS), clinical medicine (CLM), biology (BBI), engineering (ENG), computer science (CPS), and social sciences (SSS).

To further divide the ET field’s development stages, we analyzed target document and disciplinary literature quantity distributions (Figure 2 [Figure 2: see original paper]). Comparing target document (a) and major discipline (b) distributions and growth rates, we identified four stages: (1) Incubation period (1900-1967): consistently low publication volume with only neuroscience

and psychology; (2) Development period (1967-1993): gradual literature growth with increasing contributions from major disciplines; (3) Maturity period I (1994-2007): significant growth in total and disciplinary literature volumes; (4) Maturity period II (2008-2016): exponential growth, particularly in computer science and engineering.

4.2 Development Pattern Analysis in the ET Field

To reveal interdisciplinary development patterns, we calculated cross-field reference ratios (CSR_R) and cross-field citation ratios (CSCR) for neuroscience (NEB), psychology (PSS), computer science (CPS), and engineering (SSS), plotting their temporal changes (Figure 3 [Figure 3: see original paper]). These four disciplines were selected for their relatively large publication volumes, which clearly demonstrate developmental trends. CSR_R increases/decreases indicate rising/falling dependence on other disciplines' knowledge, while CSCR changes reflect increasing/decreasing knowledge export to other disciplines.

Three development patterns emerged: (1) **Independent type**: Neuroscience maintains both ratios below 1, indicating knowledge primarily flows within the discipline; (2) **Interdisciplinary type**: Psychology maintains both ratios above 1 long-term, indicating broad knowledge sources and active knowledge export despite low internal proportion; (3) **Learning type**: Computer science and engineering show high CSR_R but low CSCR, indicating strong dependence on other disciplines' knowledge while primarily exporting within their own discipline. Analysis of other ET disciplines found they all fit these three patterns, with no export-type disciplines identified.

Temporally, all pattern types show high ratio volatility in early years due to small publication volumes. Over time, independent disciplines' ratios gradually increase, indicating enhanced participation. Interdisciplinary disciplines' ratios stabilize, showing they have found stable positions and gained recognition. Learning disciplines, entering the field later, show widening gaps between ratios over time, indicating continued dependence on other disciplines' knowledge with internal absorption.

To examine knowledge absorption activity, we analyzed Price's Index for major ET disciplines, distinguishing internal and external references (Table 2). Higher Price's Index indicates faster new knowledge demand and absorption, reflecting higher participation activity. Overall, ET's Price's Index decreased from 34 to 30, showing transition from rapid development to mature, stable growth. Across disciplines, literature aging patterns differ. Neuroscience, psychology, and biology—early, high-status disciplines—show declining Price's Indices, with decreasing proportions and rankings of references within 5 years. As their reference counts increase, these disciplines require more interdisciplinary knowledge for innovation. Conversely, computer science and engineering show increasing Price's Indices, with rising proportions of references within 5 years and rapidly improving rankings. Internal reference growth exceeds external growth, yet ex-

ternal Price's Indices exceed internal ones, indicating active disciplines change across stages. Engineering and computer science are very active in recent stages but have not shaken neuroscience and psychology's status. Thematically, recent publications in these disciplines focus on robotics and virtual reality, applying eye tracking to provide new human-computer interaction methods.

We also calculated citation lag distributions for references from internal and other disciplines (Figure 4 [Figure 4: see original paper]). Citation lag refers to the time difference between a document's publication and its cited references' publication. Figure 4(a) shows ET's citation lag distribution, consistently emphasizing references within 5 years, peaking at 3-4 years, with decreasing proportions over time. Longitudinal comparison reveals decreasing proportions within 5 years across stages, indicating maturing theory and increasing recognition of early research.

Figure 4(b) shows external-internal citation lag differences across stages for four disciplines, calculated as the difference between average lags for external and internal references. Values greater than 0 indicate faster knowledge diffusion within disciplines than across them. For neuroscience, engineering, computer science, and clinical medicine, internal knowledge diffusion is faster than external, while psychology and biology show the opposite in stages II and III. Observing changes across stages, psychology, neuroscience, computer science, and biology show decreasing external-internal lags, indicating active absorption of other disciplines' knowledge. Clinical medicine, engineering, and social sciences show increasing lags, indicating relatively passive cross-disciplinary absorption.

In summary, analyzing CSRR, CSCR, and citation lags reveals four development pattern types, with ET showing independent, interdisciplinary, and learning patterns. Independent and interdisciplinary types show decreasing Price's Indices and external-internal lags, indicating reduced cross-disciplinary absorption activity over time, while learning types show increasing values, indicating growing cross-disciplinary absorption.

4.3 Disciplinary Relationship and Evolution Analysis in the ET Field

We projected disciplinary citation relationships from target documents' internal citations and visualized them using Gephi to analyze literature quantity distributions and internal citation relationship changes across stages (Figure 5 [Figure 5: see original paper]). Self-loop connections were removed due to image overlap. Edge colors indicate source disciplines, while node sizes and edge thickness represent literature volumes and citation relationship strengths.

Stage I shows neuroscience as the foundational discipline, followed by psychology and clinical medicine. In the citation network, centrally positioned neuroscience is cited by all other disciplines, while neuroscience itself cites psychology most frequently, with visible citations to clinical medicine and biology. Other disciplines show sparse citation relationships, creating a relatively sparse network. In Stage II, inter-disciplinary citation relationships grow significantly,

with new disciplines like social sciences, engineering, and computer science increasing their literature volumes. Psychology's citations to neuroscience exceed neuroscience's self-citations, and neuroscience's citations to other disciplines become more evenly distributed. All disciplines actively absorb knowledge from others, creating denser network connections. In Stage III, psychology's status approaches neuroscience's long-held core position, benefiting from information technology and human-computer interaction theory development that elevated computer science and engineering. Clinical medicine's status remained largely unchanged. Social sciences, computer science, and engineering show clear status improvements, as theories and methods from neuroscience and medicine are applied to system optimization and user experience enhancement, with results cited by other disciplines and feeding back into these fields' development.

Overall, disciplinary citation relationships become more frequent and evenly distributed across stages, with multiple closely-related discipline pairs emerging: neuroscience-psychology and neuroscience-biology in early stages, and computer science-engineering and social sciences-psychology in Stage III. All disciplines mature over time, shown by high cumulative publication volumes and greater research independence—most citations originate from or point to the same discipline.

To further analyze inter-stage citation relationships, we used Sankey diagrams to explore disciplinary citation flows across the three stages (Figure 6 [Figure 6: see original paper]). Each stage's nodes represent disciplines, with vertical lengths indicating citation counts—longer lengths represent more contributions and higher status. Flows between stages represent citation relationships, with flows to the same node in the next stage indicating citations from the same discipline, and flows to other nodes indicating cross-disciplinary citations. The diagram reveals citation flows widening from left to right like a trumpet. Stage I shows few publications, with citation counts clearly different from later stages. Stage I disciplines primarily cited by Stage II are neuroscience (70.78% internal, 29.22% external), psychology (62.16%, 37.84%), clinical medicine (42.57%, 57.43%), and biology (31.46%, 68.54%). Though neuroscience and psychology, as dominant disciplines, show lower export proportions than emerging disciplines, they are cited by nearly all other disciplines with higher absolute citation counts. Emerging disciplines' high input/output ratios often reflect immature theories and scarce internal citations—only when both ratios maintain moderate-low levels does a discipline mature within an interdisciplinary field.

Between Stages II and III, neuroscience remains primarily cited internally, but the proportion decreases (from 70.78% to 59.02%) with relatively increased external citations. Similar patterns occur in psychology (62.16% to 55.91%), clinical medicine (42.57% to 38.78%), biology (31.46% to 18.26%), and computer science (49.08% to 40.11%). This indicates increasing interdisciplinarity and full integration among disciplines in ET research.

To further discover ET field evolutionary paths, we used Pajek to calculate betweenness centrality for 1,500 documents (top 500 cited documents per stage)

and visualized them with Gephi (Figure 7 [Figure 7: see original paper]). Node colors indicate disciplines, with larger diameters for higher betweenness centrality—indicating important positions connecting other documents, often at community edges facilitating knowledge absorption and dissemination. In Stage I, the upper-left cluster belongs to psychology (document 27040), with neuroscience evenly distributed across the network. Document 27040 has the highest betweenness centrality, connecting psychology and neuroscience communities, while other high-centrality nodes belong to neuroscience—mediating documents primarily from the same discipline.

Stage II shows four dense clusters. High-centrality documents mainly appear in multidisciplinary journals (e.g., documents 28287, 21053), indicating increasing knowledge generalization in the ET field. In Stage III, edge distribution becomes more balanced than earlier stages, with third-discipline mediator nodes occupying important positions—biology documents 6662 and 8126 are crucial connectors within neuroscience, indicating freer knowledge flow and gradually broken disciplinary barriers. In summary, mediating documents initially share disciplines with their communities, then evolve into multidisciplinary or other-discipline documents, showing increasing knowledge generalization and reduced communication barriers over time. External reasons include field expansion and increasing participating disciplines making other disciplines' knowledge more important; internal reasons include strengthening interdisciplinarity in ET, with publications in multidisciplinary or other-discipline journals attracting more researcher attention and promoting cross-disciplinary citation.

To further reveal ET field evolutionary paths, we adopted T. Muñoz-Ecija et al.'s nanotechnology path analysis method, using CitNetExplorer to visualize the top 200 most cited documents (Figure 8 [Figure 8: see original paper]). Clustering citation paths divided documents into four categories with numerous cross-links. From left to right, categories focus on: visual mechanisms and cognition, face recognition, awakening and drowsiness, and REM sleep's impact on memory and cognition. The overall path shows ET's first paper in the 1950s studied visual mechanisms, with a small research burst in the 1960s. The 1970s-80s produced more papers on different ET problems, gradually bringing these issues into mainstream research and stimulating extensive related research after the 1990s. Each category shows "Sleeping Beauty" phenomena—early publications receiving little attention for long periods but providing crucial foundations for subsequent research bursts. After 1990, highly cited articles surged, with papers on different problems increasingly citing each other. Earlier core papers were jointly cited by new problem research, showing mutual citation and bibliographic coupling relationships, indicating eye tracking became a common concern across disciplines or a new approach to solving disciplinary problems.

In summary, ET shows rich diversity in both vertical and horizontal research directions and participating disciplines. Vertically, independent disciplines like neuroscience and clinical medicine drive basic theoretical innovation in different directions, including eye movement patterns, brain imaging methods, and face

recognition mechanisms. Horizontally, over time, dominant disciplines continuously integrate hot topics within and across disciplines, with interdisciplinary and learning disciplines like psychology, engineering, and social sciences joining ET research after absorbing independent disciplines' basic theories—specifically manifested in integrating eye movement patterns, brain imaging observation, psychological diseases, and social theory research. Evolutionarily, ET's early development pattern was linear, dominated by independent disciplines with relatively independent research; mid-to-late patterns transformed into mesh structures, showing deep integration of all three discipline types with increasing cooperation and dependence.

5 Conclusion and Outlook

Current interdisciplinary research has not established a unified development pattern measurement system. Building on previous work, this paper innovatively proposes an interdisciplinary development pattern and path analysis method capable of comprehensively analyzing dynamic evolution processes from macro, meso, and micro levels. Using the eye tracking (ET) interdisciplinary field as a case study, we applied this method: analyzing CSRR, CSCR, and Price's Index trends and inter-disciplinary differences to extract ET's disciplinary development patterns; examining intra-stage and inter-stage citation relationships to explore disciplinary relationship structures and role evolution; and analyzing citation relationships among important, highly cited, and reference documents to reveal specific evolutionary paths.

Results show ET development includes three stages (incubation, development, maturity) with three disciplinary patterns (independent, interdisciplinary, learning). Inter-disciplinary citation relationships become denser and more evenly distributed over time, with neuroscience, psychology, and clinical medicine as core knowledge exporters. ET's vertical development shows basic theoretical innovation in independent disciplines, while horizontal development features deep integration of the three discipline types, following an “independent-linear-mesh” path.

This study has limitations. No unified, recognized method for document disciplinary annotation currently exists, yet annotation is crucial for interdisciplinary measurement, directly affecting classification accuracy. This paper only used ESI journal categories, supplemented by automatic and manual processing based on research areas for remaining documents. Additionally, no unified measurement system exists for interdisciplinary development patterns. This paper used three indicators to summarize field development patterns from different angles, but future research needs more appropriate indicators for effective supplementation. Future work should also integrate author, citation, and topic perspectives for interdisciplinary evolution analysis, achieving cross-perspective correlation and verification to reveal universal interdisciplinary development laws.

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Call for Papers: ACM/IEEE Joint Conference on Digital Libraries (JCDL 2020)

The ACM/IEEE Joint Conference on Digital Libraries (JCDL) is the longest-running, most academically rigorous, and influential top-tier international conference in the digital libraries field, jointly organized by the Association for Computing Machinery (ACM) and the Institute of Electrical and Electronics Engineers (IEEE). Together with the European Conference on Digital Libraries (ECDL) and the International Conference on Asian Digital Libraries (ICADL), it is known as one of the three major international academic conferences in global digital library research.

JCDL 2020 will be held June 19-23, 2020 in Wuhan, Hubei Province—the “thoroughfare to nine provinces”—hosted by Wuhan University School of Information Management and the Center for Studies of Information Resources. This is the first time JCDL will be held in Asia. The conference theme is “Speedier Innovation, Sustainable Development, Societal Transformation.” We invite participants to discuss digital library theory and practice innovation, sustainable knowledge ecosystem construction, and promoting social transformation during rapid change.

JCDL 2020 Call for Papers

JCDL 2020 accepts various types of submissions in English, including: full papers, short papers, posters and demonstrations, doctoral consortium, tutorials,

workshops, panels, and practice cases. Specific requirements for each type are available at <http://2020.jcdl.org/cn/GeneralSubmissionInstructions.html>. Proceedings will be published by ACM and indexed by EI and CPCI.

The JCDL 2020 Chinese Forum will be held June 22-23, 2020 in Wuhan, Hubei. This forum aims to provide an international academic exchange platform for Chinese experts, scholars, graduate students, and practitioners to showcase the latest research results in China's digital library field, promote academic viewpoints and experience exchange, and drive rapid development and internationalization of China's library and information science cause. This forum's special feature is: it accepts research and practice with Chinese characteristics in digital libraries, or related research completed by Chinese scholars. We warmly welcome experts and scholars from relevant fields at home and abroad to submit papers and attend. The forum's theme is "Data-Driven Smart Services."

The Chinese Forum accepts submissions in both Chinese and English. Format requirements can refer to the *Journal of Library and Information Science* submission guidelines: <http://dik.whu.edu.cn/jwk3/tsqbzs/CN/column/column192.shtml>. Submitted papers will be reviewed by the JCDL 2020 Chinese Forum Program Committee. Accepted papers will be recommended for publication in *Journal of the China Society for Scientific and Technical Information*, *Library and Information Service*, *Journal of Library and Information Science*, *Library Journal*, *Library & Information*, *Information and Documentation Services*, *Library Development*, *Library Tribune*, *Journal of Information Resources Management*, *Chinese Journal of Scientific and Technical Periodicals*, *Journal of Data and Information Science*, and other journals.

For more information, please visit the conference website: <http://2020.jcdl.org/index.html>
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