Analysis of the Research Trajectory of Knowledge Visualization Design

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Abstract

Purpose: Knowledge visualization serves as a crucial tool for knowledge reproduction in the knowledge society, and its design research reflects the concerted efforts to explore new forms of knowledge creation. Methods: This study employs bibliometric analysis tools VOSviewer and CiteSpace, along with manual literature review methods, to retrieve and analyze domestic and international literature from 1985 to 2022 using "knowledge visualization design" as the keyword. Results: The study deconstructs the dialectical evolution of international design research on knowledge visualization and examines the current state of domestic research in this field. Limitations: The research posits that the field of knowledge visualization necessitates a universal framework to coordinate extensive fragmented research efforts. Conclusion: Knowledge visualization design should further enrich the cognitive perspectives of designers across diverse research levels, and design practice should employ materialist dialectics to comprehend development trends and clarify the trajectory of design research.

Full Text

Preamble

A Scheme Analysis of Knowledge Visualization Design Research

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Abstract

[**Objective**] Knowledge visualization serves as a crucial tool for knowledge reproduction in the knowledge society, and its design research reflects sustained efforts to explore new forms of knowledge creation. [**Methods**] This study employs bibliometric analysis tools VOSviewer and CiteSpace, supplemented by

manual literature sorting, to search and analyze domestic and international literature from 1985 to 2022 using the keyword "knowledge visualization design." [**Results**] The analysis reveals the dialectical trajectory of international design research development in knowledge visualization and the current state of domestic research. [**Limitations**] The study identifies that the field requires a universal framework to coordinate its highly fragmented research efforts. [**Conclusions**] Knowledge visualization design should further enrich its research levels and diversify designers' epistemological perspectives, while adopting materialist dialectics to grasp development trends and clarify design research pathways.

Keywords: Knowledge visualization; Design; Literature analysis; Materialist dialectics; Strategy
Classification Number: G353.11

In the knowledge society, people have access to vast amounts of knowledge content, and knowledge visualization has distinguished itself through its capacity to clarify complex problems, becoming an effective tool for knowledge dissemination and creation. That design can be applied to visualization research has been widely acknowledged, as design constitutes an extremely complex and sophisticated human activity, and design theory represents a demanding research domain. Design theorists recognize that ordinary language cannot address certain questions, necessitating high-level formal languages and models—precisely the theoretical paradigms urgently needed in knowledge visualization. Therefore, this study approaches knowledge visualization development from the perspective of "design."

1. Literature Sources

Knowledge visualization is an emerging research field of the past two decades, and differences between its origin and dissemination contexts are inevitable, as research priorities and layouts remain unstable in new domains. Analyzing these distinctions between domestic and international research helps illuminate historical development and future trends. This study categorizes research based on readership: international research refers to works written primarily in English for the global academic community, while domestic research refers to works written primarily in Chinese for the domestic academic community. Although this classification cannot be entirely comprehensive, it proves helpful for understanding the research context of knowledge visualization design.

2.1 Data Sources

International research data were sourced from the Web of Science Core Collection database of the Institute for Scientific Information. This includes the Science Citation Index (SCI, 1989–present), Science Citation Index-Expanded (SCIE, 1991–present), Social Sciences Citation Index (SSCI, 2001–present), Arts

& Humanities Citation Index (A&HCI, 2016-present), Emerging Sources Citation Index (ESCI, 2015-present), and Current Chemical Reactions (CCR-Expanded, 1985-present). Given the breadth of knowledge visualization literature, the author focused on two keywords– "knowledge visualization" and "design study" –conducting a subject search for publications from 1985 to 2022, yielding 1,377 documents (downloaded on January 14, 2022).

[Figure 1: see original paper] 2000–2021 International Publication Volume Trend (vertical axis: number of papers)

2.2 Discipline, Country, and Funding Distribution

According to Web of Science analysis, knowledge visualization research has shown consistent growth over the past two decades, with a particularly significant acceleration in the last three years (Figure 1). Research directions are widely distributed but concentrated primarily in natural sciences (Figure 2(a)). The top ten disciplines are: Computer Science (30.356%), Engineering (19.753%), Education Research (14.234%), Business & Economics (6.681%), Library & Information Science (6.391%), Environmental Science (4.866%), Molecular Biology (4.212%), Science & Technology (3.922%), Psychology (3.341%), and Chemistry (3.122%). Among citation indexes, SCI(E) and SSCI account for the highest proportion, while ESCI and A&HCI have fewer publications (Table 1). A total of 87 countries conduct knowledge visualization design research, which can be divided into three tiers (Table 2): the United States leads at 29%, followed by China, Germany, and the UK as the second tier (16%, 9%, and 9% respectively), and Spain, Italy, Canada, Australia, France, the Netherlands, Sweden, and others as the third tier. Funding analysis reveals a predominance of scientific funds, primarily supported by national and regional programs. Specifically, the China National Natural Science Foundation supports 87 papers, the U.S. National Science Foundation 71, the U.S. National Institutes of Health 58, the U.S. Department of Health and Human Services 58, the European Commission 50, UK Research and Innovation 34, the German Research Foundation 28, and the UK Engineering and Physical Sciences Research Council 18. Although China has numerous funded projects, funding sources remain relatively singular, with many agencies not yet recognizing knowledge visualization design as an important independent research object. The U.S. public service and health systems demonstrate notable attention to knowledge visualization design research (Figure 2(b)).

Table 1 Ranking by Citation Index Publication Volume

Rank	Citation Index Database	Publication Volume (%)
1	SCI(E) Science Citation Index	70.443%
2	SSCI Social Sciences Citation Index	38.998%
3	ESCI Emerging Sources Citation Index	11.692%
4	CPCI-S Conference Proceedings Citation Index-Science	5.229%
5	A&HCI Arts & Humanities Citation Index	1.525%
6	BKCI-S Book Citation Index-Science	0.508%
7	CPCI-SSH Conference Proceedings Citation Index-Social Sciences & Humanities	0.363%

Table 2 Top Ten Countries by Publication Volume
| Rank | Country | Publication Volume (%) | |—|——|————| | 1 | United States | 29.121% | | 2 | China | 14.524% | | 3 | Germany | 9.531% | | 4 | United Kingdom | 9.223% | | 5 | Spain | 4.430% | | 6 | Italy | 4.357% | | 7 | Canada | 4.285% | | 8 | Australia | 4.139% | | 9 | France | 4.067% | | 10 | Netherlands | 4.067% |

(a) Research Direction Quantity Ranking (b) Research Funding Support Quantity Ranking
Figure 2 International Research Focus (vertical axis: number of papers)

2.3 Research Fields and Research Clusters

[Figure 3: see original paper] Keyword Co-occurrence Analysis

This study employs two bibliometric visualization analysis software tools based on the Web of Science Core Collection. First, the author uses VOSviewer' s clustering and mapping techniques to analyze 1,377 article titles, keywords, and abstracts through co-keyword analysis. With a minimum frequency threshold of 10, 134 keywords were identified from 7,439 terms for label and cluster mapping (Figure 3). The most frequent co-occurring concepts include "visualization," "knowledge,"and "design."Knowledge visualization design research is distributed across three main domains: visualization functionality (blue and purple areas), cognitive education (green area), and knowledge management/intelligence (red and yellow area). These domains focus more on "design" issues, emphasizing design rather than mere technology to support knowledge visualization applications. Among 1,780 international visualization research institutions, 99 have published five or more papers, with 64 forming a network relationship. They constitute ten research clusters, represented by institutions including the University of Hong Kong, Zhejiang University, UC Berkeley, University of Michigan, University of Zurich, University of Utah, Oxford University, Drexel University, Leiden University, and Seoul National University (Figure 4(a)). Among 87 countries researching knowledge visualization design, 38 have published more than ten papers, with 36 forming a network relationship. The resulting inter-country collaboration map (Figure 4(b)) shows close cooperation among the U.S., China, UK, and Germany. Both the U.S. and China have extensive collaboration networks: the U.S. collaborates closely with China, Taiwan (China), UK, Germany, Netherlands, Canada, Switzerland, Italy, and South Korea; China collaborates closely with the U.S., UK, Germany, France, Netherlands, Italy, Spain, and Taiwan (China).

(a) Research Institution Collaboration Map (b) Country (Region) Research Collaboration Map
Figure 4 International Collaboration

2.4 Historical Description

To understand the evolution and development of knowledge visualization design research, this paper employs CiteSpace bibliometric analysis software. CiteSpace' s burst detection and timeline functions produce a timezone view that divides the map into temporal nodes, enabling observation of path evolution, knowledge bases, and relationships among core studies. The author set the analysis timeframe from 1985 to 2022, with two-year slices to explore key emergent terms in the raw data. Analysis reveals that frontier keywords began appearing in 1992, with continuous emergence of burst terms from 2001 to 2022.

[Figure 5: see original paper] 1992–2022 Frontier Timezone Map of Knowledge Visualization Design

According to Figure 5, burst term distribution is as follows: 1992–1993: "visualization" ; 1994–1995: "knowledge," "design," and "system" ; 1996–1997: "tool" ; 1998–1999: "model" ; 2000–2001: "performance" ; 2002–2003: "animation," "behavior," and "environment" ; 2004–2005: "information" ; 2006–2007: "science" and "education" ; 2008–2009: "technology," "framework," and "cognitive" ; 2010–2011: "management" ; 2012–2013: "meta-analysis" and "attention" ; 2014–2015: "impact," "simulation," "perception," and "exploration" ; 2016–2017: "challenge" and "communication" ; 2018–2019: "risk" and "quality," after which no significant burst terms emerged.

The burst term list (Figure 6) shows duration and intensity. The top ten burst concepts are listed below. Beginning in 2001, "animation" became a sustained research hotspot in knowledge visualization design for 16 years. In 2005, "information" design gained attention, followed in 2009 by "knowledge," "representation," and "multimedia" simultaneously becoming popular research areas, with attention to "representation" continuing until 2016. In 2013, knowledge visualization research began moving toward deeper domains, with "participation" and "exploration" becoming focal points. The 2017–2020 emergence of "risk" indicates scholars began using visualization to explore uncertainty, while "simulation" in 2019 became a new research focus.

[Figure 6: see original paper] Burst Term List in Knowledge Visualization Design (1985–2022)

2.5 Dialectical Development Analysis

Combining Figures 5 and 6 reveals that knowledge visualization design entered the academic research domain in the 1990s, forming relatively stable and concentrated research directions only after 2000. The twenty-year evolution of burst terms from 2001 to 2022 demonstrates that advances in science and technology significantly influence visualization research directions. The 2001 burst term "animation" reflects how computer technology enabled vivid knowledge representation, animating static images and greatly enhancing cognitive experience —an enlightenment condition for knowledge visualization becoming an indepen-

dent research field. Exploration of "animation" further propelled comprehensive research in "representation" (2009), with both maintaining long-term dominance until 2016. This comprehensive research required examining how information and knowledge transform across evolving media forms (2009), leading to the combination of visualization technology with "multimedia" to open new research domains. With the rapid development of the internet since 2010, "visualization" became recognized by broader audiences, attracting more scholarly attention. Knowledge visualization design research evolved from summarizing knowledge representation patterns—concrete experience to abstract theory—to focusing on human practical factors, enabling "participation" (2013), "exploration" of uncertainty (2015), and reduction of "risk" (2017). The research level continuously shifted from sensuous concreteness to abstract determination and then to rational concreteness. In recent years, rapid technological and algorithmic advances have propelled knowledge visualization design research into new domains of high quality and high challenge. The 2019 burst term "simulation" appears to return to visual representation research, yet actually responds to "participation," "exploration," and "risk" from 2013 onward through new technologies, representing more precise solutions for complex problems.

This twenty-year developmental trajectory shows knowledge visualization design research beginning with visualization effects as the cognitive starting point, through rational processing of perceptual materials to obtain partial regularized understanding that guides practice. The research context has experienced a process from concrete to abstract to concrete, from particular to universal to particular, and from deterministic representation to uncertainty exploration to deterministic precision enhancement. This process is dialectical, particularly as current "simulation" both responds to "participation," "exploration," and "risk" and represents a spiral ascent and return of the knowledge visualization design research paradigm (regarding representation)—a step forward that is taking a crucial step toward realizing the "metaverse."

3.1 Bibliometric Analysis of Domestic Research

Domestic research data were sourced from the China National Knowledge Infrastructure (CNKI) database. The author conducted a subject search using "knowledge visualization design" as the core term, obtaining 518 academic works that comprehensively cover domestic scholars' research in this field, including 186 dissertations (171 master' s and 15 doctoral). Domestic knowledge visualization design research is developing rapidly, with a significant upward trend in the past decade (Figure 7). Knowledge visualization is becoming a new popular research field in China.

Many studies treat knowledge visualization as a tool or technical means for professional knowledge extraction and dissemination, focusing primarily on application research, technical research, and educational impact research. As Figure 8 shows, knowledge visualization research is most widely applied in education, aligning with the demands of modern educational digitalization and informatiza-

tion transformation. However, funding analysis (Figure 9) reveals that current domestic support for knowledge visualization research in natural sciences exceeds that in humanities and social sciences. The author extracted the top 20 disciplines actively engaged in knowledge visualization design research (Figure 10), showing distribution primarily across computer science, education, and library & information science, with art ranking fifth but independent design research not yet forming scale. Domestic visualization design researchers should pay active attention to knowledge visualization.

[Figure 7: see original paper] Domestic Publication Volume Trend in Knowledge Visualization Design Research
[Figure 8: see original paper] Domestic Publication Unit Distribution in Knowledge Visualization Design Research
[Figure 9: see original paper] Domestic Funding Support Distribution in Knowledge Visualization Design Research
[Figure 10: see original paper] Discipline Distribution in Knowledge Visualization Design Research

3.2 Research Categories

Through further manual sorting, domestic knowledge visualization design research concentrates on three aspects: introduction to knowledge visualization, design representation of knowledge visualization, and design process of knowledge visualization, with some scholars' work cross-cutting these domains.

3.2.1 Introductory Research First, regarding the connotation of knowledge visualization, researchers primarily introduce and discuss conceptual definitions. Scholar Zhao Guoqing pioneered detailed analysis of Martin Eppler' s definition of knowledge visualization, while He Quanbing introduced visualization technology development and applications. Scholars Zhang Shuyu, Qiu Ting, and Zhao Huichen each proposed their own definitions, generally viewing knowledge visualization as graphical visual description of knowledge that facilitates acquisition, storage, discussion, evaluation, and management. Wang Xi redefined knowledge visualization in 2018, though this definition' s premise of shared decision-making (medical) contexts limits its universality.

Second, comparative studies distinguish knowledge visualization from information visualization. Yuan Guoming and Zhou Ning compared conceptual connotations, application scopes, and theoretical methods, concluding that information visualization emphasizes discovering new patterns while knowledge visualization focuses on dissemination. Zhou Ning, Chen Yongyue, Jin Dawei, and Zhang Huiping compared knowledge and information visualization across ten dimensions to identify integration strategies. Zhang Zhuo, Xuan Lei, and Hao Shuyong compared scientific computing visualization, data visualization, information visualization, and knowledge visualization across concepts, technologies, and applications, advocating integrated use. These comparative studies clarify boundaries and scope for the new research field.

Finally, review studies describe industry status, development, and research trends. Zhao Huichen reviewed visual representation research in knowledge visualization; Zhang Xia wrote "A Review of Knowledge Visualization Research" to provide references; Liu Chao reviewed ten years of international knowledge visualization research in 2012, focusing on teaching and learning and arguing for iterative practice; Wang Xi conducted bibliometric analysis of knowledge visualization literature from 1997–2017 in both Web of Science and CNKI databases. These studies provide overviews for other researchers.

3.2.2 Design Representation Research Representation research in visualization primarily builds on Paivio' s dual coding theory (1986), which posits that the linguistic system can directly process verbal and written input/output while maintaining symbolic functions related to non-verbal objects, events, and behaviors—any representation theory must accommodate this dual capability. This semantic-imagery dichotomy was introduced by Martin Eppler into knowledge visualization definitions, with Eppler arguing that visual communication and visual cognition form the foundation of knowledge visualization, whose research object is visual representation. This has spawned domestic scholars focusing on visual representation of knowledge. Zhao Huichen is a leading scholar, constructing a representation cube model for educational knowledge visualization. Qiu Ting views knowledge visualization' s essence as knowledge representation. Chen Yanyan uses visual metaphor for knowledge visualization representation design, breaking the technology-deterministic (tool-deterministic) tendency. Zhu Yonghai studies visual representation based on common knowledge classification. Two researchers incorporate user needs: Wang Chaoyun selects appropriate visualization methods by distinguishing knowledge types and analyzing learner differences and motivations, while Zhou Ning and Lü Yongfeng advocate extracting design methods from users or learners. However, dual coding theory originates from psychology, imposing certain limitations on research perspectives and paradigms for knowledge visualization products.

Wang Zhijuan argues current research focuses only on knowledge visualization representation while inadequately addressing specific disciplinary knowledge, calling for enhanced formal language and multi-dimensional complex algorithms. The author contends that while representation research is necessary, equating knowledge visualization with representation risks neglecting its essential product attributes. The boundaries blur between treating knowledge visualization as a knowledge commitment product versus a commodity, or as an accessory versus the main product. Lack of reflection on visualization product essence complicates evaluation system positioning and risks arbitrary or absent evaluation standards. Solutions lie either in more precise technology and algorithms or in research perspectives beyond psychology, though such studies remain scarce.

3.2.3 Design Framework and Process Research Much knowledge visualization design research concentrates on developing and applying process models, particularly specific steps guiding design. Zhou Ning, Zhang Huiping, and

colleagues proposed a tacit knowledge conversion process model, a knowledge visualization cube framework, and a visualization technology-based knowledge conversion model. Zhao Huichen established a knowledge visualization representation analysis framework: situation analysis, content construction, meaning interpretation, and design methods. Liu Wei summarized several aspects of knowledge visualization process design in his master's thesis. Wang Xi extracted a knowledge visualization design process in medical shared decision-making contexts. These frameworks and models primarily constitute procedural knowledge, generally linear and mechanical process patterns with limited dynamic and dialectical thinking. While process research is important, focusing only on surface phenomena without adequate attention to genetic mechanisms provides insufficient guidance. Researchers should rigorously construct various forms of knowledge through design philosophy.

4. Design Research Limitations

The above analysis indicates that knowledge visualization design research requires a universal framework. Knowledge visualization design research transcends "art design," involving numerous disciplines with extensive research foundations in other fields. However, much research focuses only on local or individual stages of knowledge creation, such as the shift from "animation" to "information," "representation," "media," and "user participation," without adequately examining connections between stages or discussing the holistic meaning of "knowledge creation." As the visualization field develops, interdisciplinary intersections become prominent, increasing demands for research universality. Burkhard argues the field needs a universal framework to coordinate its disparate independent research contents. The modern academic system locks scholars into narrow, productive specialties, diluting holistic humanistic concern for human society. Moreover, postmodernism' s opposition to universal truth, grand narratives, and meta-discourse creates wariness even among non-postmodernists, obstructing universal framework research—a problem requiring urgent resolution.

5. Summary and Reflection

From the "design"perspective, integrating domestic and international knowledge visualization research with personal design practice suggests two directions for current knowledge visualization design research.

5.1 Diversifying Epistemological Perspectives and Enriching Research Levels

Current knowledge visualization research predominantly employs scientific positivism, solving problems within psychological and computer science frameworks, with limited reflection on epistemological foundations and ontological structures. Visualization courses and textbooks typically avoid discussing various ontologies

and epistemologies of visualization and provide limited education on design and inquiry methods for visualization researchers. The field currently lacks constitutive knowledge concerning essence, requiring strengthened development. Constitutive knowledge depends on social knowledge supply, demanding researchers conduct diversified cognitive reflection on actual social conditions. Beyond psychological and computer science research, scholars should attend to the political-economic value and sociological significance of knowledge visualization products —considering both micro-level design and macro-level effects. In social knowledge reproduction, knowledge visualization plays an increasingly important role. Diversifying epistemological perspectives and enriching research levels will help designers better position and define their products, advancing knowledge visualization design research.

5.2 Grasping the Design Research Pathway

Literature review reveals that knowledge visualization development emphasizes the positivist route, where designers typically assume reality is singular and external, making knowledge visualization objectively knowable. Research methods consequently focus on reducing researcher reactivity to achieve reliability, replicability, and representativeness. As knowledge visualization expands, research complexity increases rapidly. Some visualization researchers view knowledge as socially constructed rather than objectively determined, as evidenced by numerous studies discussing "participation" and "exploration" regarding subjective agency, arguing that relativism offers explanatory advantages. Both positivist and relativist epistemological perspectives partially address visualization design problems but cannot accommodate knowledge visualization' s widespread application in the knowledge society. Relativism' s presupposition that all positions, views, and theories can articulate themselves equally and unconditionally obscures the existence of positions that "cannot speak." Knowledge visualization designers should root themselves in complex social reality, using materialist dialectics to coordinate design' s internal values and external demands to achieve sound self-discipline standards, thereby grasping knowledge visualization design research pathways.

This study analyzes the dialectical development trajectory of knowledge visualization, revealing its evolution from concrete to abstract to concrete. It concludes that knowledge visualization design researchers should transcend traditional research frameworks, diversify and enrich design understanding, comprehend knowledge visualization' s holistic meaning and value in the knowledge society, and grasp design trends and research pathways through materialist dialectics.

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