

Data Stories and Cognitive Load: A Systematic Review of the Picture Superiority Effect

Mohammed Rakibul Hassan
Department of Computer Science
Kulliyah of Information and
Communication Technology
International Islamic University
Malaysia
Kuala Lumpur, Malaysia
hassan.mr@live.iium.edu.my

*Madiahah Sheikh Abdul Aziz 
Department of Computer Science
Kulliyah of Information and
Communication Technology
International Islamic University
Malaysia
Kuala Lumpur, Malaysia
madihahs@iium.edu.my

Raini Hassan
Department of Computer Science
Kulliyah of Information and
Communication Technology
International Islamic University
Malaysia
Kuala Lumpur, Malaysia
hrai@iium.edu.my

Abstract: This study investigates the Picture Superiority Effect (PSE) as a mechanism for enhancing data storytelling and reducing cognitive load. A systematic literature review (SLR) of 16 peer-reviewed studies published between January 2022 and June 2025 was conducted following PRISMA 2020 and CASP guidelines. Results show that visual formats such as infographics, dashboards, and data comics outperform text-only approaches, particularly when tailored to audience expertise and domain context. Relevant, well-integrated visuals improve memory retention, engagement, and comprehension, whereas irrelevant or overly complex visuals can increase cognitive load. The synthesis draws on Dual Coding Theory, Cognitive Load Theory, and Cognitive Semiotics to explain these effects. Despite growing adoption of PSE-based approaches, challenges persist in developing standardized design guidelines, accurately measuring cognitive load, and adapting visuals for diverse audiences. This review consolidates empirical evidence, identifies key research gaps, and offers design recommendations for adaptive, user-centered visual storytelling applicable to domains including education, healthcare, and governance.

Keywords—Picture Superiority Effect (PSE), Data Storytelling, Cognitive Load, Memory Retention, User Engagement, Visual Communication

I. INTRODUCTION

Stories are central to human communication, just as data underlies facts and experiences. However, data is often perceived as boring or too complex, especially for audiences with limited data literacy. To address this, researchers and designers have developed techniques that present data in more understandable ways. William Playfair, widely recognized as an early pioneer of data storytelling, introduced visual formats such as pie charts, bar charts, and line graphs to communicate economic and

trade information more clearly [1]. His work shifted data communication from purely numerical reporting toward more visual, narrative-driven representations, although such approaches were still not widely accessible at the time [2].

Today, many people associate data with charts and graphs, yet these can impose a high cognitive load when viewers must invest substantial mental effort to interpret unfamiliar visual encodings. Data storytelling aims to reduce this burden by presenting information in a structured and engaging narrative form [3]. Story-based approaches can help curate, summarize, and communicate large datasets in a digestible way, improving comprehension [4]. Prior work also suggests that images support stronger memory recall than text-only communication [5, 6]. When combined with text, images can increase curiosity, encourage active engagement, and support language and narrative understanding [7]. In data storytelling, images can therefore translate numerical information into meaningful narratives that are easier to process and remember [8]. This study examines how the Picture Superiority Effect (PSE) may reduce cognitive load in data storytelling through an SLR, and identifies challenges, gaps, and future research directions.

II. LITERATURE REVIEW

Data storytelling combines narrative structure with visualization to support comprehension and reduce cognitive burden, particularly for users with limited data or visualization literacy [3, 4]. The Picture Superiority Effect (PSE) indicates that images are remembered more effectively than words [9]. Neuroscience and educational psychology further show that visual stimuli activate memory-related processes and can improve recall across different cognitive capacities [7, 10, 11]. In data storytelling, images act as metaphors and contextual cues that help audiences interpret complex insights more easily [8].

Outcomes depend on expertise and interaction level: experts often benefit from detailed interactive dashboards,

while novices perform better with simplified static visuals [13, 14]. Storytelling formats such as infographics, animations, and comic strips can increase retention, engagement, and emotional connection compared with text-only content [10, 12]. However, irrelevant or overly complex visuals may increase cognitive load and weaken effectiveness [17, 18]. Effective design requires alignment with audience expertise, domain context, and emotional salience [21, 22].

Key Patterns Identified from Literature:

1. PSE enhances recall, learning, and engagement when visuals are meaningful and well-integrated [10, 11, 13].
2. Irrelevant visuals increase cognitive load and hinder understanding [17, 18].
3. Preferred PSE formats include infographics, animations, and comic strips [14, 19, 20].
4. Visual storytelling effectiveness depends on user expertise, domain context, and emotional salience [21, 22].

III. METHODOLOGY

This study adopts a Systematic Literature Review (SLR) guided by the PRISMA 2020 framework [23]. The objective is to synthesize empirical evidence on the role of the PSE in reducing cognitive load within the data storytelling context.

A. Research Questions

This review addresses the following questions:

- What evidence exists on the PSE in Data Storytelling on memory retention and recall?
- How does audience expertise influence the effectiveness of visuals in Data Storytelling?
- To what extent does the use of pictures reduce the Cognitive Load, and how is this measured?
- What outcomes are typically associated with PSE-enhanced Data Storytelling (e.g., engagement, learning, and user satisfaction)?
- What theoretical frameworks explain the role of visuals in cognitive processing for data narratives?
- What types of visual formats (e.g., infographics, dashboards, animations) are most associated with PSE in Data Storytelling studies?

B. Search Strategy and Inclusion Criteria

A structured search was conducted between April and June 2025 across five primary databases: IEEE Xplore,

ScienceDirect, Google Scholar, ResearchGate, and selected sources from Taylor & Francis and ACM Digital Library. Supplementary material was also drawn from credible websites such as OECD iLibrary, Statista, and Pew Research.

Search queries used Boolean combinations of keywords:

"Picture Superiority Effect" OR "PSE"
 AND "Data Storytelling" OR "Data Narratives"
 AND "Cognitive Load" OR "Working Memory"
 AND "Visualization" OR "Infographics" OR
 "Dashboard" OR "Comic" OR "Comic Strip" OR
 "Comic Panel" OR "Data Comic"

Only peer-reviewed studies published between January 2022 and June 2025, in English, and with a direct focus on PSE, cognitive load, or data storytelling, were included. Exclusion criteria comprised conceptual papers lacking empirical evidence, duplicates, studies unrelated to cognitive or educational contexts, or those without full-text access.

C. Screening and Quality Appraisal

The review process was based on the PRISMA guideline, which is often used to document the screening process, ensuring that the selection of studies is systematic and unbiased [24, 25]. The quality of reporting and risk of bias in systematic reviews are influenced by several factors, including the impact factor of the journal, study registration, and adherence to reporting guidelines. Studies published in higher-impact journals tend to have better adherence to PRISMA and lower risk of bias [28, 29].

The following PRISMA Flow diagram, Fig. 1, illustrates the process:

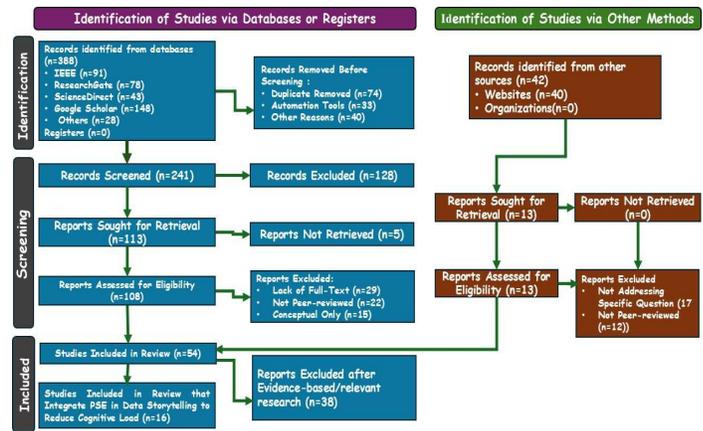


Fig. 1. PRISMA 2020 flow diagram representing the selection process of studies included in the SLR. The diagram based on [23], was redrawn by the authors.

Based on PRISMA, for quality assessment, each study is assessed for quality to ensure that only high-quality evidence is included in the review. This step is critical in maintaining the integrity and reliability of the review findings [24, 25]. For data extraction, relevant data from the selected studies are extracted to answer the research questions. This involves summarizing findings, identifying patterns, and drawing conclusions based on the evidence [26, 29]. The final stage

consists of writing the review, which includes a detailed description of the methodology, findings, and implications for future research.

Next, this study addresses CASP (Critical Appraisal Skills Program) to help address the rigor, reliability, and relevance of findings of the studies. Following PRISMA and CASP, this study performs Data Extraction, which captures the key characteristics of studies.

I. FINDINGS

A total of 388 records were initially retrieved from various databases, including IEEE Xplore (n = 91), ResearchGate (n = 78), ScienceDirect (n = 43), Google Scholar (n = 148), and others (n = 28). Additional sources from websites and organizations contributed 44 more records. After removing duplicates (n=74) and excluding studies based on date, language, and relevance (n=73), 241 titles and abstracts were screened.

From this set, 108 full-text articles were reviewed. Sixty- six were excluded for lacking empirical evidence, full-text access, or peer-review validation. The final pool of 16 high- quality studies was selected using CASP appraisal criteria for inclusion in the synthesis.

The list of reviewed papers is shown in Table I

TABLE I. LIST OF INCLUDED STUDIES.

No.	Authors(s)	Title	Year
1	[13] Zhang et al.	A Visual Storytelling Framework	2022
2	[14] Deshpande et al.	Data Storytelling - The 7 Design Principles for Narrating an Effective Data Story	2023
3	[22] Bai S, et al.	Exploring the Effects of Digital Storytelling-Enhanced Scenario-Based Learning on Students' Learning Outcomes	2023
4	[18] M. Fansher, et al.	Narrative Visualizations: Depicting Accumulating Risks and Increasing Trust in Data	2024
5	[6] L. Ciccione, et al.	The superiority of graphics over text in long-term memory retention	2025
6	[5] Silva. A	efeito superior das imagens na memorização e aprendizado	2022
7	[31] Roberts B, et al.	Memory for Symbolic Images: Findings from Sports Team Logos	2022
8	[15] Caasamayou V, et al.	Ride Your Data: Raise your Arms, Scream, and Experience your Data from a Roller Coaster Cart	2022
9	[19] Schröder K, et al.	Telling stories with data -- A systematic review	2023
10	[20] Amabili L, et al.	Show Me the GIFFerence! Using data-GIFs as Educational Tools	2024
11	[32] Shang S, et al.	Understanding the Impacts of Storytelling and Player Perspective on Learning Outcomes: The Mediating Roles of Engagements	2024

12	[33] Nabirye H K	The Role of Technology-Enhanced Storytelling in Health Education	2024
13	[34] Martinez-Maldonado R	Data Storytelling: Revolutionising Human-Data Interaction or Just Passing Hype?	2023
14	[35] Tokatrova V, et al.	Educational potential of data storytelling technology: features and prospects of implementation	2024
15	[36] Zhao J, et al.	ChartStory: Automated Partitioning, Layout, and Captioning of Charts into Comic-Style Narratives	2023
16	[37] Zhao Z, et al.	The Stories We Tell About Data: Surveying Data-Driven Storytelling Using Visualization	2023

A. Summary of Extracted Insights

The following Table II presents the outcome area and summarizes the key outcomes across studies, categorized by outcome area, visual format, target audience, interactivity, metrics, and theoretical models (e.g., Dual Coding Theory, Cognitive Load Theory).

TABLE II. OUTCOME AREA AND KEY FINDINGS

Outcome	Key Finding	Visuals	Theory	Studies
Memory & Recall	Images outperform text; familiarity aids recall	Dashboard Comics	Dual Coding, PSE	[18, 31].
Cognitive Load	Relevant visuals ↓ load; ↑ irrelevant load	Infographic, Animation	CLT	[32, 33, 34].
Engagement	Visual stories boost involvement	Comic, GIFs, Animation	PSE, Story Schema	[14, 22, 35,36].
Learning	Visual storytelling ↑ comprehension	Infographics, Dashboard Comics	Dual Coding	[5, 6, 31].
User Satisfaction	Narratives ↑ immersive experience	Comics, Infographics	PSE	[22, 33, 36, 37].
Expertise Level	Experts prefer interactive; novices prefer simple	Dashboard Comics	CLT	[15, 19].
Effective Formats	Formats vary by audience & goal	Infographics, Dashboard Comics Animation	PSE	[13, 19, 20, 36, 37].

B. Quality Appraisal and Visual Trend

Quality was assessed using a 10-point rubric (clarity, rigor, ethics, contribution). Studies scoring ≥14 was retained

for synthesis. Table IV shows that most studies scored high in research clarity, methodological fit, and relevance.

The CASP-based appraisal highlighted the relevance of these studies in this review. In Table III, CASP-based appraisal has been presented shortly.

TABLE III. CASP CRITICAL APPRAISAL.

Pattern (Cla, Met, Des, DC, Rel, Eth, DA)	Studies	Val
Y, Y, Y, Y, Y, Y, Y	Zhang (2022), Deshpande (2023), Bai S (2023), Ciccione L (2025), Schröder K (2023), Shang S (2024), Nabirye H K (2024)	H
Y, Y, Y, Y, P, Y, Y	Fansher (2024), Amabili L (2024), Zhao J (2023)	H
Y, Y, Y, Y, Y, P, Y	Silva A (2022)	M
Y, Y, Y, Y, Y, N, Y	Roberts B (2022)	M
Y, Y, Y, Y, P, P, Y	Caasamayou V (2022), Martinez-Maldonado R (2023), Tokatrova V (2024), Zhao Z (2023)	M

Legend: Cla = Clarity, Met = Methodology Fit, Des = Design Appropriateness, DC = Data Collection, Rel = Relativity, Eth = Ethical Consideration, DA = Data Analysis Rigor, (Y = Yes, P = Partial) Val = Value (H = High, M = Moderate)

The following Table IV presents the extracted data from the 16 studies included in this systematic review of the literature. Each study was analyzed for its focus area, visual format, measured outcomes, and relevance to the research questions on PSE, Data Storytelling, and Cognitive Load.

TABLE IV. DATA EXTRACTION TABLE.

Study (Year)	Country	Type	Visual	Rel.
Zhang (2022)	China	Experimental	Dashboard	H
Deshpande (2023)	India	Survey	Infographics	H
Bai S (2023)	China	Experimental	Comics	H
Fansher (2024)	USA	Qualitative	Infographics	H
Ciccione (2025)	Italy	Case Study	Dashboard	H
Silva (2022)	Brazil	Case Study	Animations	M
Roberts (2022)	UK	Mixed	Comic Strips	M
Caasamayou (2022)	France	Qualitative	Infographics	M
Schröder (2023)	Denmark	Experimental	Infographics	H
Amabili (2024)	Italy	Experimental	Images	H
Shang (2024)	China	Experimental	Animations	H
Nabirye (2024)	Uganda	Experimental	Infographics	H
Martinez-Maldonado (2023)	Australia	Case Study	Dashboard	M

Tokatrova (2024)	Russia	Experimental	Comics	M
Zhao J (2023)	China	Experimental	Infographics	H
Zhao Z (2023)	China	Experimental	Mixed Media	M

Legend: H = High, M = Moderate

Audience Tailoring: Expertise levels influence preferences; experts favor interactive dashboards, while novices benefit from simplified static visuals. **Cognitive Load Management:** Relevant visuals reduce load, while irrelevant or overly complex visuals increase it. **Emotional Saliency:** Emotionally resonant visuals improve memorability and engagement. The following figure will show the frequency of visual formats in this study.

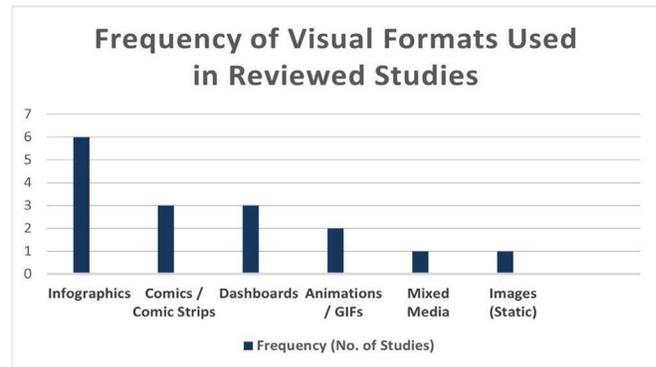


Fig 2: Frequency of visual formats across the reviewed studies.

As shown in Figure 2, Infographics were the most frequently used visual format (37.5%), followed by Comic-based storytelling and Dashboards (each 18.8%). This suggests that infographics remain the dominant medium for simplifying and summarizing data, while comics and dashboards are increasingly used to promote engagement and interactivity. Animations and mixed media formats were less common but often reported higher emotional engagement, indicating their growing potential in narrative visualization.

II. DISCUSSIONS

A. Cognitive Efficiency and Load Reduction

The Picture Superiority Effect (PSE) enhances comprehension and recall in data storytelling when visuals align with narrative intent. Such visuals support cognitive processing by distributing effort across visual and verbal channels [6, 9], consistent with Dual Coding Theory. Studies show that relevant, context-integrated images can reduce cognitive load and improve comprehension and retention [18, 31]. In contrast, decorative or irrelevant visuals increase processing demands and weaken effectiveness [17, 39]. These findings emphasize intentional visual integration for cognitive efficiency.

B. Engagement and Emotional Saliency

PSE-based storytelling often increases engagement. Comic strips, animations, and GIFs can create emotional

resonance, improving memorability through activation of prefrontal and limbic regions [12, 16]. Emotional salience supports recall and sustained attention, encourages active participation, and can strengthen trust in data [14, 22, 35, 36]. In risk communication, emotional and narrative framing increases perceived relevance and willingness to engage [18]. This aligns with Story Schema Theory.

C. Audience Expertise and Format Suitability

PSE-based storytelling effectiveness depends on audience expertise. Experts often benefit from interactive dashboards that support deeper exploration and personalized views, while novices perform better with simplified, static visuals [13, 15, 19]. This aligns with Cognitive Load Theory, which argues that instruction should match learners' processing capacity [3, 4]. Matching visual complexity to audience familiarity helps visuals support, rather than hinder, understanding. Novices often prefer clear narrative formats (infographics, comics), while experts prefer exploratory formats.

Overall, this review identifies three key conditions for effective PSE-enhanced data storytelling:

1. **Relevance:** Visuals must be directly related to the narrative's purpose and avoid extraneous detail.
2. **Audience Alignment:** Visual complexity and interactivity should match the user's expertise.
3. **Emotional and Contextual Resonance:** Incorporating meaningful, emotionally salient visuals strengthens engagement and retention.

These findings support design guidelines that balance cognitive efficiency, engagement, and accessibility across contexts. Participants who viewed concept-related images showed an 89% improvement in memory compared with those who viewed text only [38], indicating that purposeful visuals can improve comprehension and engagement. In contrast, decorative or irrelevant images may increase extraneous cognitive load by forcing unnecessary processing, particularly in instructional settings [17, 39]. Prior knowledge also shapes the Picture Superiority Effect (PSE); for example, sports team logos were recalled better when viewers were familiar with the teams [31].

Audience differences should guide visual choices. Expert users may benefit from interactive visualizations that enable deeper exploration and personalized insights. For general audiences, adding entertainment elements can improve engagement and make information more accessible, encouraging exploration and understanding [15]. Narrative visualizations can reduce cognitive workload by organizing information coherently and making complex content easier to process [40]. Narrative context may also increase trust and engagement, indirectly reducing cognitive burden [18].

PSE-enhanced data storytelling outcomes mainly relate to engagement, learning, and user satisfaction. Digital storytelling can promote behavioral and emotional

engagement through immersive experiences [24, 25], sustain interest through interactive narratives [34, 35], and support critical thinking and empathy [27]. Users often find storytelling effective because it aligns with cognitive processes and meaning making [14, 35], while enjoyment increases satisfaction [22]. Comic-style narratives such as ChartStory strengthen narrative coherence through panel-based flow [36], and multimodal storytelling remains a promising direction [37]. Theoretical grounding commonly draws on cognitive semiotics and cognitive processing models [35].

III. CONCLUSION

This SLR examined the Picture Superiority Effect (PSE) within the context of data storytelling, focusing on its role in reducing cognitive load and enhancing comprehension. The evidence shows that visual storytelling formats, particularly comic strips, can strengthen the communicative power of data storytelling by improving memory retention, learning outcomes, engagement, and overall user satisfaction. These benefits are most pronounced when visuals are relevant, clearly integrated into the narrative, and aligned with the audience's expertise, while irrelevant or poorly integrated visuals risk increasing cognitive load.

Education emerged as a particularly promising context for applying PSE in data storytelling, yet applications in journalism, health communication, and business reporting also highlight its broader potential. However, the systematic use of comic strips, especially those generated through AI technologies, remains underexplored. This presents an opportunity for future research to develop innovative, AI-enabled visual storytelling methods that are scalable, adaptive, and tailored to diverse audiences, ultimately expanding the reach and impact of data storytelling across multiple domains.

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