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The Methodology and Empirical Efficacy of Cluster Technology and Graphic Mapping in EFL Reading Instruction

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Abstract: Reading comprehension in English as a Foreign/Second Language (EFL/ESL) poses major cognitive challenges, particularly regarding macrostructure extraction, cognitive load management, and linear text decoding. This paper synthesizes empirical research and instructional methodologies surrounding 'cluster technology'—encompassing digital mind mapping, concept mapping, and closed-ended Kit-Build (KB) systems—in L2 reading pedagogy. Framed through Dual Coding Theory, Schema Theory, and Cognitive Load Theory, this investigation aggregates quantitative and mixed-methods data across K-12 and university tiers (N = 8 to N = 232). Empirical results consistently reveal statistically significant comprehension gains in experimental mapping groups (e.g., $F(1,31) = 23.55$, $p < .001$, partial $\eta^2 = .432$; $t(62) = -4.14$, $p < .001$). Furthermore, text-structure alignment demonstrates that linear cause-and-effect T-Charts ($M = 3.67$) yield superior summary accuracy compared to overlapping compare-and-contrast Venn Diagrams ($M = 3.24$, $t(199) = 6.94$, $p < .001$). Digital Kit-Build mapping with source-connection feedback significantly enhances 2-week delayed recall compared to selective underlining ($p < .05$). However, diagnostic rubric evaluations reveal a 'paraphrasing gap' ($M = 2.98$), indicating that visual mapping alone does not eliminate verbatim copying without explicit lexical instruction. Instructional recommendations and a three-stage pedagogical mapping sequence (Pre-, While-, and Post-Reading) are detailed.

Keywords: Cluster technology, Mind mapping, Concept mapping, EFL reading comprehension, Cognitive load theory, Dual coding theory, Kit-Build system.

1. Introduction:

1.1 Problem Statement

L2 academic reading is an intensely demanding cognitive endeavor. English as a Foreign Language (EFL) and English for Specific Purposes (ESP) learners frequently experience severe cognitive overload when decoding syntactically complex and information-dense academic texts. Traditional instructional paradigms rely heavily on passive, linear reading routines, such as sequential text reading, verbatim translation, and unguided highlighting. These traditional methods often fail to help L2 readers discern macrostructural relationships, parse complex arguments, or construct coherent mental models. Consequently, L2 readers demonstrate persistent difficulties in main idea identification, inferential reasoning, and structural summarization.

To mitigate these pedagogical hurdles, educational technology and applied linguistics research have converged on 'cluster technology'—the systematic application of visual, non-linear graphic organizers, mind maps, concept maps, and digital cartographic software. Cluster technology serves as an external cognitive scaffold, translating linear verbal discourse into explicit spatial-visual representations that reduce working memory pressure and facilitate deep text processing.

1.2 Theoretical Foundations

The instructional efficacy of cluster technology rests upon three primary cognitive frameworks:

- **Dual Coding Theory (Paivio, 1986)**: Human cognition processes information through two

distinct yet interconnected subsystems: an auditory/verbal system (handling linguistic logogens) and a visual/spatial system (handling non-verbal imagens). Standard L2 reading instruction relies almost exclusively on verbal channels. Cluster technology activates dual coding by simultaneously presenting structural textual propositions alongside spatial nodes and interconnecting links, thereby creating dual memory traces that enhance text recall and cognitive representation.

- **Schema Theory (Ausubel, 1968; Rumelhart, 1980):** Comprehension occurs when readers map incoming textual input onto pre-existing mental frameworks (schemata). Visual clustering techniques function as advance organizers during pre-reading stages, activating formal schemata (knowledge of text structures, such as cause-effect or problem-solution) and content schemata (domain-specific prior knowledge) before deep text processing occurs.
- **Cognitive Load Theory (Sweller, 1988) & Metacognitive Strategies:** Working memory capacity is strictly limited. L2 readers faced with unfamiliar vocabulary and complex syntax experience high intrinsic and extraneous cognitive load. By offloading structural organization into visual nodes, graphic clustering reduces extraneous processing demands. This offloading frees working memory resources for germane processing—enabling metacognitive monitoring, hypothesis testing, and inferential synthesis.

1.3 Taxonomy and Operational Definitions

In the existing literature, visual graphic organizers are operationalized across several distinct methodological configurations:

• **Mind Mapping (Buzan, 1993):** A radiant, non-linear diagram originating from a single central concept, utilizing associative branches, key symbols, color-coding, and image nodes. Mind mapping emphasizes intuitive association and holistic overview, widely deployed during brainstorming and narrative text analysis.

• **Concept Mapping (Novak & Gowin, 1984):** A formal, hierarchical node-link network where named concepts are enclosed in bubbles and connected by labeled directional arrows (e.g., 'concept A' -> [leads to] -> 'concept B'). Concept maps form explicit semantic propositions, ideal for complex expository and scientific texts.

• **Closed-Ended Digital Systems (Kit-Build):** Advanced digital mapping frameworks (e.g., Kit-Build concept map system; Alkhateeb et al., 2016; Andoko et al., 2020) where text propositions are decomposed into standardized component nodes and link cards. Students reconstruct maps under digital validation algorithms that provide real-time feedback on structural fidelity.

1.4 Research Questions

This synthesized paper addresses three primary research questions (RQs):

1. **RQ1:** What is the quantitative impact of visual clustering and mapping technologies on L2 reading comprehension scores across different educational settings?
2. **RQ2:** How does alignment between specific graphic organizer formats (e.g., T-Charts vs. Venn Diagrams) and textual discourse structures influence student summarization accuracy?
3. **RQ3:** What are the comparative cognitive affordances of open-ended student mapping versus closed-ended digital scaffolded mapping systems regarding long-term text retention?

2. METHODOLOGY

2.1 Research Designs and Aggregated Samples

This synthesis incorporates data from multiple quantitative, quasi-experimental, and mixed-methods empirical studies conducted across secondary and tertiary L2 classrooms. The empirical core comprises key research interventions:

1. Explanatory Sequential Mixed-Methods Design (Marginingsih et al., 2025): Sample of N = 200 Indonesian university EFL students evaluating graphic organizer formats across cause-and-effect and compare-and-contrast texts.

2. Quasi-Experimental Pre/Post-Test Control Group Designs: Saori (2020, N = 34 secondary students); Phan Thuy Trang (2017, N = 64 tertiary EFL students); Andoko et al. (2020, N = 232 undergraduate engineering students using Kit-Build systems); Khatimah & Rachman (2018, N = 72 high school learners comparing

mind mapping vs. semantic mapping).

3. Quade's Non-Parametric ANCOVA Experimental Design (Tsai, 2025): Sample of N = 80 tertiary EFL learners comparing bottom-up concept map creation against top-down teacher-provided map completion.

4. Classroom Action Research (CAR) & Micro-Trials: Micro-level trials utilizing iMindMap and iPad graphic systems (Alkhateeb et al., 2016, N = 8).

2.2 Instructional Interventions: The Three-Stage Routine

Across all reviewed interventions, cluster technology was embedded within a structured, three-stage pedagogical reading model:

Stage 1: Pre-Reading (Schema Activation & Topic Clustering)

Instructors introduce the central topic and prompt learners to generate associative keyword clusters around a central node. Students predict overarching macro-structures, label initial category nodes, and activate relevant prior knowledge.

Stage 2: While-Reading (Active Node Extraction & Branch Expansion)

As students navigate the passage, they track discourse signal words (e.g., 'because', 'however', 'subsequently'). They translate linear text arguments into sub-branches, linking nodes with directional arrows and proposition labels.

Stage 3: Post-Reading (Synthesis, Summarization & Self-Monitoring)

Learners utilize their finalized visual clusters as a blueprint to draft written passage summaries, verify logical propositions, and answer literal and inferential comprehension questions.

2.3 Software and System Configurations

Two distinct technological modalities were implemented in the reviewed studies: (a) Open-ended mind mapping platforms (e.g., iMindMap, XMind, Canva) which afford complete artistic and associative freedom; and (b) Closed-ended digital Kit-Build (KB) software. In KB environments, a master concept map is converted into an unlinked set of nodes and relationship cards. Students digitally connect these cards, receiving automated source-connection feedback that flags structural discrepancies without giving away solutions.

2.4 Assessment Instruments and Psychometrics

Comprehension outcomes were evaluated using standardized pre- and post-intervention reading comprehension tests alongside structured summarization rubrics. Summaries were evaluated across four core dimensions: Focus/Relevance, Accuracy, Paraphrasing, and Language Structure. Inter-rater reliability across studies was robust, demonstrating strong agreement metrics (Cohen's Kappa = 0.76; Intraclass Correlation ICC = .807; Cronbach's Alpha = 0.84).

3. RESULTS

3.1 Quantitative Impact on Reading Comprehension (RQ1)

Quantitative findings across independent experimental studies demonstrate consistent, statistically significant reading comprehension gains attributable to cluster technology interventions.

Table 1. Aggregated Quantitative Impact of Visual Mapping Interventions on L2 Reading Comprehension

Study & Sample	Intervention	Pre-Test Mean	Post-Test Mean	Statistical Significance
Saori (2020) N = 34 (High School)	Mind Mapping vs. Control	Exp: 52.35 Ctrl: 51.18	Exp: 71.76 (SD 6.55) Ctrl: 60.24 (SD 8.06)	$F(1,31) = 23.55$, $p < .001$, partial $\eta^2 = .432$
Phan Thuy Trang (2017) N = 64 (University EFL)	Mind Mapping vs. Conventional	Exp: 5.12 Ctrl: 5.08	Exp: 7.65 (SD 1.24) Ctrl: 6.40 (SD 1.10)	$t(62) = -4.14$, $p < .001$

Khatimah & Rachman (2018) N = 72 (High School)	Mind Mapping vs. Semantic Mapping	Mind: 10.35 Sem: 10.40	Mind: 84.00 (SD 8.12) Sem: 76.97 (SD 9.05)	t(70) = 3.48, p = .001
Action Research Cycle I to Cycle II	Visual Graphic Organizers	Pre-Cycle: 56% Pass Rate	Cycle I: 68% Pass Cycle II: 84% Pass	Mean Score Gain: 66.4 to 83.4

As detailed in Table 1, Saori (2020) demonstrated a substantial effect size (partial $\eta^2 = .432$), indicating that 43.2% of the variance in post-test reading comprehension scores was directly explained by the mind mapping intervention. Similarly, Phan Thuy Trang (2017) confirmed significant post-intervention superiority for experimental mapping learners (M = 7.65 vs. Control M = 6.40, $p < .001$). Khatimah and Rachman (2018) established that radiant mind mapping yielded superior narrative text comprehension compared to traditional matrix-like semantic mapping (M = 84.00 vs. M = 76.97, p = .001).

3.2 Text-Structure Alignment and Summarization Accuracy (RQ2)

Empirical evidence reveals that the pedagogical success of cluster technology depends heavily on matching specific graphic organizer formats to underlying text discourse structures. Marginingsih et al. (2025) evaluated N = 200 EFL university students summarizing Cause-and-Effect versus Compare-and-Contrast texts using T-Charts and Venn Diagrams.

Table 2. Summarization Performance by Text Structure and Graphic Organizer Format (Marginingsih et al., 2025)

Text Discourse Structure	Organizer Format	Mean (1-4)	SD	t-Test / Effect Size
Cause-and-Effect Text	Linear T-Chart	3.67	0.71	$t(199) = 6.94$, $p < .001$
Compare-and-Contrast Text	Venn Diagram	3.24	0.84	Cohen's d = 0.56 (Medium)

Students using linear T-Charts for cause-and-effect passages achieved significantly higher summary scores (M = 3.67, SD = 0.71) than students using overlapping Venn Diagrams for compare-and-contrast passages (M = 3.24, SD = 0.84), $t(199) = 6.94$, $p < .001$, Cohen's d = 0.56. This medium-to-large effect size highlights the importance of structural alignment in organizer selection.

3.3 Digital Systems, Scaffolding Modalities, and Long-Term Recall (RQ3)

Investigation of closed-ended digital Kit-Build (KB) concept mapping systems (Andoko et al., 2020; Alkhateeb et al., 2016) underscores the critical role of automated structural feedback in enhancing long-term memory retention.

In a study of N = 232 undergraduate engineering students reading complex English technical passages (Andoko et al., 2020), learners using KB systems with source-connection feedback maintained superior comprehension scores on 2-week delayed retention tests (Immediate M = 7.87; Delayed M = 7.31) compared to KB without feedback (Immediate M = 7.25; Delayed M = 6.58) and conventional text summarizing (Immediate M = 6.73; Delayed M = 6.00), ANCOVA $F(2,452) = 22.41$, $p < .001$. Similarly, Alkhateeb et al. (2016) reported an 86% delayed recall rate for questions linked to concept map nodes versus 42% for unmapped text elements ($p < .05$).

Regarding map creation scaffolding, Tsai (2025, N = 80) evaluated bottom-up (student-generated map) versus top-down (teacher-scaffolded map completion)

modalities using Quade's non-parametric ANCOVA. Students in the bottom-up generation group achieved significantly higher scores in Content (Mdn = 3.67 vs. 3.50, F(1,78) = 5.63, p = .02), Text Structure (Mdn = 3.67 vs. 3.33, F(1,78) = 8.66, p = .004), and Verbal-Visual Coherence (Mdn = 3.67 vs. 3.53, F(1,78) = 5.12, p = .03).

3.4 Diagnostic Rubric Breakdown and Student Perceptions

An analysis of student summarization rubric performance across four sub-dimensions reveals a distinct skill asymmetry:

- **Focus & Relevance**: Highest performance dimension (M = 3.81, SD = 0.74), with 57.5% of students scoring in the highest performance tier.
- **Accuracy**: Strong performance (M = 3.72, SD = 0.79), indicating high fidelity in identifying key passage propositions.
- **Language Structure**: Moderate performance (M = 3.34, SD = 0.91), reflecting occasional syntactic errors during text synthesis.
- **Paraphrasing ('The Paraphrasing Gap'):** Lowest performance dimension (M = 2.98, SD = 0.93), with 35.5% of students demonstrating low proficiency due to persistent reliance on verbatim copying.

Student perception surveys reflect overwhelming enthusiasm for cluster technology: 87.5% agreed that graphic mapping clarified text structure (M = 4.23), 85.0% reported improved main idea identification (M = 4.18), and 78.5% affirmed that digital organizers facilitated rapid reading synthesis (M = 4.01).

4. DISCUSSION

4.1 Cognitive Mechanisms and Working Memory Offloading

The empirical findings strongly validate the theoretical assertions of Dual Coding and Cognitive Load theories. By externalizing complex linguistic relationships into spatial nodes and interconnecting branches, cluster technology serves as an artificial working memory buffer. L2 readers are freed from maintaining complex syntactic structures in immediate memory, enabling them to allocate germane cognitive resources toward higher-order inferential comprehension and macrostructural synthesis.

4.2 Structural Fit vs. Cognitive Friction

The statistical superiority of T-Charts over Venn Diagrams in Marginingsih et al. (2025) underscores the concept of 'cognitive friction.' Linear T-Charts directly mirror the sequential cause-effect narrative logic of technical passages. In contrast, Venn Diagrams require readers to manage intersecting spatial sets. When applied to non-comparative or complex expository texts, overlapping Venn shapes introduce visual clutter and split-attention effects, increasing extraneous cognitive load.

4.3 Bottom-Up Generation vs. Top-Down Scaffolding

Tsai's (2025) findings highlight a vital pedagogical trade-off. While top-down, teacher-provided maps lower initial cognitive barriers for novice or low-proficiency readers, they risk fostering passive map completion. Conversely, bottom-up map generation forces active intersemiotic translation—compelling students to evaluate proposition hierarchy, select key concepts, and construct meaningful visual representations. This active mental construction drives superior structural recall and deeper text comprehension.

4.4 The Paraphrasing Gap: Pedagogical Limitations

A critical finding from the rubric analysis is the persistent 'paraphrasing gap' (M = 2.98). While cluster technology effectively helps learners isolate key facts (Focus M = 3.81; Accuracy M = 3.72), it does not automatically resolve L2 vocabulary or syntactic limitations. Without explicit vocabulary scaffolding and sentence-reconstruction drills, students tend to lift raw phrases directly from source nodes into their written summaries. Visual clustering is a powerful conceptual scaffold, but it must be paired with explicit linguistic instruction to achieve full academic literacy.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Core Contributions

This synthesis establishes cluster technology—encompassing digital mind maps, concept maps, and automated Kit-Build systems—as a highly effective, empirically validated methodology for enhancing L2 reading comprehension. The findings demonstrate that visual mapping significantly boosts comprehension scores across educational tiers, improves delayed retention, and fosters positive learner attitudes.

5.2 Practical Pedagogical Recommendations

Based on empirical evidence, educators should adopt the following instructional guidelines:

1. Enforce Text-Organizer Alignment: Match graphic formats strictly to discourse structures—use T-Charts for cause-effect/problem-solution, timeline maps for sequential narratives, and hierarchical concept maps for classification texts.
2. Bridge the Paraphrasing Gap: Combine visual clustering with targeted linguistic exercises, such as synonym substitution, sentence-combining, and frame-based summary templates, preventing verbatim copying.
3. Implement Gradual Release of Responsibility: Begin with teacher-guided top-down map completion for low-proficiency L2 readers, systematically transitioning to autonomous bottom-up map generation as learner confidence grows.

5.3 Future Directions

Future research should explore the integration of Generative AI and automated feedback engines within digital mapping platforms. Longitudinal studies tracking eye-movement patterns during digital map construction will provide deeper insights into real-time cognitive processing during L2 reading.

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