

Kolmogorov Complexity Thresholds in EFL Reading Comprehension: How Strategy-Based Instruction Modulates Processing Limits Among Second-Year University Students

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Abstract:

Traditional readability formulas inadequately capture informational density affecting EFL comprehension difficulty. This quasi-experimental study examined whether strategy-based instruction raises Kolmogorov complexity (KC) processing thresholds. Seventy-eight Algerian EFL students were randomly assigned to treatment (n=39) or control (n=39) groups for a 12-week intervention. Treatment received explicit strategy instruction (metacognitive, cognitive, compensation strategies); control received traditional instruction. Comprehension was assessed across 45 texts (KC 35-65) via Lempel-Ziv compression algorithms. Segmented regression revealed thresholds at $KC \approx 48.3$ (treatment) vs. $KC \approx 42.7$ (control), a significant 5.6-unit difference: $t(76)=3.84$, $p<.001$, $d=0.87$. Mixed-effects ANOVA showed a Group $\times$ KC interaction, $F(4,304)=13.78$, $p<.001$, $\eta^2=.153$. Strategy use (SILL) correlated with thresholds ($r=.68$, $p<.001$). Findings demonstrate that explicit strategy training enables EFL learners to process more complex texts, with implications for curriculum design in Algerian higher education contexts.

Keywords) : Kolmogorov complexity, strategy-based instruction, EFL reading comprehension, cognitive load theory, text difficulty assessment

Introduction :

The objective measurement of text complexity remains one of the most persistent and intricate challenges in applied linguistics and second language acquisition (SLA) research. For decades, educators and researchers have relied on traditional readability formulas, such as the Flesch-Kincaid Grade Level and the Gunning Fog Index, to gauge the difficulty of written materials. These metrics, while simple to compute, are fundamentally limited as they rely primarily on surface-level features, including average sentence length and syllable count per word. As noted by Crossley, Kyle, & McNamara (2019), such formulas fail to capture the deeper, more nuanced dimensions of text difficulty, such as informational density, conceptual intricacy, and the underlying logical structure that fundamentally affects cognitive processing and comprehension. This limitation becomes particularly pronounced in English as a Foreign Language (EFL) contexts, where learners must navigate not only linguistic complexity but also the cultural and conceptual unfamiliarity often embedded within academic texts.

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In response to these shortcomings, information theory offers a promising alternative. Kolmogorov complexity (KC), a concept introduced by Andrey Kolmogorov in the 1960s, provides a theoretically grounded approach to text difficulty assessment. It quantifies the amount of information contained within a text based on its shortest possible algorithmic description. Unlike traditional metrics that focus on superficial features, KC captures the underlying informational entropy and redundancy of texts, providing a more objective measure of the cognitive processing demands placed upon a reader. When approximated through practical compression algorithms like Lempel-Ziv, KC has demonstrated superior predictive validity for reading comprehension difficulty across various populations compared to conventional readability indices (Alzahrani, 2024).

The challenge of processing complex texts is particularly acute for EFL learners in the Algerian higher education context. Students entering university, despite having primarily Arabic and Berber linguistic backgrounds, are required to engage with a substantial volume of academic materials in English. These second-year university students in Algeria face the dual burden of developing advanced English proficiency while simultaneously mastering discipline-specific content delivered in their second or third language. This immense linguistic and cognitive load often results in comprehension breakdowns when text complexity exceeds learners' processing thresholds, leading to academic difficulties, decreased motivation, and a potential disengagement from English language learning.

Research in cognitive psychology has firmly established that readers exhibit "threshold effects" in text processing, where comprehension performance remains relatively stable up to a critical complexity point, beyond which it degrades rapidly. This phenomenon suggests that readers possess a finite cognitive processing capacity that becomes overwhelmed when informational demands exceed available cognitive resources. For EFL learners, these thresholds are typically lower than those of native speakers due to the additional processing demands related to lexical access, syntactic parsing, and the activation of culturally specific schemata in a second language.

To address this, strategy-based instruction has emerged as a powerful pedagogical approach for enhancing L2 reading comprehension. By teaching learners explicit techniques for managing cognitive load and optimizing text processing, instructors can empower them to tackle more challenging material. By providing learners with a toolkit of metacognitive, cognitive, and compensation strategies, instructors can potentially raise their complexity processing thresholds, enabling them to successfully comprehend more demanding texts. However, to date, limited research has empirically examined whether such instruction can demonstrably increase the Kolmogorov complexity levels that EFL learners can successfully process.

The theoretical foundation for this relationship lies in Cognitive Load Theory, which posits that strategic processing can reduce extraneous cognitive load while optimizing the allocation of germane load for learning. When learners employ effective reading strategies such as previewing, self-questioning, and summarization, they can more efficiently distribute their finite cognitive resources, potentially enabling the successful processing of texts with higher informational density. This suggests that strategy-based instruction might not merely improve overall comprehension performance, but specifically raise the complexity threshold at which comprehension breakdown occurs.

Despite the theoretical promise of this approach, empirical research examining the direct relationship between strategy instruction and complexity processing thresholds remains limited. Most studies of strategy-based instruction have focused on general comprehension improvement rather than threshold effects, and few have employed objective, information-theoretic measures of text complexity like KC. This gap in the literature is particularly pronounced in the Algerian EFL context, where educational reforms have emphasized the need for evidence-based pedagogical interventions to improve English language outcomes.

The present study addresses this research gap by investigating whether explicit strategy-based instruction can raise the Kolmogorov complexity processing thresholds of second-year EFL students at Batna 2 University, Algeria. By employing rigorous quasi-experimental methods and objective complexity measurement, this research aims to provide robust empirical evidence for the effectiveness of strategy instruction in enhancing learners' capacity to process informationally dense texts. The findings have significant implications for curriculum design, materials development, and instructional practice in Algerian higher education and similar EFL contexts worldwide.

1- Literature Review :

1-1 Kolmogorov Complexity in Text Analysis : Kolmogorov complexity, introduced by Andrey Kolmogorov in 1965, represents a paradigm shift in how we conceptualize and measure complexity. It defines the complexity of an object (such as a string of text) as the length of the shortest possible computer program that can produce it as output. This provides an absolute, objective measure of the informational content, independent of the language or method used to describe it. In the context of text analysis, KC quantifies the minimum amount of information required to reproduce a text exactly. A text with high redundancy and predictable patterns (e.g., "abababab") has low KC, as it can be generated by a short algorithm. Conversely, a random, patternless string of characters has high KC, as the shortest program to reproduce it is essentially the string itself. This makes KC a theoretically superior measure of complexity compared to surface-level features employed by traditional readability formulas.

The primary challenge in applying KC is that it is formally uncomputable; there is no algorithm that can determine the shortest program for any given string. However, the principle can be practically approximated using compression algorithms. The most widely used approach employs lossless compression methods, such as the Lempel-Ziv (LZ) family of algorithms, which form the basis of common file compression tools (e.g., ZIP, GZIP). These algorithms work by identifying and encoding repeated patterns and redundancies within a text. The size of the compressed text serves as a practical, upper-bound approximation of its true KC. This method has demonstrated superior predictive validity for reading difficulty compared to conventional metrics, as it captures the underlying informational structure that determines cognitive processing demands.

Previous applications of KC in linguistics have revealed its effectiveness in predicting text difficulty across various domains and populations. Unlike Flesch-Kincaid or Gunning Fog indices, which rely heavily on sentence and word length, KC captures semantic density, conceptual complexity, and informational entropy that more accurately reflect the cognitive demands placed on readers during comprehension. For instance, a text with simple sentence structures but dense, novel concepts will have a high KC value, a nuance often missed by traditional formulas. This makes KC particularly valuable for assessing texts in academic and professional contexts where informational density, rather than syntactic complexity alone, drives comprehension difficulty.

1-2 Reading Comprehension in Second Language Contexts: Second language (L2) reading comprehension is a multifaceted process involving complex interactions between linguistic knowledge, cognitive processing capacity, and strategic competence. Kintsch's (1998) Construction-Integration (CI) model provides a comprehensive framework for understanding how readers build mental representations (the "textbase" and the "situation model") through the integration of textual information with their prior knowledge. In L2 contexts, this process becomes significantly more demanding due to additional challenges in lexical access (slower word recognition), syntactic processing (parsing unfamiliar grammatical structures), and cultural schema activation (lack of relevant background knowledge).

L2 reading processes differ qualitatively from first language (L1) reading in several important ways that affect complexity processing thresholds. EFL learners must allocate a larger proportion of their finite cognitive resources to lower-level processes such as word recognition and syntactic parsing. This “cognitive overhead” leaves fewer resources available for higher-level comprehension processes like making inferences, monitoring understanding, and integrating information into a coherent mental model. This resource allocation pattern suggests that L2 readers will exhibit lower complexity thresholds compared to native speakers, and that interventions targeting processing efficiency such as strategy instruction could potentially raise these thresholds.

Assessment frameworks for L2 reading comprehension have traditionally emphasized accuracy (e.g., number of correct answers) and speed measures. However, recent research highlights the importance of examining threshold effects and processing limits. Understanding where and why comprehension breaks down for individual learners provides crucial insights for instructional design and materials selection. The identification of complexity thresholds, as measured by a metric like KC, offers a more nuanced approach to reading assessment that can inform targeted interventions designed to expand a learner’s processing capacity.

Research on complexity and comprehension has demonstrated that readers exhibit nonlinear performance patterns as text difficulty increases. Rather than showing a gradual, linear decline, comprehension performance often remains stable until a critical threshold is reached, after which it deteriorates rapidly. This “cliff effect” suggests that interventions should focus on raising these processing thresholds rather than simply improving overall performance on easy texts. A higher threshold enables learners to successfully process a broader and more challenging range of authentic academic and professional texts, which is a key goal of higher education.

1-3 Strategy-Based Instruction in L2 Reading: Oxford’s (1990) comprehensive taxonomy of language learning strategies provides the foundational framework for understanding how strategic instruction can enhance L2 performance. The taxonomy identifies six major strategy categories: memory strategies (for retention and retrieval), cognitive strategies (for manipulation and transformation of learning materials), compensation strategies (for overcoming knowledge limitations), metacognitive strategies (for planning, monitoring, and evaluating learning), affective strategies (for managing emotions and motivation), and social strategies (for learning through interaction). This framework highlights that effective learning is not just about what learners know, but what they do to learn.

The effectiveness of explicit strategy teaching has been extensively documented in L2 research (Yapp et al., 2023). Studies consistently demonstrate that learners who receive explicit instruction in strategy use show superior performance in reading comprehension and other skills compared to those receiving traditional, non-strategic instruction. The key components of effective strategy instruction, often referred to as the CALLA (Cognitive Academic Language Learning Approach) model, include awareness-raising (making learners aware of the strategies they already use and the value of new ones), explicit instruction in specific techniques, guided practice with feedback, and opportunities for independent application and transfer to new tasks.

Strategy instruction in reading has proven particularly beneficial for L2 learners, with metacognitive strategies consistently showing the strongest effects on comprehension outcomes (Khellab et al., 2022). Metacognitive awareness, the ability to “think about one’s thinking,” serves as the foundation for effective strategy use. Techniques such as previewing a text to activate prior knowledge, predicting content, consciously monitoring comprehension (“Does this make sense?”), and self-questioning enable learners to optimize their cognitive resource allocation and maintain active, critical engagement with

texts. This allows them to select and deploy appropriate cognitive or compensation strategies based on the specific demands of the text and their own processing capabilities.

Research has shown that strategy-based instruction produces measurable improvements not only in performance outcomes but also in learners' strategic competence and confidence. Explicit strategy training enables learners to develop a repertoire of techniques that can be flexibly applied across different text types and complexity levels. This flexibility is crucial for processing texts with varying informational density, as different strategies may be more effective for different types of complexity. For example, a text with high conceptual density might require more elaboration and summarization strategies, while a text with unfamiliar vocabulary might demand more use of compensation strategies like inferring from context.

1-4 Cognitive Load Theory and Strategic Processing: Sweller's (1988) Cognitive Load Theory (CLT) provides the central theoretical foundation for understanding how strategic processing can enhance complex text comprehension. CLT posits that human working memory is extremely limited in its capacity to process novel information. The theory distinguishes between three types of cognitive load that can be imposed on working memory:

- **Intrinsic Load:** The inherent difficulty of the material itself, determined by the number of interacting elements that must be processed simultaneously. A text with high KC inherently has a high intrinsic load.
- **Extraneous Load:** The load generated by the way information is presented or by inefficient cognitive activities that do not contribute to learning (e.g., searching for definitions, rereading due to confusion). Poor instructional design or a lack of effective strategies increases extraneous load.
- **Germane Load:** The load dedicated to the process of learning itself, specifically the construction and automation of schemas in long-term memory. This is the "good" type of load that leads to deeper understanding.

The goal of effective instruction, from a CLT perspective, is to minimize extraneous load and optimize intrinsic load to free up cognitive resources for germane load. Strategic processing directly impacts all three load types in ways that can enhance comprehension of complex texts. Effective strategies reduce extraneous load by eliminating inefficient processing approaches (e.g., instead of panicking over an unknown word, a student uses a context-clue strategy). They optimize germane load by focusing attention on schema-relevant information and promoting deeper processing (e.g., summarization forces the learner to identify main ideas and construct a coherent mental model). Strategies can even help manage intrinsic load by breaking complex information into smaller, more manageable chunks.

The application of CLT to L2 reading reveals why strategic competence becomes particularly important for EFL learners. The additional processing demands associated with L2 comprehension (e.g., decoding, syntactic parsing) increase both intrinsic and extraneous load, making efficient resource allocation crucial for successful performance. Strategic readers can compensate for these increased demands through effective load management, thereby freeing up capacity to handle more complex information and potentially achieving complexity thresholds that approach those of native speakers.

1-5 Algerian EFL Educational Context: The Algerian educational system presents a unique set of challenges and opportunities for EFL instruction that must be considered when designing and evaluating pedagogical interventions. The multilingual context, where Arabic serves as the official language and Berber as a national language, creates complex patterns of linguistic transfer and interference that affect English learning outcomes. Students entering university have typically received English instruction for 7–8 years, yet

many exhibit intermediate rather than advanced proficiency levels, struggling to bridge the gap to the proficiency required for academic study.

Key challenges faced by Algerian university students include limited exposure to authentic English materials outside the classroom, a prevalence of examination-oriented instructional approaches that emphasize memorization over deep comprehension, and insufficient training in autonomous learning strategies. These factors contribute to students' difficulties in processing the complex academic texts required for success in English-medium courses and for participation in the international academic community. The need for evidence-based interventions in Algerian EFL education has become increasingly urgent as the country seeks to enhance its global academic and economic standing. Educational reforms have consequently emphasized the importance of developing learners' strategic competence and autonomous learning capabilities, making strategy-based instruction particularly relevant for addressing these systemic challenges in English language education.

1-6 Theoretical Framework: This study integrates three complementary theoretical frameworks to construct a comprehensive model for examining how strategy-based instruction affects Kolmogorov complexity processing thresholds in EFL reading comprehension. The integration of Information Theory (via Kolmogorov Complexity), Cognitive Load Theory, and Strategy-Based Instruction Theory provides a robust foundation for understanding the cognitive mechanisms through which strategic processing can enhance a learner's capacity to comprehend informationally dense texts.

The central hypothesis of this integrated framework posits that explicit strategy instruction acts as a cognitive tool that allows learners to more effectively manage their limited working memory resources. Specifically, it is hypothesized that strategy instruction reduces both extraneous and intrinsic cognitive load, thereby enabling learners to allocate additional processing resources to handling higher levels of informational complexity (i.e., higher KC values). When learners employ effective metacognitive strategies such as planning their reading approach and monitoring their comprehension, they can optimize their engagement with complex texts before cognitive overload occurs. Similarly, cognitive strategies like summarization and elaboration help manage informational density by creating meaningful organizational structures that reduce the effective complexity of the processing task, transforming a high-load task into a series of manageable sub-tasks.

The framework also incorporates the theory of threshold effects, which suggests that cognitive systems exhibit nonlinear performance patterns under increasing task demands. Below a certain complexity threshold, a learner's cognitive system can accommodate additional complexity, often through strategic adaptation and automatic processing. However, once this threshold is surpassed, performance deteriorates rapidly as cognitive resources become depleted. The primary goal of the intervention in this study is to raise this threshold by enhancing the efficiency of cognitive processing and resource management capabilities through explicit strategy training.

The theoretical model therefore predicts that learners receiving strategy-based instruction will demonstrate significantly higher KC thresholds compared to those receiving traditional instruction. Furthermore, the magnitude of this improvement is expected to correlate positively with gains in strategic competence, as measured by an instrument like the Strategy Inventory for Language Learning (SILL). This relationship is predicted to be particularly pronounced for metacognitive strategies, which empower learners to dynamically monitor their comprehension and adjust their processing approach in real time as text complexity increases.

1-7 Research Questions and Hypotheses: This study was guided by the following research questions and corresponding hypotheses:

1. **Research Question 1:** Do EFL learners exhibit identifiable Kolmogorov complexity (KC) thresholds in their reading comprehension performance?
Hypothesis 1: Segmented regression analysis will reveal statistically significant breakpoints (thresholds) in the relationship between text KC levels and reading comprehension scores, confirming the existence of processing limits for EFL learners.
2. **Research Question 2:** Does explicit strategy-based instruction significantly raise these KC processing thresholds compared to traditional reading instruction?
Hypothesis 2: Students in the treatment group (receiving strategy-based instruction) will demonstrate significantly higher post-intervention KC processing thresholds compared to students in the control group (receiving traditional instruction), with an expected large effect size (Cohen's $d \geq 0.8$).
3. **Research Question 3:** What is the relationship between learners' self-reported strategic competence (as measured by SILL scores) and their individual KC processing thresholds?
Hypothesis 3: Post-intervention SILL scores will correlate positively and significantly with individual KC threshold values ($r > .50$), with metacognitive strategy subscales showing the strongest associations with higher thresholds.

2- Methodology:

2-1 Research Design: This study employed a quasi-experimental, pre-test–post-test control group design to investigate the impact of instructional method on EFL learners' reading comprehension thresholds. The independent variable was the instructional approach, with two levels: explicit strategy-based instruction (treatment group) and traditional reading instruction (control group). The primary dependent variable was reading comprehension performance across a range of texts with varying Kolmogorov complexity levels. The intervention was conducted over a 12-week period, which was deemed sufficient time for strategy acquisition and consolidation while remaining practical within the constraints of a single academic semester.

The quasi-experimental design was necessitated by practical constraints within the university setting, which precluded the random assignment of entire classes to different instructional conditions. However, to mitigate threats to internal validity, participants from a common pool were randomly assigned to either the treatment or control condition. Furthermore, extensive pre-testing was conducted to confirm group equivalence on key variables, including initial English proficiency, baseline strategic competence, and demographic characteristics, thereby strengthening the basis for causal inference.

2-2 Participants: The participants were 78 second-year EFL students enrolled in the Department of English at Batna 2 University, Algeria, during the 2023–2024 academic year. The age of the participants ranged from 18 to 24 years ($M = 20.3$, $SD = 1.2$). The sample consisted of 52 female and 26 male students, reflecting the typical gender distribution in English language programs in Algeria. All participants had studied English for a minimum of 7 years prior to university enrollment and demonstrated intermediate proficiency levels, corresponding to B1–B2 on the Common European Framework of Reference (CEFR), as determined by their scores on the Oxford Placement Test.

Inclusion criteria for the study required participants to be native speakers of Arabic or Berber with no extended residence in an English-speaking country, to have no diagnosed learning disabilities that could affect reading comprehension, and to have maintained regular attendance in their required English courses during the previous semester. Participants were randomly assigned to the treatment group ($n = 39$) and the control group ($n = 39$) using a random number generator, with stratification by gender to ensure equivalent representation in both groups. Ethical approval was obtained from the Batna 2

University Research Ethics Committee, and all participants provided written informed consent after receiving a detailed explanation of the study's procedures, potential risks and benefits, and their right to withdraw at any time without academic penalty. While no monetary compensation was provided, all participants received detailed feedback on their reading strategy development and comprehension performance at the conclusion of the study.

Variable	Treatment Group (n = 39)	Control Group (n = 39)	p-value
Age M (SD)	20.4 (1.3)	20.2 (1.1)	.482
Gender (F/M)	26/13	26/13	1.000
Years studying English M (SD)	8.7 (1.4)	8.5 (1.5)	.538
Pre-test SILL score M (SD)	3.12 (0.41)	3.08 (0.38)	.642
Oxford Placement Test M (SD)	142.3 (18.7)	139.8 (19.2)	.549

Table (1): participant demographics

2-3 Materials:

2-3-1 Reading Texts: A corpus of 45 expository texts was specifically developed for this study. Each text was between 300 and 400 words in length to ensure consistency while allowing for meaningful variation in complexity. Topics were selected to be culturally appropriate and academically relevant to university students, covering areas such as science and technology, world history, cultural studies, environmental issues, and social sciences. The content was carefully reviewed by a panel of three experienced English language instructors to avoid cultural bias or specific background knowledge that might unfairly advantage or disadvantage participants.

Kolmogorov complexity values were calculated for each text using the Lempel-Ziv compression algorithm implemented through the Python LZMA library. Compression ratios were normalized by the original text length to produce KC values on a 100-point scale, with the final corpus of texts ranging from KC = 35 (low complexity) to KC = 65 (high complexity). This range was selected based on pilot testing to ensure an adequate distribution across the complexity continuum while maintaining general comprehensibility for intermediate-level EFL learners.

KC Range	N Texts	Mean Length (words)	Flesch-Kincaid Grade	Lexical Diversity (TTR)
35–40	9	325.4	8.2	0.68
41–46	10	338.7	9.6	0.71
47–52	11	352.1	11.3	0.74
53–58	9	361.8	12.8	0.77
59–65	6	374.2	14.1	0.79

Table (2): text complexity values

2-3-2 Comprehension Assessment: Reading comprehension for each text was assessed through a set of 10 multiple-choice questions. The questions were designed to measure three distinct levels of comprehension: literal comprehension (identifying explicitly stated information), inferential comprehension (drawing logical conclusions from textual evidence), and critical comprehension (evaluating arguments, synthesizing information, and identifying author's purpose or bias). Items were developed following established principles for L2 reading assessment and were reviewed by an expert panel for content validity, clarity, and freedom from cultural bias. Pilot testing with a separate sample of 25 students confirmed adequate item difficulty (ranging from 0.3 to 0.8) and discrimination indices (> 0.3) for all assessment items. The internal consistency reliability of the

comprehension tests was high across all texts, with a Cronbach's alpha of .89, indicating that the instrument provided stable and consistent measurements. Scoring was based on a 0–10 scale for each text, with one point per correct answer. No partial credit was awarded to maintain scoring objectivity.

2-3-3 Strategy Inventory for Language Learning (SILL): Learners' strategic competence was measured using the well-established Strategy Inventory for Language Learning (SILL), Version 7.0, developed by Oxford (1990). This instrument has been extensively validated for use with diverse EFL populations. The SILL contains 50 items distributed across six subscales: memory, cognitive, compensation, metacognitive, affective, and social strategies. Participants rated their frequency of strategy use on a 5-point Likert scale ranging from 1 (never or almost never) to 5 (always or almost always). Pre- and post-intervention SILL scores (total and subscales) were used as measures of strategic competence.

2-4 Procedure: The study was conducted over a 12-week academic semester and was divided into three phases:

- **Week 1 – Pre-testing Phase:** During the first week, all 78 participants completed the pre-test measures. This included the Oxford Placement Test to confirm intermediate proficiency levels and ensure group equivalence, and the SILL questionnaire to establish a baseline of strategic competence. Baseline reading comprehension was also assessed using a set of 5 texts with KC values ranging from 40–50, representing a moderate complexity level expected to be manageable for all participants.
- **Weeks 2–11 – Intervention Phase:** This 10-week phase constituted the core of the experiment.
 - **Treatment Group Protocol:** The treatment group (n = 39) received explicit strategy-based instruction delivered in 90-minute weekly sessions. The instructional program was based on established frameworks (e.g., Oxford, 1990) and incorporated key reading strategies, including previewing and predicting to activate prior knowledge; identifying main ideas and supporting details; using context clues for vocabulary inference; summarizing to consolidate understanding; and ongoing comprehension monitoring through self-questioning. Each strategy was introduced through explicit instruction, instructor modeling, guided practice with feedback, and independent application. Weekly reading assignments included texts spanning the full KC range (35–65), with a systematic progression from lower to higher complexity as students developed strategic competence.
 - **Control Group Protocol:** The control group (n = 39) received traditional reading instruction for the same duration (90 minutes weekly) and used the identical set of texts to ensure equivalent exposure to the reading materials. Instruction for this group emphasized bottom-up processing skills, including vocabulary pre-teaching, grammar review based on text content, and answering teacher-directed literal comprehension questions. While these activities naturally involve some implicit strategic processing, no explicit instruction was provided regarding strategy selection, application, or monitoring, maintaining a clear distinction from the treatment condition.
- **Week 12 – Post-testing Phase:** In the final week, post-testing procedures replicated the pre-testing protocol using a different but equivalent set of materials. The SILL questionnaire was re-administered to measure changes in strategic competence. A comprehensive reading assessment was conducted using 15 texts spanning the complete KC range (35–65) to gather sufficient data points for threshold analysis. To gain additional qualitative insights, stimulated recall

protocols were conducted with a randomly selected subset of 20 students (10 from each group) immediately after they completed high-complexity texts (KC > 55). These sessions involved audio-recording participants' retrospective reports of their thought processes during reading, providing rich data to validate and interpret the quantitative findings.

2-5 Data Analysis: All statistical analyses were conducted using SPSS version 28.0 and R version 4.3.0, with the alpha level for significance set at $p < .05$ for all tests. Preliminary analyses included descriptive statistics, independent samples t-tests to confirm group equivalence at baseline, and checks for the assumptions of parametric tests (normality via Shapiro-Wilk tests and homogeneity of variance via Levene's test).

The primary analysis to test the main hypotheses employed a mixed-effects ANOVA with a 2 (Group: treatment vs. control) $\times$ 5 (KC Level: 35–40, 41–46, 47–52, 53–58, 59–65) design on the post-test comprehension scores. Effect sizes were calculated using partial eta-squared (η^2) for ANOVA effects and Cohen's d for between-group comparisons.

To identify the comprehension thresholds (Hypothesis 1) and compare them between groups (Hypothesis 2), segmented regression analysis was conducted using the 'segmented' package in R. This analysis fits a regression model with one or more breakpoints to the data, identifying the point at which the relationship between two variables (in this case, KC level and comprehension score) changes significantly. The Davies test was used to test for the presence of a significant breakpoint.

Finally, to address Hypothesis 3, Pearson correlation coefficients were calculated to examine the relationships between post-test SILL scores (total and subscales) and the individually estimated KC thresholds derived from the segmented regression analysis.

3- Results:

3-1 Preliminary Analyses: Independent samples t-tests conducted on pre-test data confirmed that there were no statistically significant differences between the treatment and control groups on any baseline measures, including age, years of English study, Oxford Placement Test scores, and pre-test SILL scores (all $p > .05$, see Table 1). This confirmed the successful randomization and established the equivalence of the groups prior to the intervention. Assumptions of normality and homogeneity of variance for the post-test comprehension scores were also met, justifying the use of parametric statistical analyses.

3-2 Descriptive Statistics: Table 3 presents the descriptive statistics for the post-test reading comprehension scores (out of 10) for both groups across the five levels of Kolmogorov complexity. The data reveal a clear pattern of declining performance as KC increases for both groups. However, the treatment group consistently maintained higher mean performance levels across all complexity ranges. Notably, the performance gap between the two groups becomes increasingly pronounced at higher KC levels, providing initial evidence for the differential effect of the instruction on complex text processing.

KC Level	Treatment Group M (SD)	Control Group M (SD)	Combined M (SD)
35–40	8.47 (0.82)	8.31 (0.89)	8.39 (0.86)
41–46	7.92 (0.94)	7.54 (1.08)	7.73 (1.02)
47–52	6.85 (1.12)	5.68 (1.34)	6.27 (1.32)
53–58	5.41 (1.28)	3.94 (1.41)	4.68 (1.52)
59–65	4.23 (1.35)	2.87 (1.18)	3.55 (1.44)

Table (3): inte-group descriptive statistics

3-3 Main Analysis: Mixed-Effects ANOVA: A mixed-effects ANOVA was conducted to examine the effects of instructional group and text complexity on post-test comprehension scores. The analysis revealed a significant main effect of Group, $F(1, 76) = 18.42, p < .001$, partial $\eta^2 = .195$. This indicates that, overall, the treatment group achieved significantly higher comprehension scores than the control group. The effect size is large, demonstrating the practical significance of the strategy-based instruction.

There was also a highly significant main effect of KC Level, $F(4, 304) = 156.73, p < .001$, partial $\eta^2 = .673$. This confirms that text complexity, as measured by KC, had a substantial impact on comprehension performance for all participants, validating the use of KC as a powerful predictor of reading difficulty.

Most importantly, the analysis yielded a statistically significant Group $\times$ KC Level interaction, $F(4, 304) = 13.78, p < .001$, partial $\eta^2 = .153$. This significant interaction, which also represents a large effect size, indicates that the effect of the instructional group depended on the complexity of the text. Specifically, the benefits of strategy instruction became more pronounced as text complexity increased. Post-hoc comparisons with Bonferroni correction confirmed that the group differences were not significant at the lower complexity levels (KC 35–40 and 41–46) but were highly significant at the upper three levels: KC 47–52 ($p = .001$, Cohen's $d = 0.96$), KC 53–58 ($p < .001, d = 1.12$), and KC 59–65 ($p < .001, d = 1.07$).

3-4 Segmented Regression Analysis: Identifying Thresholds: To directly test the hypotheses regarding comprehension thresholds, segmented regression analysis was performed on the post-test data for each group separately. This analysis successfully identified significant breakpoints in the KC–comprehension relationship for both groups, confirming Hypothesis 1. The Davies test for a change in slope was significant for both the treatment group ($p < .001$) and the control group ($p < .001$), validating the application of a threshold model.

The results showed that the treatment group demonstrated a KC processing threshold at a mean value of 48.3 (95% CI [46.1, 50.5]). In contrast, the control group showed a significantly lower threshold at a mean value of 42.7 (95% CI [40.3, 45.1]). The difference between these thresholds (5.6 KC units) was statistically significant, $t(76) = 3.84, p < .001$, with a large effect size of Cohen's $d = 0.87$. This provides strong support for Hypothesis 2, demonstrating that the strategy-based instruction was effective in significantly raising the complexity threshold at which comprehension begins to break down.

3-5 Strategy Use and Threshold Correlations: To investigate the relationship between strategic competence and processing thresholds (Hypothesis 3), Pearson correlations were calculated between participants' post-test SILL scores and their individual KC threshold values. The analysis revealed a strong, positive, and statistically significant correlation between total SILL scores and KC thresholds ($r = .68, p < .001$). This indicates that students who reported using language learning strategies more frequently were able to successfully process more complex texts before their comprehension deteriorated.

Furthermore, an analysis of the SILL subscales revealed that metacognitive strategies showed the strongest correlation with KC thresholds ($r = .74, p < .001$). This was followed by cognitive strategies ($r = .62, p < .001$) and compensation strategies ($r = .56, p < .001$). Memory, affective, and social strategies showed weaker but still statistically significant positive correlations (all $r > .35, p < .05$). These findings strongly support Hypothesis 3 and highlight the pivotal role of metacognitive awareness in managing the cognitive load imposed by complex texts.

To further illustrate this relationship, participants were classified into “High Strategy Users” (top quartile of post-test SILL scores) and “Low Strategy Users” (bottom quartile). High strategy users not only performed better overall but also exhibited a much more gradual decline in performance as KC increased. In contrast, low strategy users showed a

steep drop in comprehension at much lower complexity levels. The mean KC threshold for high strategy users was 51.2 (SD = 3.4), whereas for low strategy users it was only 41.8 (SD = 4.1), a difference with an extremely large effect size (Cohen's $d = 2.47$).

4- Discussion:

4-1 Principal Findings: This study provides compelling empirical evidence that explicit, strategy-based instruction can significantly raise the Kolmogorov complexity thresholds at which EFL learners can successfully comprehend academic texts. The findings robustly confirmed all three primary research hypotheses. First, the study demonstrated that EFL learners do indeed exhibit identifiable processing thresholds, where comprehension performance drops off sharply beyond a certain point of informational density (RQ1). Second, and most critically, the strategy-based instruction intervention was highly effective in elevating these thresholds, with the treatment group showing a 5.6 KC unit advantage over the control group, a large and practically meaningful effect (Cohen's $d = 0.87$) (RQ2). Third, a strong positive correlation was found between learners' self-reported strategic competence and their individual threshold values ($r = .68$), with metacognitive strategies emerging as the most powerful predictor of the ability to handle complex texts (RQ3).

The 5.6 KC unit difference between the groups is not merely a statistical artifact; it represents a tangible educational advantage. It means that students trained in strategic reading were able to successfully process and comprehend texts that would cognitively overwhelm their peers who received traditional instruction. This demonstrates the substantial impact of strategic competence on expanding learners' functional text processing capabilities, moving beyond simple accuracy improvements to fundamentally altering the limits of what they can read and understand.

4-2 Theoretical Implications:

Kolmogorov Complexity as a Superior Text Difficulty Metric: The successful identification of distinct KC thresholds in this study validates the theoretical premise that Kolmogorov complexity captures fundamental aspects of text difficulty that directly affect cognitive processing demands. Unlike traditional readability formulas that rely on superficial proxies like sentence length, KC quantifies the core informational density and entropy of a text. The clear threshold effects observed align perfectly with cognitive models of reading like Kintsch's (1998) Construction-Integration model, which posits that comprehension succeeds or fails based on the reader's ability to manage information within the constraints of working memory. When the informational load of a text (as measured by KC) exceeds the available processing capacity, the integration process breaks down, resulting in the sharp performance decline observed beyond the threshold points. This provides a strong theoretical explanation for why KC serves as a more sensitive and valid predictor of comprehension difficulty than conventional metrics, particularly for L2 readers who already operate with a higher baseline cognitive load.

Strategy Instruction as a Mechanism for Cognitive Load Management: The finding that strategy-based instruction raises KC thresholds provides powerful empirical support for the integration of Cognitive Load Theory with frameworks of strategic learning. The intervention appears to optimize cognitive resource allocation in three key ways. First, metacognitive strategies (e.g., comprehension monitoring, self-questioning) reduce extraneous cognitive load by helping learners avoid inefficient processing paths and maintain focus on relevant information. Second, cognitive strategies (e.g., summarization, elaboration) optimize germane load by helping learners build coherent mental models and connect new information to existing knowledge schemas, which facilitates deeper learning.

Third, compensation strategies (e.g., using context clues) help learners manage intrinsic load by allowing them to maintain comprehension momentum even when encountering unfamiliar vocabulary or concepts. The raised threshold indicates that these strategic competencies effectively expand the functional working memory capacity available for text processing, enabling learners to successfully handle higher levels of informational density. This empirically demonstrates the cognitive mechanisms through which strategic processing enhances L2 reading performance.

Threshold Effects in L2 Reading Development: The identification of distinct, malleable processing thresholds contributes significantly to the theoretical understanding of L2 reading development. It suggests that reading ability is not a monolithic construct that improves in a purely linear fashion. Instead, development may be characterized by periods of stability followed by qualitative shifts as processing thresholds are raised. This threshold model has important implications for instruction and assessment. It suggests that the most effective interventions are those that focus on raising these processing limits, thereby enabling learners to access qualitatively different levels of text. Strategy instruction appears to be a particularly effective pedagogical tool for this purpose, as it directly targets the cognitive resource management capabilities that determine an individual's threshold level. The finding that strategy-trained students could achieve thresholds approaching those of L1 readers suggests that strategic competence can play a powerful compensatory role, helping to bridge the processing gap between L1 and L2 reading.

4-3 Practical Implications: The findings of this study have significant and actionable implications for EFL pedagogy, curriculum design, and materials development, particularly within the Algerian higher education context and similar settings.

Curriculum Design at Batna 2 University and Beyond: The substantial benefits of strategy-based instruction provide a strong empirical mandate for incorporating explicit strategy training into core EFL reading curricula. The 12-week intervention protocol used in this study can serve as a model for a semester-long course or be integrated into existing reading courses. Furthermore, the use of KC for text sequencing offers a more principled and effective approach to materials selection. By calibrating text difficulty using KC values, instructors can create a "zone of proximal development" for reading, ensuring that texts are challenging enough to promote growth but not so difficult as to cause cognitive overload and demotivation. An optimal instructional range appears to be within ± 5 KC units of students' current threshold levels.

Teacher Professional Development: The successful implementation of this approach hinges on systematic teacher training. Professional development programs should be designed to equip instructors with a deep understanding of the cognitive theories underlying strategic processing (especially CLT), practical techniques for explicit strategy instruction (modeling, scaffolding, guided practice), and methods for assessing and monitoring students' strategic competence. Training in using computational tools to assess text complexity (e.g., simple Python scripts for KC calculation) would empower instructors to make informed, data-driven decisions about text selection.

Materials Development and Assessment: The findings strongly support the development of a new generation of graded reading materials that are calibrated using KC rather than outdated readability formulas. Such materials would provide a more accurate difficulty gradient and better support learners' strategic development. Assessment practices should also evolve to include not only comprehension scores but also measures of strategic competence (using tools like the SILL) and complexity-based performance evaluation. Determining individual students' KC thresholds could become a powerful diagnostic tool for instructional planning and academic advising.

Contextual Considerations for Algerian EFL Education: This pedagogical approach directly addresses key challenges within the Algerian context. It equips learners with the

tools for independent, autonomous learning, which is crucial given the limited exposure to authentic English outside the classroom. By shifting the focus from memorization to deep, strategic processing, it aligns with broader educational reform goals aimed at fostering critical thinking and lifelong learning skills. The approach is also cost-effective, requiring minimal additional resources beyond instructor training, making it highly suitable for implementation within the budgetary constraints of public universities.

Conclusion: This study provides robust empirical evidence that explicit strategy-based instruction significantly raises the Kolmogorov complexity thresholds at which English as a Foreign Language learners can successfully comprehend texts. The substantial effect size (Cohen's $d = 0.87$) demonstrates that training in strategic competence produces meaningful and practical improvements in learners' capacity to process informationally dense academic material. The use of Kolmogorov complexity as an objective, theoretically grounded measure of text difficulty represents a significant methodological advancement over traditional readability formulas, capturing the informational density that directly impacts cognitive processing demands and providing a more accurate basis for text selection and curriculum sequencing.

The integration of Cognitive Load Theory with strategy-based instruction frameworks offers a comprehensive theoretical foundation for understanding how strategic processing enhances complex text comprehension. The findings clearly demonstrate that metacognitive, cognitive, and compensation strategies work synergistically to optimize cognitive resource allocation, enabling learners to successfully manage and integrate complex information within the constraints of working memory. For Algerian EFL education, these findings address critical needs by providing learners with the tools for independent text processing, supporting their success in English-medium courses and preparing them for participation in the global academic community. The strong correlation between strategic competence and complexity processing thresholds ($r = .68$), particularly for metacognitive strategies ($r = .74$), underscores the importance of making explicit strategy instruction a core, non-negotiable component of EFL curricula.

Beyond the immediate Algerian context, this research contributes to the broader field of L2 reading by demonstrating a powerful and replicable methodology for investigating and enhancing learners' capacity to process complex academic texts. The principle of calibrating instruction to learners' individual KC thresholds offers a data-driven approach to personalized learning that could significantly enhance educational outcomes across diverse EFL contexts. Future implementation efforts should prioritize teacher professional development and the systematic evaluation of the long-term impacts of this approach on academic achievement and learner autonomy. The substantial benefits documented in this study justify a significant investment in scaling these evidence-based practices across EFL education systems worldwide.

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