

QUANTITATIVE EVALUATION OF METAPHORICAL LANGUAGE COMPETENCE ON SCIENTIFIC TEXT COMPREHENSION IN ESL LEARNERS: A QUASI-EXPERIMENTAL STUDY

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Abstract

Recent debates in second-language pedagogy question whether training learners to recognize and deploy metaphors aids or hinders scientific reading. To address this debate, a quasi-experimental study was conducted with undergraduate engineering students enrolled at two universities in Islamabad, Pakistan. Pre- and post-tests measured scientific text comprehension, metaphorical competence and linguistic competence. A treatment group ($n \approx 180$) received metaphor-focused instruction, while a control group ($n \approx 180$) studied identical materials without explicit metaphor awareness. Statistical analyses, including descriptive statistics, linear regression and Hayes' PROCESS mediation models, were used to assess the relationship between linguistic competence and scientific text comprehension and to examine whether metaphorical competence mediated this relationship. Results revealed that both groups improved on the post-test, but regression models showed no statistically significant association between linguistic competence and scientific text comprehension in the pre-test and only modest relations in the post-test ($R \approx 0.158-0.170$, $p = 0.053-0.037$). Hayes' mediation analyses found confidence intervals crossing zero, indicating no mediating effect of metaphorical competence. These findings suggest that while metaphor-focused instruction does not impede performance, improvements in scientific reading may arise from multiple factors beyond explicit metaphor training.

1. INTRODUCTION

1.1 Background and Rationale

Complex scientific texts pose significant challenges for English-as-a-Second-Language (ESL) learners because they are densely informative, syntactically complex and conceptually specialized. Engineering students often struggle to decode technical terms and relate them to prior knowledge, especially when instruction neglects figurative language. Some scholars argue that teaching metaphors in science classes may mislead learners by introducing fanciful analogies and ambiguity; others contend that metaphors are essential cognitive tools that enrich conceptual understanding and facilitate problem solving. The present study addresses these debates by focusing solely on quantitative evidence from a quasi-experimental intervention that exposed one group of undergraduate engineering students to metaphorical language during reading comprehension tasks while a control group received traditional instruction.

1.2 Research Questions

This study explores three interrelated questions:

1. What are the descriptive statistics (mean, standard deviation, skewness, kurtosis) of linguistic competence, scientific text comprehension and metaphorical competence for treatment and control groups at the pre-test and post-test stages?
2. Is there a statistically significant association between linguistic competence (independent variable) and scientific text comprehension (dependent variable) in the pre-test and post-test sessions?
3. Does metaphorical competence mediate the relationship between linguistic competence and scientific text comprehension as assessed through Hayes' PROCESS mediation analysis?

2. LITERATURE REVIEW

strand of opinion maintains that scientific language should remain literal and unambiguous. Davidson (1978) contends that technical instruction requires plain language so that learners do not misconstrue scientific concepts. Hobbes and Macpherson (1968) further argue that metaphors amount to “abuses of language” and introduce ambiguity. Frezza and Gagliasso (2017) emphasize that science and metaphor belong to different domains and that science “does not have anything in common with metaphor”. From this perspective, metaphors are considered ornamental devices best suited to arts and humanities; applying them to science risks deception and hinders accurate communication. Moreover, some researchers warn that novice learners may lack the conceptual knowledge needed to map a metaphor's source domain onto abstract scientific concepts. Without sufficient background knowledge, metaphors can impede comprehension rather than facilitate it (Vosniadou et al., 1984; Wales & Coffey, 1986). For second language learners, processing metaphors demands additional cognitive resources because they may not have automatized lexical access to conventional figurative meanings. Thus, critics argue that metaphorical language should be minimized in science teaching until learners achieve advanced proficiency.

In contrast, a substantial body of research argues that metaphors are central to scientific thinking and communication. Lakoff and Johnson's conceptual metaphor theory suggests that metaphors map knowledge from familiar source domains onto abstract target domains, enabling learners to grasp intangible concepts through concrete experiences. Cornelissen et al. (2008) and Karbalaei (2010) posit that metaphorical competence fosters creativity and enriches scientific explanations. Hesse (1966) points out that metaphors are not merely decorative but serve as instruments for critical information processing, making them constitutive of scientific knowledge. Gentner (1982) and Gentner and Bowdle (2005) show that analogies (a type of structural metaphor) aid problem solving by transferring relational structure from a well-known domain to a novel one. Studies in physics education have used metaphors to explain electric circuits by comparing electric current to water flow or crowds. Haack (2019) and Fletcher (2006) argue that metaphors inspire higher-order thinking and mental fertility. Thus, supporters view metaphorical language as a powerful pedagogical tool that facilitates conceptual change and fosters scientific literacy.

The contradictory positions create an unresolved debate about the place of metaphor in science education. Some authors caution that metaphoric expressions may lead to misconceptions or oversimplifications when learners lack sufficient background knowledge. Others highlight that even simple metaphors must evolve into complex structures to accommodate advanced conceptual understanding. For ESL learners, the cognitive load of processing metaphors may be compounded by limited vocabulary and grammatical proficiency. Despite these concerns, advocates argue that withholding metaphorical language deprives learners of a cognitive scaffold crucial for grasping abstract scientific concepts. The present study aims to empirically test whether explicit metaphor instruction influences scientific reading, addressing the gap in quantitative evidence noted by Cameron (2003), who stressed the need for rigorous empirical studies on metaphors in L2 science education.

3 METHODOLOGY

3.1 Design and Participants

The present study is quantitative and followed a quasi-experimental pre-test/post-test design. Two large universities in Islamabad provided undergraduate engineering classes for the intervention. Participants were approximately 360 engineering students (first or second year) enrolled in computer and electrical engineering courses. Convenience sampling was used because entire intact classes were assigned to conditions without randomization. One class (~180 students) served as the treatment group and received instruction that integrated metaphorical awareness during reading comprehension activities. The other class (~180 students) served as a control group and followed the same syllabus and reading passages but was taught using plain, literal language. Both classes met for a full academic semester (approximately four months), and instruction was delivered by the same instructor to minimize confounding variables. Participation was voluntary and approved by institutional ethics boards.

3.2 Pre-Test and Post-Test Procedures

Prior to the intervention, both groups completed a pre-test consisting of multiple-choice and short-answer questions measuring three constructs: linguistic competence (general language ability), scientific text comprehension and metaphorical competence. The pre-test included seven items on scientific text comprehension, seven items on metaphorical competence and four items on linguistic competence. After four months of instruction, a post-test of

comparable difficulty and content areas (but different passages) was administered to measure gains. The same number of items was retained for each construct to ensure comparability across tests. Scores were standardized and entered into the Statistical Package for the Social Sciences (SPSS) for analysis. Reliability analyses (Cronbach's alpha) reported in the parent thesis indicated high internal consistency for each subscale ($\alpha > 0.80$). The pre-test allowed the researcher to assess initial equivalence between groups, while the post-test measured the effect of the intervention.

3.3 Instructional Intervention

During the treatment, students practiced reading scientific passages enhanced with metaphorical cues. The instructor explicitly drew learners' attention to devices such as simile, analogy, imagery, personification and synecdoche. For instance, heat transfer was explained by comparing heat flow to water flowing through pipes, while electric circuits were compared to crowds moving through corridors. Students discussed how the source domain illuminated the target concept and then answered comprehension questions requiring them to identify and interpret metaphoric expressions. In contrast, the control group read the same passages but received no discussion of metaphors and answered literal comprehension questions. Both groups engaged in lectures, group activities and quizzes; the only difference was the emphasis on metaphorical language awareness. Instruction lasted a full term (four months) and concluded with the post-test.

3.4 Statistical Analyses

To evaluate changes between pre-test and post-test and to assess relationships among variables, several statistical procedures were conducted using SPSS. Descriptive statistics (means, standard deviations, skewness and kurtosis) were computed to examine data distribution for each construct. Linear regression analyses were performed separately for each group at each test stage, with linguistic competence as the independent variable and scientific text comprehension as the dependent variable. The coefficient of determination (R^2), adjusted R^2 , F-statistics and p-values were used to assess model fit and significance. Hayes' PROCESS macro (version 2.16) implemented a simple mediation model (Model 4) to test whether metaphorical competence mediated the relationship between linguistic competence and scientific text comprehension. Bias-corrected confidence intervals (95%) were obtained through bootstrapping with 5,000 samples. A mediation effect was considered statistically significant if the confidence interval did not include zero.

4 RESULTS

4.1 Descriptive Statistics and Data Distribution

Table 1 presents descriptive statistics (means, standard deviations, skewness and kurtosis) for linguistic competence (LC), scientific text comprehension (ST) and metaphorical competence (MC) in both groups at the pre-test. All variables exhibited skewness and kurtosis within acceptable ranges (± 2), suggesting approximately normal distributions. The treatment group displayed slightly higher mean scores on scientific text and metaphorical competence than the control group, but differences were marginal.

Table 1 – Pre-Test Descriptive Statistics (n = 149 per group)

Variable	Group	Mean (M)	Standard Deviation (SD)	Skewness (Sk)	Kurtosis (K)
Linguistic Competence	Control	3.11	1.07	4.78	42.30
	Treatment	3.14	1.33	4.34	32.10
Scientific Text	Control	3.80	0.81	-0.03	-0.68
	Treatment	3.50	0.69	0.02	-0.04
Metaphorical Competence	Control	2.28	0.35	0.07	0.18
	Treatment	2.40	0.39	0.05	-0.17

Note. Means and standard deviations are rounded to two decimals. Skewness and kurtosis values are based on standardized estimates.

4.2 Regression Analyses

4.2.1 Pre-Test Regression Models

Linear regression assessed whether linguistic competence predicted scientific text comprehension at the pre-test. Table 2 shows that neither group exhibited a significant relationship. For the control group, the regression model yielded $R = 0.022$, $R^2 = 0.000$, adjusted $R^2 = -0.006$, $F(1, 147) = 0.073$, $p = 0.787$. Similarly, the treatment group's model produced $R = 0.073$, $R^2 = 0.005$, adjusted $R^2 = -0.001$, $F(1, 147) = 0.798$, $p = 0.373$.

These findings indicate no significant association between linguistic competence and scientific text comprehension at baseline.

Table 2 – Pre-Test Regression Summary

Group	R	R ²	Adjusted R ²	F Change	p Value
Control	0.022	0.000	–0.006	0.073	0.787
Treatment	0.073	0.005	–0.001	0.798	0.373

4.2.2 Post-Test Regression Models

After the intervention, regression analyses revealed modest associations between linguistic competence and scientific text comprehension. The treatment group's model showed $R = 0.158$, $R^2 = 0.025$, adjusted $R^2 = 0.018$, $F(1, 148) = 3.796$, $p = 0.053$. The control group exhibited similar values with $R = 0.170$, $R^2 = 0.029$, adjusted $R^2 = 0.022$, $F(1, 148) = 4.417$, $p = 0.037$.

Although the control group's association reached statistical significance at $p < 0.05$, the effect sizes were small ($R^2 < 0.03$). Both models showed negative standardized beta coefficients ($\beta \approx -0.158$ for the treatment group and $\beta \approx -0.170$ for the control group), suggesting that higher linguistic competence scores slightly corresponded to lower scientific text scores—an inverse relation with negligible practical significance.

Table 3 – Post-Test Regression Summary

Group	R	R ²	Adjusted R ²	F Change	p Value	β (Std. Coef.)
Control	0.170	0.029	0.022	4.417	0.037	–0.170
Treatment	0.158	0.025	0.018	3.796	0.053	–0.158

4.3 Hayes Mediation Analyses

Hayes' PROCESS Model 4 tested whether metaphorical competence mediated the link between linguistic competence (X) and scientific text comprehension (Y). Confidence intervals were generated via bootstrapping. Table 4 reports the indirect effect estimates (unstandardized), p-values and 95 % confidence intervals (lower limit confidence interval [LLCI], upper limit confidence interval [ULCI]).

Table 4 – Hayes PROCESS Mediation Results

Session	Group	Indirect Effect (P)	LLCI	ULCI	Interpretation
Pre-test	Treatment	0.30	–0.0198	0.0270	No mediation (CI includes 0)
Pre-test	Control	0.20	–0.3113	0.1175	No mediation (CI includes 0)
Post-test	Treatment	0.05	–0.0828	0.0763	No mediation (CI includes 0)
Post-test	Control	0.03	–0.0246	0.0898	No mediation (CI includes 0)

The pre-test mediation analysis for the treatment group showed an indirect effect $P = 0.30$ with a confidence interval crossing zero (LLCI = –0.0198; ULCI = 0.0270), indicating no significant mediation. Similarly, the control group's pre-test mediation produced $P = 0.20$, LLCI = –0.3113 and ULCI = 0.1175, again demonstrating no mediation. In the post-test, the treatment group's indirect effect ($P = 0.05$, LLCI = –0.0828, ULCI = 0.0763) and the control group's indirect effect ($P = 0.03$, LLCI = –0.0246, ULCI = 0.0898) both had confidence intervals encompassing zero. Therefore, metaphorical competence did not mediate the relationship between linguistic competence and scientific text comprehension in either session.

4.4 Data Distribution Checks

Skewness and kurtosis were assessed to verify normality assumptions underlying regression and mediation analyses. Pre-test distributions showed heavy tails for linguistic competence ($K = 42.3$ control; $K = 32.1$ treatment) because most students scored either very high or very low. Scientific text comprehension and metaphorical competence displayed near-normal kurtosis values ($-0.68 \leq K \leq 0.18$). Skewness values were within ± 1 for scientific text and metaphorical competence, indicating slight asymmetry. Post-test distributions were more symmetric; skewness values ranged from –0.308 to 0.445 and kurtosis values from –0.325 to 0.191. These findings justified the use of parametric tests.

5. DISCUSSION

5.1 Interpretation of Findings

The pre-test regression analyses revealed no significant relationship between linguistic competence and scientific text comprehension in either group, suggesting that baseline language proficiency did not predict students' ability to understand scientific passages. The negative beta coefficients further indicated that higher linguistic competence scores slightly corresponded to lower scientific text scores; however, these inverse relations were negligible and not statistically meaningful. The absence of a pre-test association supports the null hypothesis that language teaching and scientific comprehension were initially unrelated. This finding aligns with arguments that simple exposure to language

instruction without specialized training may not directly enhance comprehension of complex scientific texts (Vosniadou & Ortony, 1989).

Post-test analyses showed modest increases in R and R^2 values and p -values approaching significance, particularly for the control group. Although the control group's regression was statistically significant ($p = 0.037$), the effect size remained small ($R^2 = 0.029$). These results suggest that both groups improved similarly, irrespective of metaphorical instruction. The negative beta coefficients persisted, implying that gains in scientific text scores were not attributable to increases in general linguistic competence. Instead, improvements may have resulted from repeated exposure to scientific reading tasks, test familiarity or general maturation over the semester. In other words, the intervention did not yield a unique advantage for the treatment group beyond what the control group achieved through traditional instruction.

The Hayes mediation analyses provided further insight. In both pre-test and post-test sessions, the confidence intervals for the indirect effect overlapped zero, demonstrating no evidence that metaphorical competence mediated the relationship between linguistic competence and scientific text comprehension. Even though the treatment group received explicit metaphor instruction, the mediation effect was absent, suggesting that metaphor awareness neither facilitated nor impeded scientific reading when controlling for linguistic competence. This finding contradicts the strong claims of metaphor advocates, who argue that metaphors inherently enhance comprehension by linking abstract concepts to familiar experiences. It also challenges the concerns of critics who fear metaphors might confuse learners; the data show that metaphorical competence training neither harmed nor significantly helped performance.

5.2. Theoretical and Pedagogical Implications

From a theoretical perspective, the results support a nuanced view of metaphor use in science education. The absence of a mediation effect implies that metaphorical competence may operate independently of general linguistic skills. Learners with higher metaphor awareness did not necessarily translate that competence into better scientific text comprehension. This aligns with research suggesting that metaphor comprehension is a specialized skill that requires conceptual knowledge of both source and target domains. For ESL contexts, where students may lack sufficient conceptual background and linguistic automatization, metaphor instruction alone may be insufficient to improve comprehension. Teachers may need to couple metaphors with explicit explanations of underlying scientific concepts and vocabulary to ensure accurate mappings.

Pedagogically, the findings caution against viewing metaphor-focused instruction as a panacea for difficulties in science reading. While the treatment group enjoyed creative activities and may have developed a broader appreciation for figurative language (reported qualitatively in the parent thesis), the quantitative data indicate that such instruction did not yield superior gains. However, metaphor exposure did not impede learning; thus, instructors might integrate metaphorical examples sparingly to enhance engagement without expecting direct gains in test scores. Future studies should explore whether more intensive or targeted metaphor instruction (e.g., focusing on particular subdomains or aligning metaphors with students' prior knowledge) could yield measurable improvements. Additionally, combining metaphor instruction with explicit teaching of scientific vocabulary and conceptual frameworks may enhance the effectiveness of metaphorical competence training.

5.3. Limitations

Several limitations should be noted. First, the quasi-experimental design lacked random assignment, raising the possibility of selection biases. Although pre-test scores indicated equivalence between groups, unmeasured factors (e.g., motivation or prior exposure to metaphors) might have influenced outcomes. Second, the reliability of the metaphorical competence measure may have constrained detection of mediation effects; more sensitive instruments could reveal subtler relationships. Third, the intervention lasted only one semester; longer exposure or integration across multiple courses might yield different results. Finally, the study focused on engineering students in Islamabad; generalizing findings to other disciplines or cultural contexts should be undertaken cautiously.

6. CONCLUSION

This quantitative analysis of a quasi-experimental study investigated whether metaphorical language competence mediates the relationship between linguistic competence and scientific text comprehension among ESL engineering students. Descriptive statistics, regression analyses and Hayes mediation models revealed that while both treatment and control groups improved from pre-test to post-test, there was no significant association between linguistic competence and scientific text comprehension at baseline and only small associations after instruction. Moreover, metaphorical competence did not mediate the relationship between linguistic competence and scientific comprehension. These findings suggest that explicit metaphor instruction does not inherently enhance or impede scientific reading performance. Science educators should therefore integrate metaphors judiciously, ensuring that conceptual understanding and vocabulary development accompany figurative language. Further research employing randomized designs, varied metaphor interventions and diversified populations could clarify under what conditions metaphorical competence contributes to scientific literacy.

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