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Research Article

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ABSTRACT

Background: Early childhood education (ECE) in northern Nigeria continues to register chronic deficits in literacy and numeracy outcomes, compounded by acute resource constraints and limited use of technology-enhanced instruction (UNICEF, 2023; UNESCO, 2023). Audio-visual rhymes, grounded in Dual Coding Theory (Paivio, 1991) and the Cognitive Theory of Multimedia Learning (Mayer & Fiorella, 2022), offer a scalable, low-cost approach to bridging these gaps.

Objective: The study examined the effect of audio-visual rhyme instruction on literacy skills, numeracy skills, classroom engagement, and overall learning outcomes among ECE pupils across all five education zones of Adamawa State, Nigeria.

Methods: A quasi-experimental non-equivalent control group pre-test/post-test design was employed. Two schools were selected from each of the five education zones of Adamawa State (Yola, Mubi, Numan, Ganye, and Song zones), yielding 10 schools in total. One school per zone was assigned to the experimental condition and one to the control condition (five experimental schools, five control schools), drawn from purposively matched urban ECE centres. All Nursery 2 pupils in each school constituted the study sample, yielding $N = 210$ ($n_1 = 105$ experimental; $n_2 = 105$ control). Data were collected via the Early Learning Achievement Test (ELAT; $\alpha = .84$; concurrent validity $r = .71$) and the Classroom Engagement Observation Checklist (CEOC; $\kappa = .78$), and analysed using ANCOVA and independent-samples t-tests.

Results: Significant large treatment effects were observed across all outcome domains: literacy ($d = 0.76$), numeracy ($d = 0.84$), classroom engagement ($d = 0.69$–0.84, escalating progressively), and overall learning outcomes ($d = 0.80$); all $p < .001$. ANCOVA F-values ranged from $F(1, 207) = 52.26$ to 63.88, with partial eta-squared values of .202 to .236, substantially exceeding conventional thresholds for large effects.

Conclusion: Audio-visual rhyme instruction produced robust improvements in early learning outcomes across geographically and infrastructurally diverse ECE settings within Adamawa State. These findings extend the ecological validity of Mayer's (2022) Cognitive Theory of Multimedia Learning into northern Nigerian ECE contexts and provide a direct evidence base for low-cost curriculum integration across the state and comparable settings in north-eastern Nigeria.

Keywords: *audio-visual rhymes; early childhood education; literacy; numeracy; classroom engagement; quasi-experimental; dual coding theory; multimedia learning; Adamawa State; Nigeria*

INTRODUCTION

Early childhood education (ECE) constitutes the most critical window for cognitive, linguistic, and socio-emotional development across the human lifespan. Evidence from developmental neuroscience and longitudinal educational research consistently demonstrates that high-quality instructional experiences during the preschool and early primary years exert a disproportionate and largely irreversible influence on foundational academic competencies, particularly literacy and numeracy (Barnett, 2011; Heckman & Mosso, 2014). The imperative to improve ECE quality has intensified in the wake of the COVID-19 pandemic's documented erosion of early learning gains, particularly in low- and middle-income countries where recovery has been uneven and instructional innovation limited (UNICEF, 2023).

Within sub-Saharan Africa, less than half of young children have access to pre-primary education, and where access exists, the quality of instruction frequently fails to meet developmental needs (UNESCO, 2021). Nigeria exemplifies this challenge at scale: with the world's largest population of out-of-school children, an estimated 10.2 million primary-aged children were out of school in 2022, with disproportionate concentration in the northern states (UNICEF, 2022; Nwoke et al., 2024). National assessments and international monitoring data consistently indicate that Nigerian ECE pupils perform below grade-level benchmarks in literacy and numeracy, with rote-based, teacher-centred instruction identified as a principal driver of poor learning outcomes (UNESCO, 2023).

The north-eastern geopolitical zone of Nigeria comprises Adamawa, Borno, Gombe, Taraba, Bauchi, and Yobe states, which record some of the most severe educational deficits in the country. Adamawa State records a primary completion rate of 73%, well below the national average (NBS & UNICEF, 2022), while the broader Borno-Adamawa-Yobe (BAY) corridor has experienced systematic destruction of educational infrastructure, mass teacher displacement, and chronic underfunding of the ECE sector as a result of over a decade of armed conflict (GPE, 2023; UNICEF, 2023). Instructional quality across Adamawa State's ECE centres is characterised by resource constraints, large class sizes, heterogeneous pedagogical approaches, and the near-total absence of technology-enhanced learning tools, with variation observable across the five education zones of Yola, Mubi, Numan, Ganye, and Song (Saleh et al., 2025).

A growing body of evidence from the learning sciences identifies multisensory instructional approaches as effective strategies for improving engagement, cognitive development, and knowledge retention in early childhood settings, particularly where conventional instruction has failed to sustain learner attention (Solichah & Fardana, 2024; Mpolomoka et al., 2025). Among multisensory modalities, audio-visual stimuli occupy a privileged position in early childhood instruction, owing to the developmental primacy of auditory-visual integration in young learners' cognitive processing. Audio-visual rhymes are instructional media that combine rhythmic melodic content with synchronised animated imagery; they are theoretically positioned to activate dual cognitive coding channels simultaneously, thereby producing deeper and more durable encoding than unimodal instruction (Mayer & Fiorella, 2022).

Quasi-experimental and experimental studies have established significant positive effects of rhythmic and musical activities on phonological awareness (Skubic et al., 2021), early numeracy development (Jylänki et al., 2022), and classroom engagement across multisensory instructional contexts (Theresia & Recard, 2022). However, these studies were conducted predominantly in European or East Asian contexts. Empirical evaluations of audio-visual

rhyme instruction in West African ECE settings are largely absent, and no published study to date has examined this intervention across the administrative education zones of Adamawa State. This gap is consequential: the effectiveness of instructional interventions is known to vary systematically with contextual variables, including infrastructure availability, pupil-to-teacher ratio, baseline achievement levels, and the linguistic diversity of learner populations, all of which differ substantially in northern Nigerian ECE settings from those in which most available evidence was generated.

This study addresses that gap by employing a quasi-experimental non-equivalent control group pre-test/post-test design across all five education zones of Adamawa State, thereby generating both rigorous and geographically representative context-specific empirical evidence on the effect of audio-visual rhyme instruction on four outcome domains: literacy skills, numeracy skills, classroom engagement, and overall learning outcomes among ECE pupils. Its findings contribute to the early childhood education literature in northern Nigeria and provide an actionable evidence base for instructional policy reform at the state level.

STATEMENT OF THE PROBLEM

Despite well-documented deficits in early literacy and numeracy outcomes across Adamawa State's public ECE sector, and despite growing international evidence on the efficacy of audio-visual instructional media in early childhood settings, no study has empirically evaluated the effect of audio-visual rhyme instruction on learning outcomes across the state's five education zones. Conventional, unimodal chalk-and-talk instruction continues to dominate urban and peri-urban ECE classrooms throughout the state, with no systematic evidence base to guide the adoption of alternative approaches. The absence of this state-wide evidence constitutes a critical policy-practice gap that this study is designed to fill.

OBJECTIVES OF THE STUDY

The study pursued the following specific objectives:

1. To determine the effect of audio-visual rhymes on pupils' literacy skills.
2. To assess the influence of audio-visual rhymes on pupils' numeracy skills
3. To examine the effect of audio-visual rhymes on pupils' classroom engagement.
4. To compare the overall learning outcomes of pupils exposed to audio-visual rhymes with those taught using conventional methods.

RESEARCH QUESTIONS

1. What is the effect of audio-visual rhymes on pupils' literacy skills?
2. How do audio-visual rhymes influence pupils' numeracy skills?
3. What effect do audio-visual rhymes have on pupils' classroom engagement?
4. Is there a significant difference in overall learning outcomes between pupils taught with audio-visual rhymes and those taught using conventional methods?

HYPOTHESES

- H_{01}: There is no significant difference in literacy skills between pupils exposed to audio-visual rhymes and those taught using conventional methods.

- H_{02}: There is no significant difference in numeracy skills between pupils exposed to audio-visual rhymes and those taught using conventional methods.
- H_{03}: Audio-visual rhymes have no significant effect on pupils' classroom engagement.
- H_{04}: There is no significant difference in overall learning outcomes between the experimental and control groups.

THEORETICAL FRAMEWORK

Paivio's (1991) Dual Coding Theory posits that human cognition operates through two distinct but interconnected symbolic systems: verbal and non-verbal and that learning is most effectively consolidated when both channels are simultaneously activated. Audio-visual rhymes, by presenting linguistic content through melody and synchronised imagery, instantiate dual coding directly within the learning event, producing richer and more retrievable memory representations than either channel alone.

Mayer and Fiorella's (2022) Cognitive Theory of Multimedia Learning (CTML) extends dual coding into instructional design, identifying principles of multimedia, spatial contiguity, temporal contiguity, and coherence as determinants of effective audio-visual materials. Under CTML, audio-visual rhymes that synchronise lyrical content with congruent visual representations while minimising extraneous cognitive load are predicted to produce superior encoding and retention outcomes (Sweller et al., 2019; Plass et al., 2010).

Vygotsky's (1978) Sociocultural Theory further contextualises the study by locating audio-visual rhyme instruction within the zone of proximal development (ZPD), where scaffolded, engaging stimuli support learners in acquiring competencies that exceed their independent capacity. The rhythmic repetition characteristic of nursery rhymes provides a predictable linguistic scaffold enabling young learners to progressively internalise sound-letter correspondences and number sequences within the supportive context of a motivating audio-visual stimulus.

AUDIO-VISUAL RHYMES, RHYTHM, AND LITERACY DEVELOPMENT

Phonological awareness which is the ability to perceive and manipulate the sound structure of language, is the strongest single predictor of early reading success (Adams, 1990; Ehri et al., 2001). Rhyme, by directing explicit attentional focus to phonological patterns through end-rhyme and alliteration, scaffolds phonemic segmentation and blending skills that underpin decoding. Bryant et al. (1990) established a causal link between early rhyme exposure and subsequent reading attainment that has been consistently replicated across cultural and linguistic contexts.

More recent quasi-experimental evidence has confirmed that musical and rhythmic activities specifically support phonological awareness development in early childhood populations. Skubic et al. (2021), using an ANCOVA-controlled quasi-experimental design with 70 children aged 4 to 7 years, demonstrated that music instruction rooted in rhythmic and melodic activities produced significant phonological awareness gains. Their design is directly analogous to the present investigation and provides strong methodological precedent. Similarly, Maderazo et al. (2024) reported significant improvements in literacy-related working memory performance through rhythm training, corroborating the role of rhythm as a cross-modal phonological processing scaffold.

Olayiwola (2022) documented gains in language skills and reading culture among young learners through community-based oral literature programmes in north-central Nigeria, providing evidence that culturally embedded

oral and rhythmic approaches to literacy instruction can yield measurable outcomes even in low-resource settings comparable to those found across Adamawa State's five education zones.

AUDIO-VISUAL RHYMES AND NUMERACY DEVELOPMENT

The contribution of rhythmic instructional media to numeracy development has received growing empirical attention. Counting rhymes engage verbal-sequential processing of number words, supporting the acquisition of Gelman and Gallistel's (1978) foundational counting principles: stable order, one-to-one correspondence, and cardinality. Audio-visual formats reinforce these principles by providing synchronised visual quantity representations alongside verbal number sequences, a format shown to accelerate early number concept acquisition in preschool populations.

Jylänki et al. (2022), in a quasi-experimental preschool numeracy intervention study published in the International Journal of Early Childhood, demonstrated that structured interventions combining relational skill learning with engaging contextual scaffolds produced significant early numeracy gains maintained at delayed post-test. A 2024 meta-analysis further confirmed that music integration in mathematics instruction yields significant performance improvements, with overall effect sizes in the medium-to-large range across 23 studies and 49 effect sizes (Wang et al., 2024). Independently, Guo et al. (2023) conducted a meta-analysis specifically examining the effect of musical training on mathematical performance, reporting a statistically significant positive relationship across 38 studies ($g = 0.41$, $p < .001$), further substantiating the theoretical rationale for rhythmic audio-visual instruction as a vehicle for numeracy development.

CLASSROOM ENGAGEMENT IN ECE: MULTISENSORY AND AUDIO-VISUAL EFFECTS

Classroom engagement in early childhood settings is a composite construct encompassing behavioural engagement (on-task attention and participation), cognitive engagement (active mental processing), and emotional engagement (interest and enjoyment; Fredricks et al., 2004). A systematic scoping review by Solichah and Fardana (2024) identified multiple forms of multisensory programmes as effective early literacy interventions, concluding that multisensory approaches significantly improve cognitive development, engagement, and knowledge retention in early childhood learners.

Williams and Bentley (in press), reporting results from a randomised controlled trial with 213 children in disadvantaged Australian communities, found that rhythm and movement programmes delivered by generalist ECE teachers produced significant and sustained improvements in behavioural development across three time points. This study establishes an important precedent for the durability of rhythm-based ECE intervention effects in communities characterised by chronic resource constraints.

EMPIRICAL GAP AND JUSTIFICATION

The reviewed literature, while extensive, is concentrated in European, North American, and East Asian ECE contexts. Studies evaluating audio-visual rhyme instruction specifically within West African or northern Nigerian ECE settings are absent from the indexed literature. The GPE-UNICEF BAY States Education Programme (2020–2023) documents acute deficits in teacher qualification, classroom resources, and learning material availability that define the instructional baseline against which the present intervention is tested. These contextual factors render direct

extrapolation from international evidence bases problematic and generate a compelling justification for context-specific, state-wide empirical evaluation. This study fills that gap.

RESEARCH DESIGN

A quasi-experimental non-equivalent control group pre-test/post-test design was adopted. Random assignment of pupils to treatment conditions was not feasible given the administrative structure of intact school classes. Accordingly, schools were purposively matched within each education zone and assigned to experimental and control conditions, with pre-test scores entered as covariates in all ANCOVA analyses to statistically control for any residual baseline differences. This approach is consistent with best-practice quasi-experimental methodology in educational research (Shadish et al., 2002) and has been employed in analogous audio-visual and rhythmic instruction studies in ECE settings (Skubic et al., 2021; Jylänki et al., 2022).

STUDY AREA

The study was conducted across all five education zones of Adamawa State, Nigeria: Yola Zone (covering Yola North and Yola South LGAs), Mubi Zone (covering Mubi North, Mubi South, and Hong LGAs), Numan Zone (covering Numan, Demsa, and Lamurde LGAs), Ganye Zone (covering Ganye, Jada, Toungo, and Shelleng LGAs), and Song Zone (covering Song, Guyuk, Gombi, and Maiha LGAs). This multi-zone sampling framework ensures that findings represent the full geographic, infrastructural, and demographic range of Adamawa State's ECE sector, rather than being confined to a single urban locality. Adamawa State is in north-eastern Nigeria, bordering Cameroon to the east, within the Borno-Adamawa-Yobe corridor that has experienced sustained educational disruption attributable to armed conflict since 2009 (GPE, 2023).

POPULATION AND SAMPLING

The target population comprised all ECE Nursery 2 pupils enrolled in public and private ECE centres across Adamawa State's five education zones. Purposive sampling was used to select two schools per education zone, yielding 10 schools in total. Within each zone, schools were matched on enrolment size, infrastructure profile, teacher qualification levels, and school type; one school per zone was designated the experimental group and the other the control group, producing five experimental and five control schools. All Nursery 2 pupils in each selected school constituted the zonal sample (approximately 21 pupils per school). Across all five zones, this yielded a total sample of $N = 210$ ($n_1 = 105$ experimental; $n_2 = 105$ control). Table 5 presents the zonal distribution of schools and participants.

Table 1

Zonal Distribution of Schools and Participants Across Adamawa State's Five Education Zones

Education Zone	LGA(s)	Condition	n per School	Zonal n
Yola Zone	Yola North, Yola South	Exp. + Ctrl.	21	42 (21 + 21)
Mubi Zone	Mubi North, Mubi South, Hong	Exp. + Ctrl.	21	42 (21 + 21)
Numan Zone	Numan, Demsa, Lamurde	Exp. + Ctrl.	21	42 (21 + 21)

Ganye Zone	Ganye, Jada, Toungo, Shelleng	Exp. + Ctrl.	21	42 (21 + 21)
Song Zone	Song, Guyuk, Gombi, Maiha	Exp. + Ctrl.	21	42 (21 + 21)
Total	**All 5 zones, 17 LGAs**	**5 Exp. + 5 Ctrl.**	**21**	**N = 210 (105 + 105)**

Note. Exp. = Experimental; Ctrl. = Control. Each zone contributed one experimental school and one control school, with approximately 21 Nursery 2 pupils per school. LGA = Local Government Area.

A priori power analysis using G*Power 3.1 for ANCOVA (large effect, $f = 0.40$; $\alpha = .05$; power = 0.80) indicated a minimum of $n = 28$ per group; the achieved $n = 105$ per group ensures observed power exceeding .999 for all ANCOVA tests, providing a substantially over-powered design that enhances confidence in the precision of effect size estimates and the stability of findings across zones.

INSTRUMENTATION

Early Learning Achievement Test (ELAT)

A 40-item criterion-referenced achievement test comprising 20 literacy items (letter recognition, phonics, word formation) and 20 numeracy items (number recognition, counting, basic operations). The ELAT was adapted from the Early Grade Reading Assessment (EGRA) and Early Grade Mathematics Assessment (EGMA) frameworks (RTI International, 2009) and underwent a three-stage validation process: (1) content validity was established through expert review by five ECE specialists (Content Validity Index, CVI = .92); (2) concurrent validity was assessed against the Nigerian National Pre-Primary School Assessment Battery ($r = .71$, $p < .001$, $n = 30$ pilot sample); and (3) item discrimination indices were computed for all 40 items (range: 0.31–0.68; M = 0.49), with items below 0.30 revised or removed prior to final administration. Internal consistency: Cronbach's $\alpha = .84$. Test–retest reliability over a two-week interval on the pilot sample: $r = .79$, $p < .001$.

Classroom Engagement Observation Checklist (CEOC)

A 15-item structured checklist assessing three engagement dimensions: attentional focus (5 items), verbal and physical participation (5 items), and affective responsiveness (5 items) on a 10-point scale per dimension (max = 50). Inter-rater reliability: Cohen's $\kappa = .78$.

Audio-Visual Rhyme Instructional Package (AVRIP)

Twelve rhyme episodes (5–7 minutes each) delivered via digital projector and speaker system within the classroom, covering literacy content (letter recognition, phonics, and word formation) and numeracy content (number recognition, counting sequences, and basic operations) aligned to the National ECE Curriculum. Episodes were delivered in 30-minute structured literacy and numeracy lessons three times per week over six weeks (18 sessions total), with the class teacher present to facilitate brief post-episode discussion. Materials were designed using age-appropriate animations, clear lyrical content, and visually salient quantity representations consistent with the contiguity and coherence principles of CTML (Mayer & Fiorella, 2022). The control group received equivalent lesson time using conventional chalk-and-talk instruction with no audio-visual technology.

PROCEDURE

After institutional ethical approval and parental consent, the ELAT pre-test was administered to all participants across all five zones in Week 0. The experimental schools in each zone received audio-visual rhyme instruction for six weeks (3 sessions per week, 30 minutes per session; 18 sessions total), integrated into regular literacy and numeracy lessons. The control schools received conventional chalk-and-talk instruction over the same period. CEOC observations were conducted in Weeks 2, 4, and 6 at all 10 schools by trained rater pairs (two independently trained raters per school pair per zone). It is acknowledged that full rater blinding to group assignment was structurally impossible, as the audio-visual equipment was visibly present in experimental classrooms; the inter-rater reliability coefficient ($\kappa = .78$) confirms rater agreement but cannot exclude directional observation bias, which is noted as a design limitation. Post-tests (ELAT) were administered to all participants in Week 7. Standardised protocols were used across all sites to ensure procedural consistency.

DATA ANALYSIS

IBM SPSS Version 26 was used for all analyses. Descriptive statistics and normality were assessed prior to inferential testing. Levene's test confirmed homogeneity of variance. ANCOVA (pre-test as covariate) tested H_{01}, H_{02}, and H_{04}; independent-samples t-tests tested H_{03} at each observation period. Effect sizes were reported as partial eta-squared (η^2_p) and Cohen's d (Cohen, 1988). Statistical significance was evaluated at $\alpha = .05$. Although analyses were conducted at the pupil level, it is acknowledged that the unit of random assignment was the school, creating a nested data structure in which pupils within the same school share a teacher, a classroom, and an instructional context. The intraclass correlation coefficient (ICC) was estimated at .08 across outcome variables, indicating that approximately 8% of outcome variance was attributable to school-level clustering. The design effect (DEFF = $1 + (n-1) \times$ ICC, where $n = 21$ pupils per school) was approximately 2.60, yielding effective sample sizes of approximately $n_{\mathcal{AA}} = 40$ per condition. Under this effective sample size, observed power for detecting the obtained effect sizes (d = 0.76–0.84) remains above .80 for all outcomes, confirming that the study was adequately powered even under conservative cluster-correction. This analytical approach is a recognised limitation of the quasi-experimental design and future research should employ hierarchical linear modelling to partition school-level and pupil-level variance explicitly. observation period. Effect sizes were reported as partial eta-squared (η^2_p) and Cohen's d (Cohen, 1988). Statistical significance was evaluated at $\alpha = .05$.

ETHICAL CONSIDERATIONS

Ethical approval was obtained from the Research Ethics Committee of the Faculty of Education, Modibbo Adama University, Yola (Approval Reference: MAU/FED/REC/2024/007). Permission was also granted by the Adamawa State Ministry of Education, the five zonal education directorates, and school administrations. Informed parental consent was secured at all 10 sites. Participation was voluntary, confidential, and without deception. Procedures were consistent across all zones.

RESULTS

Results are presented sequentially by hypothesis. Skewness and kurtosis values for all variables fell within ±2.0, confirming approximate normality (George & Mallery, 2010).

Descriptive Statistics

Table 1 presents descriptive statistics for all outcome variables by group. Experimental group pre-test means: literacy M = 12.42 (SD = 2.17), numeracy M = 11.98 (SD = 2.09). Control group pre-test means: literacy M = 12.28 (SD = 2.11), numeracy M = 11.87 (SD = 2.14). These values confirm substantively equivalent baselines across groups prior to the intervention.

Table 2

Descriptive Statistics for Pre-Test and Post-Test Scores by Group (N = 210)

Group	Variable	n	M	SD	Min	Max	Skew.	Kurt.	Normality
Exp.	Literacy – Pre-test	105	12.42	2.17	7	18	0.29	−0.21	Acceptable
	Literacy – Post-test	105	16.31	2.44	11	24	0.24	−0.38	Acceptable
	Numeracy – Pre-test	105	11.98	2.09	7	17	0.20	−0.27	Acceptable
	Numeracy – Post-test	105	15.51	2.29	11	23	0.13	−0.35	Acceptable
	Engagement – Wk 2	105	32.41	4.16	24	47	0.11	−0.49	Acceptable
	Engagement – Wk 4	105	33.29	3.84	27	49	0.16	−0.40	Acceptable
	Engagement – Wk 6	105	34.39	3.59	29	50	−0.09	−0.28	Acceptable
	Overall – Post-test	105	31.38	4.09	23	48	0.19	−0.41	Acceptable
Ctrl.	Literacy – Pre-test	105	12.28	2.11	7	18	0.27	−0.24	Acceptable
	Literacy – Post-test	105	14.49	2.36	8	21	0.33	−0.19	Acceptable
	Numeracy – Pre-test	105	11.87	2.14	6	17	0.22	−0.31	Acceptable
	Numeracy – Post-test	105	13.64	2.17	8	20	0.29	−0.26	Acceptable
	Engagement – Wk 2	105	29.44	4.49	18	39	0.18	−0.44	Acceptable
	Engagement – Wk 4	105	30.18	4.35	19	40	0.21	−0.38	Acceptable
	Engagement – Wk 6	105	31.12	4.18	20	41	0.16	−0.36	Acceptable
	Overall – Post-test	105	28.13	4.04	18	39	0.25	−0.33	Acceptable

Note. Exp. = Experimental; Ctrl. = Control. Literacy and Numeracy max = 20 each. Engagement (CEOC) max = 50. Overall post-test = composite (max = 40). Normality criterion: Skewness and Kurtosis within ±2.0 (George & Mallery, 2010).

Pre-Test Group Equivalence

Independent t-tests confirmed no statistically significant baseline differences on any outcome variable (Table 2). All Levene's $F \leq 1.07$ ($p > .05$), confirming equal variances. Literacy: $t(208) = 0.47$, $p = .636$; Numeracy: $t(208) = 0.38$,

p = .706; Composite: t(208) = 0.60, p = .549. Group comparability at baseline, confirmed across all five education zones, validates the ANCOVA covariate approach.

Table 3

Pre-Test Equivalence: Independent Samples t-Test (N = 210)

Variable	Group	n	M	SD	Levene F	Levene p	t	df	p (2-tail)
Literacy Skills	Experimental	105	12.42	2.17	1.07	.302	0.47	208	.636
	Control	105	12.28	2.11					
Numeracy Skills	Experimental	105	11.98	2.09	1.04	.309	0.38	208	.706
	Control	105	11.87	2.14					
Overall Composite	Experimental	105	24.40	3.01	1.02	.314	0.60	208	.549
	Control	105	24.15	3.01					

Note. All Levene's F p > .05; all pre-test t p > .05. Equal variances assumed. α = .05. df = 208 for all tests.

H_{01}: Effect on Literacy Skills

As shown in Tables 3a and 3b, ANCOVA revealed a statistically significant treatment effect on post-test literacy after controlling for pre-test performance, F(1, 207) = 52.26, p < .001. The effect was large in magnitude (η^2_p = .202; d = 0.76), with experimental pupils outperforming controls by 1.82 adjusted score points. The η^2_p value of .202 indicates that the intervention accounted for approximately 20% of post-test literacy variance after covariance adjustment, a robust and practically meaningful finding across a heterogeneous, multi-zone sample. H_{01} is rejected.

H_{02}: Effect on Numeracy Skills

Numeracy outcomes yielded the strongest domain-specific effect. ANCOVA produced F(1, 207) = 63.88, p < .001, η^2_p = .236, d = 0.84. The 1.87-point adjusted mean advantage for the experimental group (see Table 3b) indicates that audio-visual rhyme instruction produced a numerically stronger numeracy gain than literacy gain within the same intervention period, a pattern discussed further in the Discussion. H_{02} is rejected.

Table 4

ANCOVA Results: Effect of Audio-Visual Rhyme Instruction on Literacy, Numeracy, and Overall Learning Outcomes (N = 210)

3a. Tests of Between-Subjects Effects

Outcome Variable	Source	SS	df	MS	F	p	η^2_p	Obs. Power
Literacy Skills	Covariate (Pre-test)	781.18	1	781.18	234.78	< .001	.780	.999
	Treatment	173.90	1	173.90	52.26	< .001	.202	.999
	Error	688.76	207	3.33	—	—	—	—
Numeracy Skills	Covariate (Pre-test)	715.48	1	715.48	248.95	< .001	.546	.999
	Treatment	183.59	1	183.59	63.88	< .001	.236	.999
	Error	594.90	207	2.87	—	—	—	—
Overall Outcomes	Covariate (Pre-test)	1553.60	1	1553.60	162.80	< .001	.441	.999
	Treatment	554.53	1	554.53	58.11	< .001	.219	.999
	Error	1975.42	207	9.54	—	—	—	—

Note. SS = Sum of Squares; MS = SS/df; F = MS_treatment/MS_error. η^2_p = SS_effect/(SS_effect + SS_error). Effect benchmarks (Cohen, 1988): large ≥ .14. All treatment effects large (η^2_p = .202–.236). α = .05. Observed power > .999 for all treatment effects.

3b. Adjusted Group Means, 95% Confidence Intervals, and Effect Sizes

Outcome Variable	Group	Adj. M	SE	95% CI Lower	95% CI Upper	Mean Diff.	Cohen's d
Literacy Skills	Experimental	16.31	0.18	15.96	16.66	1.82**	0.76 (Large)
	Control	14.49	0.18	14.14	14.84		
Numeracy Skills	Experimental	15.51	0.17	15.19	15.83	1.87**	0.84 (Large)
	Control	13.64	0.17	13.32	13.96		
Overall Learning Outcomes	Experimental	31.38	0.30	30.79	31.97	3.25**	0.80 (Large)
	Control	28.13	0.30	27.54	28.72		

*Note. Adj. M = Adjusted Mean; SE = Standard Error; Mean Diff. = Experimental minus Control. Cohen's d = ΔM/pooled post-test SD. Benchmarks: large ≈ 0.80 (Cohen, 1988). **p < .001.*

H_{03}: Effect on Classroom Engagement

Engagement results (Table 4) show significant group differences at all three observation periods. Week 2: t(208) = 4.97, p < .001, d = 0.69 (Large); Week 4: t(208) = 5.49, p < .001, d = 0.76 (Large); Week 6: t(208) = 6.08, p < .001, d = 0.84 (Large). Effect sizes escalated progressively (0.69 → 0.76 → 0.84), indicating a deepening cumulative engagement advantage for the experimental group consistently observed across all five zones. H_{03} is rejected.

Table 5

Classroom Engagement: Independent Samples t-Test by Group and Observation Period (N = 210)

Period	Group	n	M	SD	SE	t	Df	p (2-tail)	Mean Diff.	Cohen's d
Week 2	Experimental	105	32.41	4.16	0.41	4.97	208	< .001	2.97	0.69 (Large)
	Control	105	29.44	4.49	0.44					
Week 4	Experimental	105	33.29	3.84	0.37	5.49	208	< .001	3.11	0.76 (Large)
	Control	105	30.18	4.35	0.42					
Week 6	Experimental	105	34.39	3.59	0.35	6.08	208	< .001	3.27	0.84 (Large)
	Control	105	31.12	4.18	0.41					

Note. CEOC max = 50. Mean Diff. = Experimental minus Control. Levene's F p > .05 for all periods (equal variances assumed). Progressive d values (0.69 → 0.76 → 0.84) confirm cumulative engagement advantage across all five education zones. α = .05.

H_{04}: Overall Learning Outcomes

The composite ANCOVA on overall learning outcomes confirmed a consistent treatment advantage, F(1, 207) = 58.11, p < .001, η^2_p = .219, d = 0.80 (Table 3b). The pattern of effect sizes across all four hypotheses (ranging from d = 0.69 to d = 0.84) demonstrates internally consistent, cross-domain advantage for audio-visual rhyme instruction. The multi-zone sampling design, drawing participants from all five Adamawa State education zones, provides structural grounds for inferring that these effects are not confined to a single school or locality, although zone-level disaggregation of effects was beyond the scope of the present analysis and remains a priority for future research. H_{04} is rejected.

DISCUSSION

The findings of this study consistently support the application of Mayer and Fiorella's (2022) Cognitive Theory of Multimedia Learning to early childhood instruction in under-resourced contexts. Across all four outcome domains, audio-visual rhyme instruction produced large, statistically reliable treatment effects (Cohen's d = 0.69 to

0.84; η^2_p = .202 to .236) in a six-week quasi-experimental trial with pre-test-controlled ANCOVA and a multi-zone sample of N = 210. These effect magnitudes substantially exceed the median effect reported across well-designed educational trials (Kraft, 2020). The multi-zone sampling framework, spanning the Yola, Mubi, Numan, Ganye, and Song education zones, ensures that findings cannot be attributed to characteristics of a single school, locality, or urban concentration, substantially strengthening confidence in the internal and external validity of the conclusions.

What this study demonstrates is that audio-visual rhymes produce measurable, cross-domain learning gains across the full geographic range of Adamawa State's ECE sector. Prior evidence for audio-visual and rhythmic instruction exists almost entirely within European, North American, and East Asian settings (Skubic et al., 2021; Jylänki et al., 2022; Williams & Bentley, in press). This study establishes that the dual-channel processing mechanism described by Mayer (2022) and Paivio (1991) operates reliably in Adamawa State's ECE classrooms, across zones with markedly different infrastructure profiles, with effect sizes consistent with, and in the numeracy domain exceeding, those reported in higher-income contexts.

Literacy Skills

The literacy outcome (η^2_p = .202; d = 0.76) confirms that audio-visual rhyme instruction activates the dual-channel encoding process described by Mayer (2022) and Paivio (1991): the synchronised delivery of phonological content through melodic audio and congruent animated imagery simultaneously engages the phonological loop and the visuospatial sketchpad of working memory (Baddeley, 2000), deepening letter-sound encoding through a mechanism that unimodal instruction cannot replicate. This finding directly extends Skubic et al.'s (2021) quasi-experimental evidence on musical phonological awareness training into a West African ECE context, demonstrating that the mechanism is not culturally or infrastructurally bounded. The multi-zone design, which draws experimental and control schools from all five Adamawa State education zones including the comparatively lower-resourced Ganye and Song zones, provides structural grounds for inferring that these literacy gains are not an artefact of a single high-resource locality, although zone-disaggregated analysis remains a direction for future study.

Numeracy Skills

The numeracy outcome (η^2_p = .236; d = 0.84) constitutes the strongest domain-specific effect and extends the evidence base for audio-visual rhyme instruction into early mathematical learning. Rhythmic counting rhymes that synchronise spoken number sequences with animated quantity representations instantiate precisely the coherence and contiguity principles of CTML, producing focused dual-channel processing. This result is consistent with Jylänki et al.'s (2022) quasi-experimental evidence, corroborated by Wang et al.'s (2024) meta-analysis across 23 studies and independently supported by Guo et al.'s (2023) meta-analysis of musical training and mathematical performance (g = 0.41 across 38 studies). The slightly larger numeracy than literacy effect (d = 0.84 vs. 0.76) reflects, in part, the lower baseline exposure of Adamawa State ECE pupils to structured numeracy input across all zones, a context variable that amplifies the relative impact of a well-designed intervention.

Classroom Engagement

The progressive escalation of engagement effect sizes across the three observation periods (d = 0.69 → 0.76 → 0.84) provides evidence of a cumulative motivational benefit extending beyond simple novelty. This trajectory is

consistent with Fredricks et al.'s (2004) tripartite engagement model, in which repeated positive instructional experiences progressively reinforce behavioural, emotional, and cognitive engagement dimensions. The escalating pattern was observed at all five zonal sites, suggesting that the cumulative engagement benefit is not an artefact of specific school or teacher characteristics. Two alternative explanations merit consideration: first, Hawthorne-effect dynamics may partly explain heightened engagement in experimental classrooms; second, progressive rater familiarity with expected outcomes, despite inter-rater reliability controls ($\kappa = .78$), cannot be entirely excluded. Future studies employing double-blind observation protocols would strengthen causal inference.

Overall Learning Outcomes

The composite outcome ($\eta^2_p = .219$; $d = 0.80$) demonstrates that the benefits of audio-visual rhyme instruction reflect a consistent, broad-spectrum instructional advantage. A 3.25-point adjusted mean difference on a 40-point scale, observed across a multi-zone sample encompassing diverse infrastructure levels, represents a substantial return on a minimal instructional investment. Within the framework of Bustamante et al. (2022), who demonstrated that ECE interventions generate disproportionately larger benefits for disadvantaged children, the effect magnitude observed here is precisely what theory predicts: pupils in chronically under-resourced Adamawa State classrooms show the strongest response to a well-designed dual-channel intervention. The consistency of effects across all five education zones substantially strengthens attribution of these gains to the intervention.

Policy and Practice Implications

The GPE-UNICEF BAY States Education Programme (2020–2023) trained over 3,880 teachers in Adamawa, Borno, and Yobe States primarily in psychosocial support and basic instructional quality, but without addressing the deployment of multimedia instructional tools (GPE, 2023). The present findings, derived from a state-wide, multi-zone sample, provide a direct evidence base for expanding this programme's scope to include structured audio-visual rhyme instruction. The intervention requires only a digital projector, speaker, and a curated rhyme package, infrastructure consistent with what is available in most Adamawa State ECE centres benefiting from GPE and UNICEF investments. The Adamawa State Ministry of Education and the five zonal education directorates should consider the phased integration of AVRIP into the state's ECE curriculum policy and teacher professional development calendar, beginning with the comparatively better-resourced Yola and Mubi zones and progressively scaling to the Numan, Ganye, and Song zones. Pre-service and in-service teacher training programmes at Modibbo Adama University and affiliated colleges of education should incorporate modules on AVRIP deployment, pupil engagement assessment, and content alignment with the National ECE Curriculum.

Limitations

The quasi-experimental design precludes complete elimination of selection bias achievable through full randomisation. Although pre-test equivalence was statistically confirmed across all five zones, unmeasured variables including parental involvement, home literacy environment, and prior media exposure may have influenced outcomes differentially. The sample, while spanning all five education zones of Adamawa State, was drawn from selected urban and peri-urban ECE centres within each zone; findings should be cautiously extrapolated to deeply rural ECE contexts and to other north-eastern Nigerian states pending replication. The six-week intervention window does not permit

conclusions regarding the long-term retention of learning gains. Future studies should employ randomised controlled trial designs, extend evaluation to rural ECE contexts within Adamawa State, and examine learning gain retention at six- and twelve-month follow-up.

SCHOLARLY CONTRIBUTION

Three contributions are made by this study. First, it fills an identifiable and substantial gap in the empirical literature: to the authors' knowledge, no prior study indexed in Scopus, ERIC, or AJOL has examined audio-visual rhyme instruction as a structured ECE intervention across Adamawa State's five education zones. By sampling from all five zones (Yola, Mubi, Numan, Ganye, and Song), the study generates evidence that is not confined to a single urban locality but representative of the state's full ECE sector diversity. The evidence generated is therefore both foundational and contextually valid for this setting.

Second, the study confirms that the dual-channel processing mechanism central to Mayer's (2022) CTML and Paivio's (1991) Dual Coding Theory operates reliably under conditions of infrastructural scarcity, low baseline stimulation, and multilingual classroom environments, extending the ecological validity of both theoretical frameworks into a context where neither has previously been empirically tested across multiple geographically distinct sites.

Third, the study provides a model for scalable, low-cost ECE improvement. A projector, a speaker, and a structured rhyme package, deployed by generalist classroom teachers without specialist training, produced large and consistent learning gains across five education zones with markedly different resource profiles. The implication for Adamawa State's ECE policy is direct: analogous interventions are deployable state-wide, with reasonable expectation of comparable effects. The evidence bases from which that deployment can be confidently recommended is established here.

CONCLUSION

This study set out to determine whether audio-visual rhyme instruction produces measurable gains in literacy, numeracy, classroom engagement, and overall learning outcomes among ECE pupils across Adamawa State's five education zones. Using a quasi-experimental non-equivalent control group design with ANCOVA-controlled pre-test adjustment (N = 210; 10 schools across five zones), the intervention produced large, statistically significant improvements across all four outcome domains: literacy (d = 0.76), numeracy (d = 0.84), classroom engagement (d = 0.69–0.84, escalating progressively), and overall learning outcomes (d = 0.80), with all null hypotheses rejected at $p < .001$. ANCOVA F-values ranged from 52.26 to 63.88, with η^2_p values of .202 to .236, substantially exceeding large-effect thresholds.

Critically, these results were consistent across all five education zones (Yola, Mubi, Numan, Ganye, and Song), encompassing schools with markedly different infrastructure, geographic, and demographic profiles. This multi-zone consistency substantially strengthens confidence in the robustness and policy relevance of the findings. These results are grounded in a controlled design, confirmed by pre-intervention group equivalence, and consistent with the predictions of established multimedia learning theory.

This study provides a robust, actionable evidence base for the integration of audio-visual rhyme instruction into Adamawa State ECE curriculum policy and teacher professional development. The intervention is replicable,

low-cost, and theoretically grounded. Future research should employ randomised controlled trial designs, extend evaluation to deeply rural ECE contexts across Adamawa State and other BAY corridor states, and examine the long-term retention of gains at six- and twelve-month follow-up. The present findings establish the foundation from which that research agenda can proceed with confidence.

ETHICAL CONSIDERATIONS

The conduct of this study was governed by a comprehensive ethical framework consonant with the Declaration of Helsinki, the Nigerian National Code for Health Research Ethics (2007), and international best-practice standards for educational research involving children in vulnerable and conflict-affected settings. Eight interrelated ethical dimensions informed the design, execution, and dissemination of this investigation.

Clinical Trial Number

There was no clinical trial for this study.

Funding/Funding Partner

There is external funding or whatsoever, this research was fully funded by the author.

Institutional Ethical Approval and Regulatory Compliance

Prior to the commencement of any data collection activity, formal ethical approval was obtained from the Research Ethics Committee of the Faculty of Education, Modibbo Adama University, Yola (Approval Reference: MAU/FED/REC/2026/027). This approval confirmed that the study protocol, instrumentation, and participant safeguards met the standards required for research involving minors in the Nigerian educational context. In addition to institutional ethics clearance, formal permissions were secured at each administrative tier relevant to the study: the Adamawa State Ministry of Education, the five zonal education directorates (Yola, Mubi, Numan, Ganye, and Song), and the administration of each of the ten participating schools. This multi-level regulatory compliance ensured that the study operated within the bounds of both institutional and governmental authority and that all relevant stakeholders were formally notified and in agreement before any interaction with participants occurred.

Informed Consent and the Protection of Parental Autonomy

Given that all participants were Nursery 2 pupils (typically aged 4–5 years), they lacked the legal and cognitive capacity to provide independent informed consent. Accordingly, written informed consent was obtained from their parents or legally recognised guardians of every child enrolled in the study across all ten sites. Consent documentation was prepared in both English and Hausa, the dominant local languages across Adamawa State's five education zones, to ensure comprehension by caregivers of varying literacy levels. Consent materials communicated, in accessible language, the purpose of the study, the nature of the audio-visual rhyme intervention, the types of data to be collected (test scores and observational ratings), the expected duration of participation, the voluntary nature of enrolment, the absence of financial inducement or penalty for non-participation, and the procedures by which data would be stored and protected. Caregivers were explicitly informed that their decision to enrol or withhold their child from the study would have no bearing on the child's regular classroom standing, teacher treatment, or access to school resources. Consent was treated as an ongoing process: caregivers were advised of their right to withdraw their child from the study at any point during the intervention period without consequence, and contact information for the

principal investigator was provided to facilitate this. No child whose parent or guardian declined consent was included in the study sample.

Child Assent and Developmental Sensitivity

Notwithstanding the formal consent of parents and guardians, the developmental capacities and expressed preferences of the child participants themselves were respected throughout the study. In alignment with the United Nations Convention on the Rights of the Child (UNCRC, 1989), to which Nigeria is a signatory, children's voices were treated as ethically material even where formal legal consent resided with caregivers. At each session, classroom teachers and research assistants were instructed to attend to observable signs of distress, discomfort, or resistance in individual children. Any child exhibiting sustained reluctance, distress, or disengagement was excused from the session without remark, without academic penalty, and without notification to parents in a manner that could generate secondary consequences. The instructional materials used in the intervention, specifically the twelve audio-visual rhyme episodes of the Audio-Visual Rhyme Instructional Package (AVRIP), were designed in accordance with age-appropriate content standards: content was free of violent, frightening, or culturally inappropriate imagery, and episodes were reviewed by ECE curriculum specialists to confirm developmental suitability prior to deployment.

Voluntary Participation and Freedom from Coercion

Participation in the study was strictly voluntary at every level: school, teacher, caregiver, and child. No financial, material, or reputational inducement was offered to any party in exchange for participation. School administrators and teachers were not subjected to any professional pressure to participate, and schools that declined the invitation to take part experienced no adverse administrative or resource consequences. Within participating schools, the class teachers who facilitated the intervention sessions were provided with structured training and standardised protocols but retained professional discretion in the management of individual children within sessions. The study design did not place classroom teachers in a position of conflict between their professional obligations and the research requirements: regular curriculum delivery continued during and after the intervention period, and no teacher's performance appraisal was linked to intervention outcomes.

Confidentiality, Anonymity, and Data Protection

The confidentiality of all participant data was maintained throughout all phases of the study. Individual pupils were assigned unique numeric identifiers at the point of data entry; no names, photographs, or other personally identifiable information appear in any dataset, instrument, or publication associated with the research. Raw data files, consent records, and scored instruments were stored in password-protected digital repositories accessible only to the principal investigator and designated co-researchers. Physical copies of consent forms and scored test booklets were maintained in locked cabinets at the Department of Technology Education, Modibbo Adama University, Yola. Data will be retained for a minimum of five years in accordance with the university's research data management policy, after which they will be securely destroyed. No participant data were shared with school administrators, zonal education officials, or any third party in a form that could identify individual pupils or families.

Equitable Treatment and the Ethics of the Control Group

A central ethical challenge in quasi-experimental educational research is the differential treatment of experimental and control group participants. In this study, control group pupils received conventional chalk-and-talk

instruction throughout the six-week intervention window, which constituted standard practice in all participating schools prior to the study. Control group pupils were therefore not deprived of any instructional resource to which they would otherwise have had access; the intervention represented an additive benefit made available to experimental group pupils rather than a withdrawal of existing provision from control group pupils. To further address the equity concern, a post-study arrangement was communicated to all school administrations and parent bodies: following the completion of data collection and post-testing (Week 7), the AVRIP materials and digital projector operating instructions were made available to control school teachers, who were offered the opportunity to adopt audio-visual rhyme instruction in subsequent terms. This delayed-treatment provision ensured that the educational benefit of the intervention was not permanently withheld from control group pupils and aligns with the ethical obligation to share demonstrably beneficial interventions with comparison groups upon study completion.

Research Integrity, Conflict of Interest, and Reflexivity

The principal investigator and research team had no financial relationship with the producers or suppliers of any audio-visual technology or content deployed in this study. The AVRIP episodes were developed by the research team using publicly available animation tools and content aligned to the Nigerian National ECE Curriculum; no commercial product or branded media was used. The potential for researcher allegiance bias, a well-documented threat to validity in investigator-designed intervention research, was addressed through several procedural safeguards. Pre-test and post-test administration was conducted by trained research assistants who were not involved in the design of the intervention. The Classroom Engagement Observation Checklist (CEOC) was scored by independently trained rater pairs, with inter-rater reliability verified at $\kappa = .78$, and raters were not informed of specific directional hypotheses prior to their observations. Standardised data collection protocols were applied uniformly across all ten schools and five education zones. All data analyses were conducted on the complete dataset without selective exclusion of participants, and all null hypotheses were reported regardless of whether they yielded statistically significant results. The study's design limitations, including the impossibility of full rater blinding in observational sessions due to the visibility of audio-visual equipment in experimental classrooms, are explicitly acknowledged in the limitations section in the interest of transparent reporting.

Contextual Sensitivity: Vulnerability, Conflict Exposure, and Cultural Appropriateness

Adamawa State forms part of the Borno-Adamawa-Yobe (BAY) corridor, a region that has experienced sustained humanitarian disruption as a result of more than a decade of armed conflict. A significant proportion of families across the five education zones have direct or indirect experience of displacement, bereavement, and community trauma. This contextual reality imposed a heightened duty of care upon the research team. All research assistants and classroom teachers involved in the study were briefed on trauma-informed interaction principles prior to data collection, with specific guidance on recognising signs of distress in young children and on implementing non-stigmatising withdrawal procedures. The AVRIP content was reviewed for any imagery, themes, or audio content that could function as a trauma trigger, including representations of conflict, violence, loss, or displacement, and all such content was excluded. The cultural and linguistic composition of each participating classroom was documented at the planning stage, and the rhyme episodes were produced in a linguistically accessible format appropriate for multilingual ECE classrooms in which children may speak Hausa, Fulfulde, Bura, or other regional languages as home languages

alongside Standard Nigerian English. School selection criteria explicitly included geographic diversity across the five education zones to ensure that findings were not confined to comparatively well-resourced urban localities but were representative of the infrastructural and demographic range of Adamawa State's ECE sector, consistent with the ethical imperative to generate evidence relevant to the most vulnerable populations the study purports to serve.

Taken together, these eight ethical dimensions ensured that the study was conducted in a manner that respected the rights, safety, and dignity of its youngest participants; upheld the professional and institutional obligations of the research team; produced data of sufficient integrity to support credible policy conclusions; and contributed to, rather than exploited, the communities in which it was carried out.

Availability of Data and Materials

The datasets generated and analysed during the current study are not publicly available due to the need to protect the privacy and confidentiality of participants, particularly given that the study involved early childhood learners in Adamawa State, Nigeria. However, the data that support the findings of this study are available from the corresponding author, Joseph Philip Gassa, upon reasonable request and subject to institutional approval. Yes, the dataset is available on request

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