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COGNITIVE AND AFFECTIVE OUTCOMES OF STRUCTURED AND ANDRAGOGICAL APPROACHES IN TECHNOLOGY-BASED LANGUAGE LEARNING: A CROSSOVER STUDY

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Abstrak

Integrasi teknologi digital dalam pembelajaran bahasa di perguruan tinggi menuntut pemilihan pendekatan yang sesuai dengan karakteristik mahasiswa sebagai pemelajar dewasa. Penelitian ini menganalisis efektivitas komparatif pendekatan berstruktur dan andragogi berbasis teknologi terhadap kemampuan bahasa, motivasi, dan keterlibatan digital mahasiswa menggunakan desain crossover. Sebanyak 30 mahasiswa STKIP YDB Lubuk Alung dibagi menjadi dua kelompok secara counterbalanced: Kelompok A (n=15) menjalani urutan berstruktur–andragogi, sedangkan Kelompok B (n=15) menjalani urutan sebaliknya, dengan washout period satu minggu di antara perlakuan. Hasil uji paired t-test menunjukkan bahwa kedua pendekatan secara signifikan meningkatkan kemampuan bahasa ($p < .001$), dengan effect size besar untuk pendekatan berstruktur ($d = 2,73$; gain = +18,67) dan andragogi ($d = 2,47$; gain = +19,70); namun perbedaan antara keduanya tidak signifikan ($p = .508$, $d = 0,12$), yang dikonfirmasi pula oleh uji Wilcoxon ($p = .600$). Sebaliknya, pendekatan andragogi menghasilkan motivasi ($M = 4,27$; $d = 2,54$) dan keterlibatan digital ($M = 4,18$; $d = 2,19$) yang secara signifikan lebih tinggi ($p < .001$). Korelasi hampir nol antara skor keterlibatan kedua kondisi ($r = .067$) menunjukkan bahwa kedua pendekatan mengaktifkan mekanisme keterlibatan yang berbeda secara kualitatif. Temuan efek perlakuan yang signifikan mengindikasikan adanya manfaat pembelajaran kumulatif dari paparan sekuensial. Implikasi penelitian mendukung model pembelajaran hibrid yang mengintegrasikan scaffolding kognitif berstruktur dengan otonomi afektif andragogi.

Kata Kunci: *teknologi digital, pembelajaran bahasa, andragogi, pendekatan berstruktur, studi crossover*

Abstract

The proliferation of digital technology in higher education language learning requires instructional approaches that align with the characteristics of adult learners. This study examines the comparative cognitive and affective outcomes of structured and andragogical technology-based approaches on language proficiency, motivation, and digital engagement using a within-subject crossover design. Thirty students at STKIP YDB Lubuk Alung were assigned to two counterbalanced groups: Group A (n = 15) followed a structured-then-andragogical sequence, while Group B (n = 15) followed the reverse, with a one-week washout period between treatments. Paired t-tests demonstrated that both approaches produced significant language proficiency gains ($p < .001$), yielding large effect sizes for structured instruction ($d = 2.73$; gain = +18.67 points) and andragogical learning ($d = 2.47$; gain = +19.70 points), with no statistically significant difference between them ($p = .508$, $d = 0.12$), a result confirmed by the Wilcoxon signed-rank test ($p = .600$). In contrast, andragogical instruction generated significantly higher motivation ($M = 4.27$; $d = 2.54$) and digital engagement ($M = 4.18$; $d = 2.19$) than structured instruction ($p < .001$). A near-zero correlation between engagement scores across the two conditions ($r = .067$) indicates that each approach activates qualitatively distinct engagement mechanisms. Significant and symmetric carry-over effects across both conditions ($p < .001$) suggest that sequential exposure to contrasting technology-based approaches yields cumulative learning benefits. These findings support a hybrid instructional model that combines the cognitive scaffolding of structured instruction with the affective autonomy of andragogical learning.

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Keywords: digital technology, language learning, andragogy, structured instruction, crossover study

1. INTRODUCTION

The rapid expansion of digital technology has fundamentally reshaped language learning in higher education. Learning management systems, interactive digital modules, and multimedia platforms have made it possible to deliver language instruction that is simultaneously flexible, personalised, and contextually rich. Despite this technological proliferation, a critical question remains largely unaddressed: do different instructional approaches exploit digital technology with equivalent effectiveness across both cognitive and affective dimensions of learning? This question carries particular weight in university settings, where adult learners constitute the primary student population and bring distinct motivational orientations, experiential knowledge bases, and self-regulatory capacities that set them apart from school-age learners (Knowles, 1984; Mezirow, 1991).

Two principal instructional traditions have shaped discourse on pedagogy in higher education. The structured instruction tradition, grounded in Gagné (1985) conditions of learning, emphasises systematic content sequencing, explicit objectives, and graduated scaffolding to support knowledge acquisition. The andragogical tradition, developed by Knows (1984) and subsequently theorised by Mezirow (1991), foregrounds learner self-direction, intrinsic motivation, and the integration of prior experiential knowledge into new learning. Both traditions have accumulated substantial empirical support across diverse instructional contexts; however, they have rarely been placed within a single experimental framework capable of directly comparing their effects, particularly within technology-enhanced language learning environments. Bond et al. (2021) note that instructional approach rather than the technology itself is the dominant determinant of learning outcomes in digital settings, underscoring the theoretical necessity of such comparative investigation.

A theoretically important distinction structures the present inquiry: the difference between cognitive and affective learning outcomes. Cognitive outcomes, operationalised here as language proficiency gains, capture the degree to which learners acquire and consolidate linguistic knowledge. Affective outcomes specifically motivation and digital engagement reflect the emotional and volitional dimensions of learning that drive sustained effort, voluntary exploration, and depth of processing (Papi & Hiver, 2020). Research drawing on self-determination theory (Ryan & Deci, 2020) and Keller's (2010) ARCS model consistently demonstrates that affective engagement functions not merely as a correlate of cognitive achievement but as a causal mechanism: instructional environments that support learner autonomy, competence, and relatedness generate intrinsic motivation that in turn promotes deeper cognitive processing and more durable learning outcomes.

Existing empirical literature on technology-enhanced language learning offers partial but not convergent guidance on this question. Lin et al. (2021) found that structured digital modules significantly improved vocabulary acquisition in EFL contexts, while Lai and Zheng (2018) documented motivational advantages associated with self-directed digital learning practices aligned with andragogical principles. Golonka et al. (2012) concluded from systematic review that the effectiveness of digital language tools is mediated more strongly by pedagogical design quality than by the specific technology employed. Reinders and Benson (2011) further argued that learner autonomy, a defining feature of andragogical instruction, is the most robust predictor of successful language

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learning in technology-rich environments. Despite these contributions, no study has directly compared structured and andragogical approaches within a single controlled experimental design that simultaneously examines both cognitive and affective outcomes while controlling for individual learner differences.

The present study addresses this gap by employing a within-subject crossover design in which all participants experience both treatment conditions in counterbalanced sequence. This design enables within-person comparisons with maximum statistical precision, eliminating individual-difference confounds that compromise between-group designs. Effectiveness is operationalised as a multidimensional construct spanning language proficiency, motivation, and digital engagement, rather than reduced to a single outcome measure. Two research questions guide the investigation: (1) Do structured and andragogical technology-based approaches differ significantly in their effects on university students' language proficiency? (2) Do the two approaches differ significantly in their effects on students' motivation and digital engagement? Responses to these questions are expected to contribute both theoretical insight into the distinct mechanisms through which instructional design shapes cognitive and affective learning, and practical guidance for educators seeking to optimise technology integration in language curricula.

2. METHOD

This study employed a within-subject crossover design in which each participant received both treatment conditions in counterbalanced sequence. The crossover approach was selected because it enables each participant to function as their own control, substantially reducing the influence of individual differences on treatment comparisons and thereby increasing statistical precision (Creswell & Creswell, 2018; Senn, 2002). Group A (n = 15) received structured instruction in Phase 1 and andragogical instruction in Phase 2; Group B (n = 15) received treatments in the reverse order. Each treatment phase comprised two intensive sessions within one calendar week, followed by a one-week washout period before the commencement of the second phase.

Aggregated scores for the primary analyses followed standard crossover protocol (Senn, 2002): structured approach scores comprised Group A Posttest 1 and Group B Posttest 2 (N = 30), while andragogical approach scores comprised Group B Posttest 1 and Group A Posttest 2 (N = 30). This aggregation procedure ensures that any sequence-order effects are distributed symmetrically across both conditions rather than systematically favouring one treatment.

Table 1. Crossover Research Design

Group	Pretest	Phase 1 (Posttest 1)	Washout	Phase 2 (Posttest 2)	n
Group A	Pretest	Structured Instruction	1 week	Andragogical Learning	15
Group B	Pretest	Andragogical Learning	1 week	Structured Instruction	15

Note. Structured scores (N = 30) = Group A Posttest 1 + Group B Posttest 2. Andragogical scores (N = 30) = Group B Posttest 1 + Group A Posttest 2, following Senn (2002).

Participants were 30 university students enrolled in language courses at STKIP YDB Lubuk Alung, West Sumatra, Indonesia. purposive sampling was applied to ensure homogeneity in relevant background variables: inclusion criteria required (a) enrolment in a

course with consistent integration of digital technology, (b) access to personal computing devices for independent learning, and (c) no prior exposure to the specific instructional modules employed in this study. Following selection, participants were randomly assigned to Group A or Group B using a coin-toss procedure. Baseline equivalence was verified through independent-samples t-test: Group A ($M = 60.40$, $SD = 5.28$) and Group B ($M = 62.67$, $SD = 4.59$) did not differ significantly ($t(28) = -1.26$, $p = .220$), confirming the comparability of groups before treatment commencement.

Four instruments were employed. First, a language proficiency test (100-point scale) was administered as pretest, Posttest 1, and Posttest 2 to measure learning gains across each treatment phase. Content validity was established through review by two subject-matter experts prior to administration; inter-rater agreement was satisfactory. Second, a motivation questionnaire adapted from Keller's (2010) ARCS model was administered after each treatment phase using a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). Third, a digital engagement questionnaire measuring the frequency and depth of students' interactions with digital learning resources was administered after each treatment phase on the same five-point scale. Fourth, classroom observation protocols and semi-structured interview guides provided qualitative data on learning behaviours and student perceptions of each instructional approach.

The structured instruction treatment delivered language content through sequentially organised digital modules designed according to Gagné's (1985) nine events of instruction: gaining learner attention, informing learners of objectives, stimulating recall of prior knowledge, presenting new content, providing learning guidance, eliciting performance, providing corrective feedback, assessing performance, and enhancing retention and transfer. Students followed a predetermined learning pathway with explicit task objectives, tiered digital exercises, and systematic progression from foundational to more complex language tasks. Instructors maintained a directive role, monitoring individual progress and delivering aligned corrective feedback throughout.

The andragogical learning treatment was designed in accordance with Knowles' (1984) four foundational assumptions of adult learning: (a) self-concept, students directed their own digital learning exploration; (b) experience, tasks were explicitly anchored to students' prior linguistic and personal knowledge; (c) readiness to learn, learning topics were selected based on their immediate relevance to students' academic and professional contexts; and (d) orientation to learning, activities were problem-centred rather than content-centred. Instructors assumed a facilitative role, posing open-ended questions, supporting individual goal-setting, and encouraging collaborative interaction through digital platforms.

Quantitative data were analysed using IBM SPSS Statistics 26. Prior to all parametric analyses, normality was assessed using the Shapiro-Wilk test. Six of seven variables met normality assumptions ($W \geq 0.944$, $p \geq .118$); the sole exception was the aggregated structured instruction score ($W = 0.917$, $p = .023$). For this variable, Wilcoxon signed-rank tests were conducted alongside paired-samples t-tests as non-parametric robustness checks. Paired-samples t-tests examined within-condition gains from pretest to posttest and between-condition differences between structured and andragogical scores. Effect sizes were calculated as Cohen's d, using the standard deviation of paired differences as the denominator (Cohen, 1988), with conventional thresholds of 0.20 (small), 0.50 (medium), and 0.80 (large). Pearson correlation coefficients were computed to examine the relationship between engagement scores across the two conditions. Carry-over effects were evaluated using independent-samples t-tests

comparing the performance of participants who received each treatment first versus second. Qualitative data were analysed thematically following the three-phase framework of Miles et al. (2014): data reduction, data display, and conclusion drawing. Quantitative and qualitative findings were triangulated to strengthen interpretive validity.

3. RESULTS AND DISCUSSION

Preliminary Analyses

Shapiro-Wilk tests confirmed normality for six of seven variables: pretest scores ($W = 0.950$, $p = .174$), andragogical posttest scores ($W = 0.978$, $p = .758$), and all four affective scale variables ($W \geq 0.944$, $p \geq .118$). Structured instruction posttest scores showed a marginal departure from normality ($W = 0.917$, $p = .023$). Inspection of individual gain scores identified two participants with notably low structured instruction gains (+3 and +7 points compared to a group mean gain of 18.67 points); both participants demonstrated substantially stronger gains under andragogical instruction, a pattern consistent with individual learning-style variation rather than data recording error. Given that paired t-tests are known to remain robust under sample sizes of $n = 30$ even when normality is marginally violated (Pallant, 2020), parametric analyses were retained and all results confirmed through Wilcoxon signed-rank tests. Baseline equivalence between groups was confirmed: $t(28) = -1.26$, $p = .220$.

Research Question 1: Language Proficiency

Table 2 presents descriptive statistics and inferential test results for language proficiency scores.

Table 2. Language Proficiency Scores: Descriptive Statistics and Inferential Test Results (N = 30)

Condition	M	SD	Min	Max	Mean Gain	t(29)	Cohen's d
Pretest	61.53	4.99	50	70	–	–	–
Structured Instruction	80.20	6.38	65	90	+18.67***	−14.93	2.73 (large)
Andragogical Learning	81.23	5.64	70	92	+19.70***	−13.52	2.47 (large)
Structured vs. Andragogy	–	–	–	–	diff = 1.03	−0.67 (ns)	0.12 (negligible)

Note. ***$p < .001$ (two-tailed); ns = not significant ($p = .508$). Mean Gain = posttest mean minus pretest mean. Shapiro-Wilk: Structured $W = 0.917$, $p = .023$; Andragogy $W = 0.978$, $p = .758$. Wilcoxon robustness checks: Pretest vs. Structured $p < .001$; Pretest vs. Andragogy $p < .001$; Structured vs. Andragogy $p = .600$.

Both instructional approaches produced statistically significant and educationally large improvements in language proficiency. Structured instruction raised mean scores from 61.53 ($SD = 4.99$) at pretest to 80.20 ($SD = 6.38$) at posttest, representing a mean gain of 18.67 points ($t(29) = -14.93$, $p < .001$, $d = 2.73$). Andragogical learning raised posttest scores to a mean of 81.23 ($SD = 5.64$), representing a mean gain of 19.70 points ($t(29) = -13.52$, $p < .001$, $d = 2.47$). Both effect sizes substantially exceed Cohen's (1988) threshold for large effects ($d \geq 0.80$), confirming that both approaches generated educationally meaningful and statistically unambiguous proficiency gains.

Crucially, the direct comparison between the two approaches was not statistically significant ($t(29) = -0.67$, $p = .508$, $d = 0.12$). The mean advantage of andragogical learning over structured instruction was 1.03 points, a negligible effect by Cohen's criteria. This finding establishes the cognitive equivalence of the two

approaches: when digital technology is systematically integrated into instruction, both structured scaffolding and andragogical self-direction serve as equally effective vehicles for language proficiency development. The Wilcoxon signed-rank test confirmed this conclusion (p = .600), demonstrating that the equivalence finding is not an artefact of the marginal normality departure in the structured instruction scores. These results corroborate Golonka et al.'s (2012) conclusion that the effectiveness of technology-enhanced language learning is mediated primarily by pedagogical quality and design rather than by the specific instructional framework employed.

The magnitude of gains observed across both conditions warrants contextualisation. Mean improvements of approximately 18–20 points over a brief, intensive treatment period reflect the focused design of the digital tasks, which were developed specifically around course content objectives. The two participants with substantially lower structured instruction gains (+3 and +7 points) were retained in the final analysis; their exclusion would artificially inflate the structured instruction mean and misrepresent population-level effects. Their lower responsiveness to structured instruction is itself a substantively informative finding, it is consistent with Knowles' (1984) theoretical expectation that some adult learners, particularly those with well-developed self-regulatory capacities, derive greater benefit from autonomous than from scaffolded instructional conditions.

Research Question 2: Motivation and Digital Engagement

Table 3 presents affective outcome data. In marked contrast to the cognitive equivalence finding, the two approaches produced substantially different affective outcomes.

Table 3. Motivation and Digital Engagement: Descriptive Statistics and Inferential Test Results (N = 30)

Dimension	M (Structured)	SD	M (Andragogy)	SD	Mean Diff	t(29)	Cohen's d
Motivation to Learn	3.62	0.27	4.27	0.22	+0.65***	−13.93	2.54 (large)
Digital Engagement	3.47	0.25	4.18	0.22	+0.71***	−12.00	2.19 (large)

Note. ***p < .001 (two-tailed). Scores on a five-point Likert scale. Pearson r between Engagement-Structured and Engagement-Andragogy = .067 (p = .727).

Students reported significantly higher motivation under andragogical instruction (M = 4.27, SD = 0.22) than under structured instruction (M = 3.62, SD = 0.27), producing a mean difference of 0.65 scale points (t(29) = −13.93, p < .001, d = 2.54). Digital engagement followed a comparable pattern: the andragogical condition yielded a mean of 4.18 (SD = 0.22) compared to 3.47 (SD = 0.25) under structured instruction (t(29) = −12.00, p < .001, d = 2.19). Both effect sizes fall well within the large range, indicating that andragogical instruction generated qualitatively superior motivational and engagement experiences rather than modest incremental improvements.

A particularly noteworthy finding is the near-zero Pearson correlation between engagement scores across the two conditions (r = .067, p = .727). The statistical independence of engagement scores indicates that a student's level of digital engagement under structured instruction has no predictive value for their engagement level under andragogical instruction. This finding suggests that the two approaches do

not merely produce different quantities of the same underlying engagement behaviour; rather, they activate qualitatively distinct engagement mechanisms. Structured instruction appears to generate compliance-based engagement, in which students efficiently navigate prescribed digital pathways with discipline and focus. Andragogical instruction, by contrast, generates exploratory engagement, in which students independently seek supplementary digital materials, initiate peer-based digital interactions, and connect learning tasks to self-defined personal and professional goals. These represent different modes of participation in digital learning environments, not simply different magnitudes of the same mode.

These affective findings are coherent with self-determination theory (Ryan & Deci, 2020), which holds that learning environments satisfying the three basic psychological needs for autonomy, competence, and relatedness generate intrinsic motivation and deeper cognitive processing. Andragogical instruction directly addresses all three needs: learner-selected digital tasks support autonomy, facilitated mastery experiences build competence, and peer digital collaboration fosters relatedness. Structured instruction, while optimally designed for cognitive scaffolding and the reduction of extraneous cognitive load, constrains learner agency in ways that systematically limit the autonomy-supportive conditions necessary for sustained intrinsic motivation. The ARCS model Keller (2010) further supports this interpretation: the relevance and satisfaction components of motivation, both of which are more strongly activated by personally meaningful, goal-directed learning, are inherently better served by andragogical than by structured instructional design.

Carry-Over Effects and Sequential Learning

Table 4 presents carry-over analysis results.

Table 4. Carry-Over Effect Analysis: Performance by Treatment Order (N = 15 per cell)

Condition	M (Phase 1)	SD	M (Phase 2)	SD	t(28)	p	Cohen's d
Structured Instruction	76.40	6.59	84.00	3.16	−4.03	.0004***	1.47 (large)
Andragogical Learning	78.07	5.40	84.40	3.91	−3.68	.001***	1.34 (large)

Note. ***p < .001. Phase 1 = treatment received first; Phase 2 = treatment received second. Compared by independent-samples t-test.

Significant carry-over effects were detected for both treatment conditions. Structured instruction scores were 7.60 points higher when the treatment was received in Phase 2 compared to Phase 1 (M = 84.00 vs. 76.40; t(28) = −4.03, p = .0004, d = 1.47). Andragogical learning scores were 6.33 points higher in Phase 2 (M = 84.40 vs. 78.07; t(28) = −3.68, p = .001, d = 1.34). These large effect sizes confirm that the one-week washout period was insufficient to prevent learning transfer across treatment phases, constituting a methodological limitation of the present design.

Two considerations partially mitigate the interpretive implications of these effects. First, the carry-over pattern is symmetric: neither treatment produced a significantly larger Phase 2 advantage than the other (d = 1.47 vs. d = 1.34). Had carry-over been asymmetric, it would have introduced systematic bias favouring the condition received second; the symmetric pattern confirms that the one-week washout, while not

fully effective at eliminating transfer, did not differentially distort the primary cognitive equivalence finding. Second, the symmetric carry-over itself constitutes a substantive finding: regardless of which treatment was received first, exposure to both technology-based approaches in sequence produced compounding learning gains. This complementarity suggests that the cognitive scaffolding of structured instruction and the autonomous exploration of andragogical learning may mutually reinforce each other when experienced in sequence, producing cumulative benefits beyond what either approach might achieve alone. Future research should employ longer washout periods, four weeks or more to more cleanly isolate treatment-specific effects from transfer-based learning gains.

Qualitative Insights

Observation and interview data provided contextual depth that enriched the quantitative findings. Under structured instruction, students demonstrated consistent adherence to prescribed digital learning pathways, progressing through module sequences in the designated order. Interview responses revealed that students valued the clarity and predictability of structured objectives, particularly for precision-demanding language tasks such as grammatical analysis and text reconstruction. A recurring theme was the perception of structured instruction as cognitively 'safe': the predetermined pathway minimised decision-making demands and supported sustained task completion even among students who reported lower intrinsic motivation for that condition.

Under andragogical instruction, qualitatively different behavioural patterns were consistently observed. Students actively sought resources beyond those explicitly provided, initiated peer discussions through digital communication channels without instructor prompting, and repeatedly connected learning activities to self-identified personal and professional objectives. Interview data revealed a heightened sense of ownership over the learning trajectory, with participants characterising andragogical sessions as more 'meaningful' because the content was oriented toward goals they had personally defined. This pattern is consistent with Mezirow's (1991) transformative learning theory, which identifies critical reflection and personal relevance as the conditions under which deep and lasting learning change occurs. The qualitative evidence further confirmed the engagement independence finding: students who performed most efficiently within structured digital modules were not reliably the most exploratory self-directed learners under andragogical conditions, reinforcing the interpretation of qualitatively distinct rather than simply quantitatively different engagement profiles.

Implications

The multidimensional effectiveness profile documented in this study cognitive equivalence combined with affective superiority of andragogical instruction, alongside qualitatively distinct engagement mechanisms, carries significant implications for both theory and instructional practice. Theoretically, the finding that cognitive and affective outcomes are responsive to different instructional conditions challenges approaches to effectiveness evaluation that collapse both dimensions into a single criterion measure. The large and equal cognitive gains produced by both approaches confirm that technology-enhanced language learning environments support robust knowledge acquisition regardless of whether instruction is structured or andragogical, provided that pedagogical design quality is maintained. The significantly stronger affective outcomes under andragogical conditions, however, indicate that sustained motivation and voluntary digital engagement require instructional designs that privilege learner autonomy and self-direction.

Practically, these findings argue for a hybrid instructional model that strategically deploys structured and andragogical phases according to learning objectives and course stage. Structured instruction is best suited to foundational phases in which learners require explicit scaffolding, clear progression pathways, and corrective feedback to establish basic linguistic competencies. Andragogical instruction is best deployed during integrative and creative phases, when the motivational and engagement conditions it generates promote deeper processing, voluntary application, and long-term retention. Instructors are advised to sequence structured phases in the early stages of a learning unit to build the cognitive foundations that andragogical phases can subsequently leverage through autonomous goal-directed exploration.

4. CONCLUSION

This crossover study examined the cognitive and affective outcomes of structured and andragogical technology-based instructional approaches to language learning among 30 university students, producing three evidence-based conclusions grounded in verified empirical data.

First, both instructional approaches produced statistically significant and large language proficiency gains relative to baseline: structured instruction ($d = 2.73$, mean gain = +18.67 points) and andragogical learning ($d = 2.47$, mean gain = +19.70 points). The difference between approaches was negligible ($p = .508$, $d = 0.12$), confirmed by Wilcoxon signed-rank test ($p = .600$). This establishes the cognitive equivalence of the two approaches in technology-enhanced language learning contexts.

Second, andragogical instruction produced significantly higher motivation ($d = 2.54$) and digital engagement ($d = 2.19$) than structured instruction ($p < .001$ for both). The near-zero cross-condition engagement correlation ($r = .067$) indicates that the two approaches activate qualitatively distinct engagement mechanisms, compliance-based engagement under structured instruction and exploratory engagement under andragogical learning. The pattern of cognitive equivalence coupled with affective differentiation constitutes the central theoretical contribution of this study.

Third, significant and symmetric carry-over effects in both conditions (structured $d = 1.47$; andragogy $d = 1.34$) suggest that sequential exposure to contrasting technology-based approaches generates cumulative learning benefits. While this carry-over represents a methodological limitation requiring longer washout periods in future research, it also points toward the inherent pedagogical complementarity of the two approaches when combined.

These findings collectively support the development of hybrid instructional models that deploy structured approaches for foundational cognitive scaffolding and andragogical approaches for motivationally engaging, integrative application. Future research should investigate optimal sequencing and proportioning within formalised hybrid models, employ extended washout periods to isolate treatment-specific from transfer-based gains, and determine whether the cognitive equivalence and affective differentiation patterns documented here generalise across diverse language skills, student populations, and digital platform contexts.

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