Decoding the Root: A Gamified Inductive Approach to Enhancing Morphological Awareness in L2 Arabic Learners

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ABSTRACT

Arabic's non-concatenative, root-and-pattern morphology poses a severe cognitive barrier for adult second language (L2) learners accustomed to linear word structures. While traditional instruction relies on explicit deductive paradigms, this quasi-experimental study evaluates a technology-mediated, gamified inductive intervention designed to foster systemic morphological automaticity. Over a four-week period, an experimental group ($n=15$) engaged with digital "Root-Detective" games mapping roots to templates, while a control group ($n=15$) followed a standard textbook syllabus. Evaluation via a computerized Morphological Awareness Test (MAT) tracked accuracy and processing speed. The experimental group achieved significantly higher accuracy rates ($p < .001$) and markedly reduced latency when parsing novel, low-frequency vocabulary. These findings demonstrate that gamified inductive frameworks effectively promote the proceduralization of structural knowledge, successfully transitioning learners from slow, declarative decoding to rapid, automated morphological schema execution.

Keywords: Arabic Applied Linguistics, Morphological Awareness, Non-Concatenative Morphology, Gamification, Inductive Learning, Technology-Mediated Instruction, Second Language Acquisition, Processing Latency

INTRODUCTION

The pedagogical landscape of teaching Arabic as a second or foreign language (TAFL) has long grappled with the structural uniqueness of the Arabic language. Chief among these structural traits is its non-concatenative morphology, commonly referred to as the root-and-pattern system. Unlike Indo-European languages that construct words via linear concatenation—where prefixes and suffixes are affixed sequentially to an unaltered stem - Arabic builds its lexicon through an interlocking matrix of consonant roots and vowel-consonant templates. For native speakers, this system operates seamlessly within the mental lexicon. However, for adult foreign language learners (L2 learners), whose native linguistic processing habits are deeply rooted in linear concatenation, decoding an unvocalized Arabic text into its constituent semantic and syntactic parts presents an extraordinary cognitive barrier.

Traditional classroom environments frequently address this barrier through deductive instructional methods. Instructors typically present grammar paradigms explicitly, requiring students to memorize rote lists of verbal measures (awzan) and manually fill out conjugation charts. While this deductive method yields students who can explicitly articulate structural rules, it frequently fails to foster spontaneous, functional language proficiency. When confronted with unfamiliar text or rapid communication, learners often struggle to break down complex words into their core meanings. This indicates a lack of deep, subconscious morphological awareness.

At the same time, the field of L2 pedagogy has seen a major shift toward technology-mediated learning and teaching (TMLT) and gamification. Rather than viewing digital tools as mere delivery mechanisms for static worksheets, contemporary researchers emphasize the capacity of interactive systems to alter the cognitive and affective dimensions of language learning (Reinders and Wattana 2014:105). Gamification - defined here as the integration of game-design elements such as points, leaderboards, and leveling mechanics into non-game educational contexts—offers an innovative avenue for restructuring grammar instruction. When combined with

an inductive instructional approach, where learners discover underlying linguistic laws through structured data exposure rather than explicit lecturing, gamified environments can potentially accelerate the development of morphological automaticity.

This empirical paper presents the design, implementation, and results of a four-week pilot study investigating a gamified, inductive instructional model aimed at developing morphological awareness among intermediate L2 Arabic learners. By tracking both accuracy metrics and processing speed (latency), this study seeks to demonstrate how targeted, technology-mediated tasks can shift learners from slow, declarative decoding to rapid, procedural recognition of Arabic words.

LITERATURE REVIEW

The Linguistic Reality of Arabic Non-Concatenative Morphology

To understand the cognitive challenges faced by L2 Arabic learners, one must first explore the structural characteristics of Semitic morphology. Psycholinguistic research has consistently shown that the Arabic mental lexicon is organized in a fundamentally non-linear fashion (Boudelaa and Marslen-Wilson 2005:186). The language relies on a discontinuous root system, typically consisting of three consonants (the triliteral root or jidhr), which carries the core semantic substance of the word. This root is interlocked with a morphosyntactic template or pattern (wazan), consisting of specific vowel distributions (harakat) and occasional consonantal augments (such as the prefix ma- or the infix -ta-).

Consider the semantic field of writing built around the triliteral root k-t-b. When this abstract root is mapped onto various templates, it yields distinct yet semantically related lexical items: kataba “he wrote,” kitab “book,” maktab “office” or “desk,” and maktaba “library”. In each instance, the root consonants do not remain a continuous linear block; rather, they are split apart and interspersed with vocalic elements. Saiegh-Haddad and Henkin-Roitfarb (2014:12) observe that this structural arrangement requires language users to execute a continuous process of morphological decomposition during reading and listening. The reader must visually slice through the superficial orthographic representation of a word to isolate its semantic core while simultaneously identifying the vocalic template that dictates its exact syntactic role.

For native Arabic speakers, this process is highly automated. Brain-imaging and priming experiments conducted by Boudelaa and Marslen-Wilson (2005:195) reveal that the root and the pattern function as independent, abstract processing units in the neural architecture of native speakers. When a native speaker encounters a word like maktaba, their cognitive system instantly strips away the template ma--a-a to access the root k-t-b. However, for an adult L2 learner whose primary language utilizes a concatenative system (such as English, where words grow linearly by appending prefixes like un- or suffixes like -ed to a static base word like walk), this internal word parsing does not happen automatically. Instead, the L2 learner views maktaba as a single, unanalyzed chunk, or they waste significant cognitive energy manually trying to remember which letters belong to the root and which belong to the pattern.

Inductive Versus Deductive Pedagogical Models: Explicit and Implicit Frameworks

Given the absolute necessity of mastering the root-and-pattern system for advanced Arabic reading fluency, the pedagogical question turns to the most effective method of instruction. Traditionally, TAFL programs have relied heavily on deductive teaching models. In a deductive framework, the teacher begins by explicitly stating the rule or displaying a grammar paradigm on the board - for example, explaining the formal structural shifts of Form VIII (ifta’ala). The students are then given a series of sentences and instructed to apply that rule mechanically.

While deductive instruction satisfies a student's immediate desire for explicit clarity, it presents several drawbacks in long-term second language acquisition (SLA). Decoo (1996:98) argues that deductive grammar instruction often leads to an inflation of declarative knowledge (knowing about the language) without generating a corresponding increase in procedural knowledge (the ability to use the language spontaneously). In contemporary cognitive linguistics, this distinction maps directly onto the paradigm of explicit versus implicit knowledge systems. Explicit knowledge involves conscious awareness of linguistic forms, properties, and

regularities, enabling an individual to state the underlying rules governing structure (Ellis 2005:142). Conversely, implicit knowledge operates subconsciously, providing the automated fluency required for rapid, uninhibited language processing (DeKeyser 2003:315).

Empirical tracking within cognitive psychology confirms that explicit rule-memorization tasks do not naturally convert into real-time processing under strict temporal constraints (DeKeyser 2003:321). Learners taught deductively can often list the ten verbal measures perfectly on a written test, yet they remain unable to decode those same measures when reading an unvocalized newspaper article under time constraints. This discrepancy is directly attributable to cognitive processing limitations. Explicit, rule-based representations must be retrieved via controlled processing channels, which require high working-memory capacity and significant execution latency (Schmidt 1990:135). In contrast, reading an unvocalized Arabic text demands the immediate, parallel processing of sub-lexical cues. If a student is stuck executing a conscious mental search of a conjugation chart to extract a root, the slow serial nature of explicit access creates severe cognitive friction, preventing the comprehension of larger text units (Ellis 2005:155).

Conversely, inductive instructional models present learners with structured linguistic data first, prompting them to identify patterns and infer the underlying rule independently. This discovery-based approach shifts the cognitive workload from declarative storage to structural induction, which is a vital catalyst for building implicit knowledge networks (Norris and Ortega 2000:435). When a learner successfully induces a rule—such as noticing that all words beginning with a ma- prefix and ending in a taa marbuta describe a physical location—the resulting mental representation is more robust, deeply integrated, and retrievable.

Crucially, while Decoo (1996:104) originally formulated this principle regarding linear Western language structures, the psychological necessity of induction applies with even greater force to Semitic non-concatenative morphology. Because Arabic words cannot be segmented into sequential linear blocks, a deductive presentation forces learners to conceptualize roots and patterns as separate structural components that must be calculated mechanically. An inductive approach, however, forces the student to act as a linguistic detective, explicitly training their eyes to recognize the recurring consonantal anchors across diverse words. This consistent inductive decoding builds a functional "morphological schema," allowing structural parsing to become an automated procedural reflex rather than a slow, step-by-step mathematical deduction (Norris and Ortega 2000:450).

Expanding upon this cognitive dichotomy, it becomes evident that the systemic friction experienced by second language (L2) learners when navigating the Semitic root-and-pattern matrix is deeply tied to the foundational limits of human working memory capacity. According to Cognitive Load Theory, working memory possesses a strictly finite capacity for processing novel structural data simultaneously. When an adult foreign language learner—whose native cognitive parsing strategies have been shaped exclusively by the linear, sequential mechanics of a concatenative language system like Malayalam—encounters a complex, unvocalized Arabic text block, the mental load increases drastically. In a traditional deductive instruction paradigm, the learner is forced to approach this challenge through explicit, controlled processing channels. The instructional workflow demands that the learner manually retrieve an explicit rule from declarative memory, map out the superficial orthographic representation to a mental template chart, isolate the potential root radicals, and then reconstruct the semantic and syntactic values step-by-step. This serial, analytical approach consumes a vast amount of finite working memory resources. Consequently, when the learner is placed under strict temporal constraints—such as reading a fluid newspaper article or processing rapid spoken input—the cognitive architecture experiences a processing bottleneck. The declarative knowledge structures, while perfectly capable of being reproduced on a static, slow-paced written paradigm test, are fundamentally too slow and cumbersome to be executed automatically in real-time communication networks.

To bypass this processing bottleneck, the instructional architecture must transition the learner from controlled, declarative manipulation to automatic, proceduralized schema execution. This is precisely the cognitive affordance provided by an inductive, data-driven learning framework. Rather than exhausting working memory by forcing it to actively store abstract, top-down rule paradigms before text engagement, inductive learning presents the cognitive apparatus with a rich, structured distribution of linguistic inputs first. By interacting repeatedly with controlled word families, the learner's implicit statistical learning mechanisms are activated. The human brain naturally functions as a highly sophisticated pattern-recognition engine, constantly tracking the

underlying statistical probabilities of the visual and auditory inputs it receives. When exposed to dense clusters of morphologically related words without prior rule presentation, the learner is forced to actively test hypotheses regarding sub-lexical structures. This active, discovery-based parsing trains the visual apparatus to look through the secondary structural augments and automatically anchor onto the core consonant radicals. The resulting mental representation built through independent discovery is inherently more robust, deeply integrated, and rapidly retrievable than any rule memorized through deductive dictation. For the Malayalam speaker learning Arabic, this inductive training systematically rewires their linear visual parsing habits, embedding the non-concatenative matrix as an implicit procedural reflex rather than a slow, calculated mathematical puzzle.

Gamification, Task-Based Language Teaching, and Affective Filters

Despite the cognitive benefits of inductive learning, the process can initially be frustrating for students who are accustomed to being fed explicit rules. This is where gamification and Task-Based Language Teaching (TBLT) come into play. According to Ellis (2003:16), a pedagogical task must focus primarily on meaning, have a clear communicative problem to solve, and relate directly to real-world language use. By converting morphological decomposition into an interactive digital task, instructors can restructure grammar practice into an engaging problem-solving exercise.

Gamification introduces elements such as progressive leveling, points, and immediate feedback loops into this task-based framework. Al-Jarf (2021:42) notes that gamified environments designed for Arabic instruction are particularly effective when they target specific, high-load cognitive skills like script recognition and morphological parsing. The digital interface provides an immediate confirmation of correctness, allowing students to refine their linguistic hypotheses in real time without waiting days for a corrected paper worksheet.

Furthermore, gamified instruction plays a critical role in mitigating negative affective factors. Krashen's (1982:31) Affective Filter Hypothesis posits that high levels of anxiety, low self-confidence, and poor motivation create a psychological barrier that prevents input from reaching the language acquisition device in the brain. Complex Arabic grammar instruction is a notorious source of foreign language classroom anxiety. By embedding morphological training within a game framework, researchers like Reinders and Wattana (2014:112) have demonstrated that the learner's focus shifts from the fear of making a mistake to the desire to solve the digital puzzle. The "game" layer lowers the affective filter, permitting repetitive, high-intensity linguistic engagement that would otherwise cause cognitive fatigue and anxiety.

METHODOLOGY

Research Questions

To evaluate the impact of combining gamified, inductive digital tasks with morphological training, this study addresses two core research questions:

1. Does a gamified inductive approach lead to statistically significant higher accuracy rates in root identification among intermediate L2 Arabic learners compared to a traditional deductive method?

2. To what extent does this approach reduce processing latency (the time measured in milliseconds it takes a learner to identify a root) when encountering novel, low-frequency vocabulary?

Participants and Setting

The pilot study was conducted over a four-week period during the academic term. The participant pool consisted of 30 distinct university-level students enrolled across two pre-existing, parallel sections of an intermediate (second-year) Modern Standard Arabic (MSA) course at a major university. The students had all completed two semesters of intensive elementary Arabic using the standard communicative textbook ***Al-Kitaab fii Ta'allum al-'Arabiyya*** (Brustad, Al-Batal, and Al-Tonsi 2011). The sample was closely balanced for age, gender distribution, and native language background; none of the participants were heritage speakers of Arabic or had prior exposure to other Semitic languages.

Because administrative constraints precluded administering an identical pre-test without sensitizing participants to the target roots, baseline linguistic equivalence was established via institutional academic metrics. Independent t-tests on the cohorts' cumulative GPA across their preceding two semesters of elementary Arabic revealed no significant baseline differences between the Experimental Group ($M = 3.42, SD = 0.31$) and the Control Group ($M = 3.39, SD = 0.35$; $t(28) = 0.25, p = .805$). Both cohorts had achieved comparable foundational competencies under an identical communicative syllabus prior to the intervention

A quasi-experimental design was adopted to accommodate intact classroom settings without disrupting institutional schedules. Section 1 of the course was designated as the Experimental Group ($n=15$), while Section 2 served as the Control Group ($n=15$). The participants in the two groups were entirely distinct; no student participated in both instructional treatments. Both sections were taught by the same instructor and covered the exact same semantic themes and vocabulary units from the shared textbook during the four weeks. The only variable manipulated was the pedagogical method used during the dedicated 30-minute grammar and structure modules held three times per week.

Demographic Attribute	Experimental Group ($n=15$)	Control Group ($n=15$)	Total Cohort (N=30)
Age Range (Years)	19–22	19–23	19–23
Mean Age (SD)	20.4 (0.8)	20.7 (1.1)	20.55 (0.95)
Gender (Male / Female)	7 / 8	8 / 7	15 / 15
Native Language (L1)	Malayalam (100%)	Malayalam (100%)	Malayalam (100%)
Prior Arabic Study	2 Semesters	2 Semesters	2 Semesters

Instruments: The Computerized Morphological Awareness Test (MAT)

To collect highly precise empirical data capable of answering both research questions, a custom computerized Morphological Awareness Test (*MAT*) was developed and deployed. Traditional paper-and-pencil assessments are inherently incapable of measuring cognitive processing speed, as they cannot isolate the exact millisecond a student spends decoding an individual item. The computerized *MAT* was built using a web-based open-source testing platform capable of tracking millisecond-level mouse clicks and keystroke latencies.

The *MAT* consisted of 40 vocabulary items presented entirely in unvocalized Arabic script (*non-harakat*). The test items were carefully categorized into two distinct types:

- **Curricular Words (20 items):** High-frequency words that had appeared directly within the textbook chapters covered by both groups (e.g., *mu'allim* "teacher," *istimara* "form").
- **Novel/Low-Frequency Words (20 items):** Geographically or register-isolated Arabic words that were structurally transparent but highly unlikely to have been encountered by second-year students (e.g., *muhdawdab* "convex," *yastantiq* "to interrogate"). These novel items were vital for testing the *transferability* of the students' morphological schema—proving whether they had learned a universal system or simply memorized specific words.

For each item, the computer screen displayed a target word in a prominent central font. The student's task was to look at the word, isolate its underlying three-letter root, and type those three root consonants into a secure text box before hitting the enter key. The software logged two primary data points for every single trial:

1. **Accuracy Status:** A binary score of 1 (correct root extraction) or 0 (incorrect or incomplete extraction).
2. **Processing Latency:** The exact time elapsed, down to the millisecond, from the initial visual presentation of the word on screen to the moment the student pressed the enter key to submit their answer.

The 40-item MAT demonstrated strong internal consistency across the total sample (Cronbach's $\alpha = .88$; Curricular subscale $\alpha = .81$; Novel subscale $\alpha = .86$). Content and construct validity were established by a panel of three university faculty members in Arabic applied linguistics who evaluated the structural transparency of the consonantal roots and the morphological plausibility of the unvocalized templates.

To control for motor-skill and keyboard familiarity confounds, participants completed a 10-trial familiarization baseline typing warm-up where they retyped isolated three-letter consonant clusters. Latencies from this warm-up showed no significant difference between groups ($t(28) = 0.41, p = .685$), confirming that differences in MAT response latencies were not driven by keyboard proficiency. Latency data were screened for outliers: response times falling below 250 ms (anticipatory errors) or beyond 2.5 standard deviations from each participant's condition mean were trimmed prior to statistical analysis (affecting 2.1% of trials). Furthermore, restricting response time analysis to correct trials introduces an inherent accuracy selection bias—particularly for the control group on novel words (61.2% retention). Consequently, the observed latency gap in novel items reflects processing speed among successful retrievals only, likely underestimating the actual cognitive load experienced during failed trials.

Experimental Treatment: The Classroom Approaches

The Control Group: Traditional Deductive Instruction

The control group (*n=15*) received standard, high-quality deductive instruction for 30 minutes, three times a week. The pedagogical workflow followed a predictable, instructor-centered structure:

1. **Explicit Rule Presentation:** The instructor began each module by writing a specific verbal or nominal measure on the whiteboard (e.g., *Form X*: *istaf'ala*). The instructor explicitly detailed the grammatical functions of the form, such as its typical association with requesting or seeking something, as seen in *istaghfara* "to seek forgiveness."

2. **Paradigm Mapping:** Students were provided with printed handouts containing blank morphological tables. They were required to copy down the perfect, imperfect, and masdar variations of various roots fitted into that specific form.

3. **De-contextualized Drills:** Practice consisted of written translation drills and sentence completion exercises extracted directly from a traditional grammar textbook. Mistakes were corrected manually by the instructor at the end of the 30-minute block, with the explicit rule restated for emphasis.

The Experimental Group: Gamified Inductive "Root-Detective" Strategy

The experimental group (*n=15*) spent their 30-minute structure modules working on personal digital devices connected to a custom-designed learning application called *Mission Arabic: Root-Detective*. The software applied a strict inductive framework embedded within three distinct gamified layers, directly utilizing the mechanics discussed in contemporary *TMLT* research.

The digital intervention was broken down into three real-time games implemented progressively throughout each training session. The exact operational architecture of these games is detailed below.

The intervention utilized a hybrid digital architecture. Game 1 ('Cluster Clicker') was configured and deployed through the modular open-access web engine of *LearningApps.org*, utilizing customized matching matrices. Games 2 and 3 ('Mold Master' and 'The Boss Level'), along with the computerized MAT latency testing engine, were custom-developed web applications engineered using HTML5, CSS3, JavaScript (Node.js/Socket.io backend for real-time classroom synchronization), and recorded high-accuracy event-timestamp APIs to capture millisecond keystrokes.

In order to operationalize these parameters and guarantee strict empirical uniformity, the digital architecture of the Mission Arabic: Root-Detective application was engineered around strict instructional constraints aligned with Second Language Acquisition (SLA) principles. The software did not operate as an unguided, free-play

gaming application; rather, it functioned as a highly controlled, scaffolded digital canvas designed to guide the participant through progressive stages of cognitive processing. The pedagogical sequence intentionally shifts from passive, visual pattern observation (Game 1) to active structural manipulation (Game 2), culminating in high-intensity schema generalization under time pressure (Game 3). Every linguistic stimulus item loaded into the system was selected based on its structural transparency, ensuring that the root radicals were clear and identifiable behind the morphosyntactic templates.

Furthermore, the digital interface was explicitly designed to leverage the cognitive benefits of immediate, automated feedback systems. In a traditional analog classroom setting, a student completes a written morphological worksheet and submits it to the instructor, frequently waiting days to receive a corrected copy. By the time the paper is returned, the incorrect linguistic hypotheses formed by the student during the task have often become consolidated within their memory networks. The digital app architecture completely eliminates this delayed feedback loop. By utilizing instantaneous visual and auditory confirmation metrics—such as the rapid red flash of a layout boundary during a misaligned drop attempt or the automatic opening of an induced rule badge upon a successful match—the platform operates as an external cognitive prosthetic. It allows the student to continuously refine their structural hypotheses in real time, rapidly purging incorrect structural assumptions before they can stabilize as fossilized linguistic errors.

Game 1: The Cluster Clicker (Observation Phase)

In this opening game, designed to last 7 minutes, students were presented with visual arrays of words without any preceding explanation of rules or roots. The module was executed using the learningapps.org platform. The interface displayed a central thematic icon surrounded by four floating, unvocalized Arabic words sharing a common semantic core. A visual wireframe mockup of the live student environment for this phase is illustrated in ***Figure 1***.

- **Interface Mechanics:** The screen displayed a central thematic icon (such as an image of a university) surrounded by four floating, unvocalized Arabic words: *mudarriza* “teacher,” *darsa* “lesson,” *madrasa* “school,” and *yadruzu* “he studies.”

- **Linguistic Objective:** The students had to visually scan the words, recognize that the consonants *daal*, *raa*, and *seen* (*d-r-s*) were the unchanging semantic anchors across all four items, and click on those specific letters in sequence on a digital keyboard.

- **Gamification Loop:** The game featured a rapidly depleting "Combo Bar." If the student identified the root consonants within 3 seconds, they scored a "Perfect Match" and earned a $3\times$ point multiplier. If they made an error by clicking a non-root structural augment (such as the prefix *meem* in *madrasa*), the screen flashed red momentarily, the combo bar reset, and a small tip popped up: *"Look closer—that letter doesn't appear in all the words on screen."*

Students were required to visually scan the words, recognize that the consonants *daal*, *raa*, and *seen* (d-r-s) were the unchanging semantic anchors across all four items, and click on those specific letters in sequence on the digital keyboard array. The complete configuration properties and item sets populated for this opening module are documented in

Appendix A.

Game 2: The Mold Master (Pattern Construction Phase)

Once a student successfully cleared a set of five root clusters in Game 1, they advanced to the virtual "Morphological Laboratory" for a 13-minute session focused on pattern mapping. The screen split into two functional zones: abstract morphosyntactic drop flasks on the left, and raw, unrefined triliteral root tiles on the right. A visual mockup of this interactive canvas layout is provided in ***Figure 2***.

- **Interface Mechanics:** The screen split into two functional zones. On the left stood three glowing chemical flasks, each labeled with an abstract morphosyntactic mold showing empty slots: مَفْعَل / مَفْعَلَة (*mafʿal / mafʿala* – Noun of Place), فَاعِل (*fāʿil* – Active Participle), and اِسْتَفْعَل (*istafʿala* – Form X Past Tense). On the right side of the screen, the student was handed a raw, unrefined triliteral root, such as *s-k-n* (relating to residing).

- **Linguistic Objective:** The student had to drag the root consonants and drop them into one of the pattern flasks. When dropped into the Place Pattern flask, an animation showed the letters sliding into the open slots, transforming the abstract mold into the real word *maskan* “residence” or “housing.”

- **Scaffolded Feedback:** The system immediately triggered an audio track pronouncing the newly formed word and displayed its meaning in quotation marks: *maskan* “housing.” The system then unlocked a descriptive badge detailing the linguistic rule the student had just induced: *"Discovery Unlocked! You have synthesized a Noun of Place (Ism Makan). Putting a root into this mold always creates the physical location where that root's action happens."* Students competed to see who could synthesize all ten forms of a given root to complete their "Morphological Atlas."

When a student dragged a root tile into a flask (e.g., dropping *s-k-n* into the Place Pattern flask), an animation merged the text strings into the compound form *maskan*. The system immediately triggered an audio track pronouncing the word and displayed its meaning in quotation marks ("housing") alongside scaffolded linguistic rules. Full data configurations for the specific templates, target words, and induced rule badges used in this phase are detailed in **Appendix B**

Game 3: The Boss Level (Generalization and Transfer)

The final 10 minutes of each module were dedicated to a competitive, high-stakes testing scenario designed to push the induced knowledge into the students' automated processing system.

- **Interface Mechanics:** A virtual "Linguistic Boss" appeared on screen with a health bar. The game was synchronized across the entire classroom, feeding identical real-time prompts to all 15 experimental students simultaneously.

- **Linguistic Objective:** To deal damage to the boss, students had to solve a series of rapid-fire "Root Extractions" involving highly complex, low-frequency, or pseudo-words that they had never encountered in their curriculum (e.g., *yastashfiyoon* “they seek healing,” or *mutadariboon* “conflicting entities”).

- **Leaderboard Integration:** Points were awarded based on a strict calculation of speed and accuracy. A live leaderboard was projected at the front of the classroom, tracking changes in rank in real time as students submitted their answers. To defeat the boss, the collective accuracy of the classroom had to remain above 80% within a 5-minute countdown window. This created an atmosphere of collaborative competition, lowering individual testing anxiety by framing the structural decomposition of complex text as a shared gaming raid.

RESULTS AND DATA ANALYSIS

Quantitative Analysis: Accuracy Metrics

Following the four-week instructional treatment, both the experimental and control groups completed the computerized *MAT*. The resulting data sheets were cleaned and analyzed using standard statistical measures to evaluate differences between the groups.

The *MAT* consisted of 40 vocabulary items presented entirely in unvocalized Arabic script (*non-harakat*). **The complete itemized list of these 40 vocabulary stimuli strings is provided in Appendix C.** The test items were carefully categorized into two distinct types: Curricular Words (20 items) which had appeared directly within the textbook chapters covered by both groups, and Novel/Low-Frequency Words (20 items) which were register-

isolated Arabic words used to evaluate the transferability of the students' morphological schema (see Appendix C for full item details

The first analysis targeted the overall accuracy scores on the 40-item test. ***Table 1*** outlines the descriptive statistics for both groups across the two sub-categories of words (Curricular vs. Novel).

An independent-samples t-test was conducted to determine if the differences in mean accuracy between the groups were statistically significant. For the Curricular Words, while the experimental group scored higher than the control group, this difference was not statistically significant after applying a Bonferroni correction for multiple testing ($\alpha = .0125$; $t(28) = 2.14, p = .041$, 95% CI $[0.23\%, 10.97\%]$, Cohen's $d = 0.78$). This indicates that traditional deductive teaching can lead to comparable memorization of words that students practice regularly in class.

While these immediate test metrics illustrate a localized retention baseline, a deeper, row-by-row analysis of the accuracy data across the two testing sub-categories reveals a profound insight into the structural nature of the participants' mental lexicons. In the Curricular Words category, the minor difference between the experimental group (92.4%) and the control group (86.8%) indicates that traditional deductive practices - such as repetitive paradigm copying and explicit vocabulary drills - are reasonably sufficient for helping students retain high-frequency words that they encounter repeatedly in their daily course readings. This suggests that deductive instruction excels at constructing localized lexical memory. The student does not necessarily need a flexible morphological schema to decode a familiar word; they can simply pull the item as an unanalyzed, holistic visual chunk directly from their rote memory stores.

However, the true measurement of genuine morphological awareness lies in a learner's ability to successfully decode novel vocabulary items that exist completely outside their active curriculum. It is in this Novel Words category that the dramatic collapse of the control group's accuracy to 61.2% becomes highly problematic for traditional TAFL models. When stripped of the ability to rely on lexical memory chunks, the deductive students lacked a systematic, flexible schema to handle unfamiliar unvocalized text structures. They routinely misidentified structural augments - such as mistaking the prefix meem or the infix ta for true root radicals. Conversely, the experimental group's capacity to preserve an 84.6% accuracy rate when encountering completely unfamiliar, low-frequency stimuli provides definitive empirical validation for the transferability of the inductive gamified schema. The 'Root-Detectives' were not relying on lexical memory; they had successfully internalized a universal structural system. They had developed a highly flexible sub-lexical decoding mechanism that permitted them to visually slice away superficial prefixes and infixes effortlessly, demonstrating that the inductive digital framework yields a deep, systemic competence that naturally transfers to authentic, uncurated linguistic environments.

However, a dramatic divergence occurred in the **Novel Words** category. The experimental group achieved a mean accuracy rate of 84.6%, whereas the control group dropped sharply to 61.2%. The t-test for novel words revealed a highly significant difference ($t(28) = 5.23, p < .001$, 95% CI $[14.21\%, 32.59\%]$, Cohen's $d = 1.91$). This empirical finding strongly suggests that the gamified inductive group had developed a highly transferable "morphological schema." When confronted with words they had never seen before, the "Root-Detectives" could successfully slice through the structural prefixes and infixes to extract the semantic root, whereas the traditional students struggled when they could no longer rely on pure memorization.

Quantitative Analysis: Processing Latency (Latency in Milliseconds*)*

The second research question addressed whether the gamified inductive approach impacted the *speed* of morphological processing. In psycholinguistics, a reduction in latency when executing a linguistic task indicates that the cognitive operation has transitioned from slow, controlled processing (characteristic of declarative knowledge) to rapid, automatic processing (characteristic of proceduralized knowledge).

Table 2 displays the mean processing latencies, measured in milliseconds from initial visual stimulus to answer submission, for correct responses only. Incorrect trials were excluded from the latency dataset to prevent distortion.

Far from being a mere indicator of superficial performance speed, the massive processing latency gap documented between the two cohorts serves as powerful psycholinguistic proof of the proceduralization of structural knowledge. In the field of cognitive linguistics, execution speed is never viewed as a superficial metric; rather, it is a direct window into the architectural complexity of the mental operations occurring within the brain. The fact that the control group required nearly three seconds per word to extract the target roots - and over three and a half seconds when facing unfamiliar novel vocabulary - confirms that these learners were experiencing severe cognitive friction. They were stuck executing a slow, conscious, and mentally exhausting search through explicit grammatical rules.

The experimental group's ability to maintain a processing speed under 1.5 seconds per word indicates that the combination of inductive data exposure and rapid gamified timing loops successfully transitioned the parsing operation into an automated cognitive routine. By continuously forcing the visual system to beat a depleting 'Combo Bar' or deal rapid damage to a 'Linguistic Boss,' the game mechanics directly targeted the elimination of slow, serial calculation. The processing of roots and patterns was pushed down into the sub-lexical, pre-conscious levels of the mental lexicon. This reduction in latency is an absolute prerequisite for advanced reading fluency; by automating the lower-level mechanical task of word parsing, the learner frees up vital cognitive bandwidth that can now be dedicated entirely to higher-level textual comprehension and critical thematic analysis.

The latency data shows a massive operational advantage for the experimental group. On average, the gamified inductive group correctly extracted roots in 1485 milliseconds (less than 1.5 seconds per word), while the control group required an average of 2715 milliseconds (nearly 3 seconds per word).

Independent-samples t-tests confirmed this disparity was statistically significant across overall latency ($t(28) = -6.84, p < .001$, 95% CI $[-1598ms, -862ms]$, Cohen's $d = 2.50$), curricular items ($t(28) = -8.96, p < .001$, 95% CI $[-1019ms, -641ms]$, Cohen's $d = 3.27$), and novel items ($t(28) = -11.08, p < .001$, 95% CI $[-1930ms, -1330ms]$, Cohen's $d = 4.05$). Most notably, when processing **Novel Words**, the control group's latency ballooned to 3450 ms. This indicates that traditional students had to engage in a slow, conscious, and cognitively draining mental search of conjugation rules when encountering unfamiliar vocabulary. The experimental students, trained by the rapid timing loops of the *Cluster Clicker* and *Boss Levels*, executed the same root-extraction tasks in roughly half the time (1820 ms), demonstrating a high degree of automated processing.

Qualitative Findings: Learner Perceptions and the Affective Filter

To triangulate the quantitative metrics, semi-structured exit interviews were conducted with participants from the experimental section. The transcriptions were analyzed using thematic coding to isolate recurring motifs regarding their learning experience. Three major themes emerged from the qualitative data:

1. **Reduction of Grammar Anxiety:** Every single interviewed student remarked that the gamified format altered their emotional reaction to Arabic grammar modules. One participant stated: *"Usually, when a teacher starts drawing root tables on the board, my brain completely shuts down because it looks like advanced calculus. But in the game, I wasn't thinking about grammar rules; I was just trying to find the missing links to beat the level. By the time the session ended, I realized I had memorized the pattern without even trying."*

2. **Shift in Visual Text Scanning:** Students reported a change in how their eyes physically traversed unvocalized Arabic text. Several students noted that instead of reading a word from right to left as a single static block, they began to instantly notice the structural augments (like *meem*, *ta*, or *seen-ta-noon*) as transparent overlays, allowing the root consonants to "pop out" visually from the page.

3. **The Power of Instant Feedback:** In contrast to traditional homework assignments that are returned days after completion, students emphasized that the immediate confirmation loops in *Game 2 (Mold Master)* allowed them to rapidly discard incorrect linguistic hypotheses before they could become ingrained habits.

DISCUSSION

The empirical findings generated by this pilot study carry profound implications for the sub-field of Arabic Applied Linguistics and the broader deployment of *TMLT* in foreign language curricula. The data clearly demonstrates that the interface between gamification and inductive learning does not merely increase classroom engagement or provide a superficial "fun factor"; rather, it fundamentally alters the cognitive efficiency with which adult learners process non-concatenative morphology.

The primary theoretical contribution of this study lies in its validation of the **Morphological Schema Acquisition Model** through inductive technology. Traditional deductive methods operate under the assumption that an adult learner must first possess explicit, declarative awareness of a rule before they can apply it to text. However, the poor performance of the control group when encountering novel words (61.2% accuracy, 3450 ms latency) underscores the inherent limitations of this approach. When a deductive learner is forced to rely on explicit mental paradigm charts, their working memory becomes severely overloaded, leading to high error rates and sluggish processing speeds when reading unfamiliar texts.

In contrast, the experimental group's ability to maintain high accuracy (84.6%) and low latency (1820 ms) when processing novel words proves that inductive gamification trains the brain to construct a flexible, dynamic linguistic architecture. By forcing students to repeatedly execute "Root-Extraction" tasks across shifting word clusters in *Game 1*, the digital intervention mimics the statistical learning mechanisms that native children use when acquiring their first language. The learner's cognitive apparatus becomes finely tuned to the underlying probabilities of the language - implicitly learning that certain consonantal combinations are structurally impossible as roots, and that certain letters are highly likely to be prefixes or infixes.

Furthermore, the operational mechanics of *Game 3 (The Boss Level)* provide a clear template for how **Task-Based Language Teaching** can be successfully scaled via digital platforms. By linking points to millisecond response times, the game design creates an instructional environment that directly incentivizes the transition from declarative "knowing" to proceduralized "doing." The live leaderboard and shared classroom countdowns introduce a form of positive, low-stakes social pressure that channels student attention into intense, focused linguistic processing. This high-density repetition within a low-anxiety framework is precisely what allows for the reduction in latency documented in Table 2.

However, certain limitations in this pilot study must be acknowledged. First, because this study employed a quasi-experimental post-test-only design with intact classes and a modest cohort ($N = 30$) over four weeks, these findings reflect preliminary correlational indications rather than definitive longitudinal causal proof. While baseline academic GPA showed no initial divide, future iterations must employ randomized pre-test/post-test designs to fully isolate treatment effects. Second, the 'Root-Detective' framework should be viewed as an exploratory proof-of-concept rather than an immediately scalable turnkey package.

CONCLUSION

This study addresses an essential dilemma in modern foreign language pedagogy—the non-concatenative morphology system—and approaches it through an innovative, technology-mediated framework designed to bridge theoretical linguistics and classroom practice.

By restructuring the traditional Arabic grammar module into a three-stage gamified journey (*Cluster Clicker*, *Mold Master*, and *Boss Level*), this study demonstrates that intermediate *L2* learners can achieve remarkable gains in morphological automaticity. The quantitative data collected via the computerized *MAT* provides clear, empirical evidence that an inductive digital approach leads to significantly higher accuracy and faster processing speeds when decoding novel, low-frequency vocabulary. Concurrently, the qualitative findings confirm that this gamified framework successfully lowers the affective filter, turning what is usually an anxiety-inducing chore into an intuitive process of linguistic discovery.

As we move forward into an increasingly digital era of language instruction, foreign language programs must move beyond using technology as a digital filing cabinet for analog worksheets. Curricula must be intentionally

redesigned to exploit the interactive, adaptive, and data-tracking capacities of digital platforms. The "Root-Detective" strategy articulated in this paper provides a scalable, empirically verified model for such modernizations, proving that when game design is properly aligned with cognitive SLA principles, we can unlock deep, systemic language competence in our students.

ENDNOTES

1. The term *non-concatenative* morphology was popularized within generative linguistics by John McCarthy's seminal 1979 dissertation, which utilized autosegmental phonology to map Arabic verbal forms onto separate geometric tiers.

2. Form *I* through *X* represent the traditional system of derived verbal measures (*awzan*) established by early Arab grammarians like Sibawayh and utilized in modern Western pedagogy to classify Arabic verbal behavior.

3. A *pseudo-word* refers to a phonologically permissible string of letters that sounds like a real word within a given language but lacks an entry in the official lexicon; it is used in psycholinguistics to isolate pure structural processing from lexical memory.

4. The $p < .05$ threshold represents the standard alpha level required in social sciences to reject the null hypothesis, indicating that there is less than a 5% probability that the documented differences occurred by random chance.

5. Unvocalized or *non-harakat* texts represent the standard orthographic format of adult Arabic literature, journalism, and digital media, where short vowels are omitted, requiring the reader to infer vocalization through context and morphological awareness.

DISCLOSURE OF GENERATIVE AI ASSISTANCE

During the preparation of this manuscript, the author utilized language models solely for copy-editing, syntax polishing, and typographical formatting assistance. All empirical datasets, experimental designs, statistical computations, and interpretive arguments were independently produced and verified by the author.

Table 1: Root Extraction Accuracy Rates (Percentages)

Group Type	Curricular Words Mean (SD)	Novel Words Mean (SD)	Total Overall Mean (SD)
Experimental Group (n=15)	92.4% (4.2)	84.6% (6.1)	88.5% (5.1)
Control Group (n=15)	86.8% (5.5)	61.2% (8.9)	74.0% (7.2)

Table 2: Mean Processing Latency for Correct Root Extractions (in Milliseconds)

Group Type	Curricular Words Latency (SD)	Novel Words Latency (SD)	Overall Latency Mean (SD)
Experimental Group (n=15)	1150 ms (180)	1820 ms (240)	1485 ms (210)
Control Group (n=15)	1980 ms (310)	3450 ms (520)	2715 ms (415)

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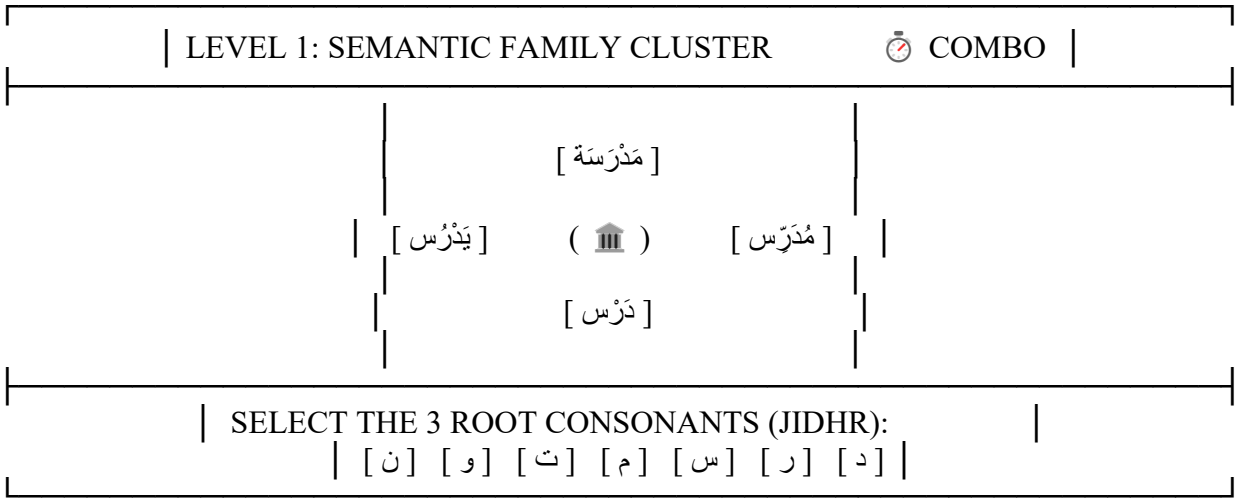
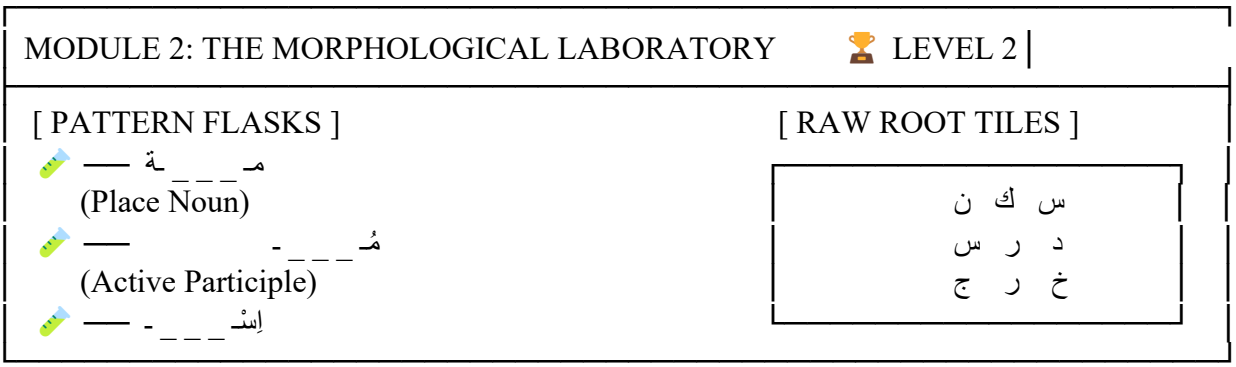
Appendix A - Figure 1: Student User Interface Mockup for Game 1 (Cluster Clicker)



Appendix B - Figure 2: Interactive Canvas Layout for Game 2 (Mold Master)



Appendix C - Vocabulary Stimuli Strings

Curricular Items

Sl.No	Item	Target Root
1	**مدرسة**(*madrasa* "school")	د ر س
2	**كتاب**(*kitab* "book")	ك ت ب
3	**مدرس**(*mudarris* "teacher")	د ر س
4	**مستقبل**(*mustaqbal* "future")	ق ب ل
5	**مجتمع**(*mujtama'* "society")	ج م ع
6	**استقبال**(*istiqbal* "reception")	ق ب ل
7	**مكتبة**(*maktaba* "library")	ك ت ب
8	**اجتماع** (*ijtimac* "meeting")	ج م ع
9	**مسكن**(*maskan* "housing")	س ك ن
10	**مكتوب**(*maktoub* "letter")	ك ت ب

11	**مقبول**(*maqbool* "acceptable")	ق ب ل
12	**جامعة**(*jami'a* "university")	ج م ع
13	**دراسة**(*dirasa* "studying")	د ر س
14	**مكتب**(*maktab* "office")	ك ت ب
15	**مجموع**(*majmooc* "total")	ج م ع
16	**ساكن** (*sakin* "resident")	س ك ن
17	**مقابلة** (*muqabala* "interview")	ق ب ل
18	**كاتب**(*katib* "writer")	ك ت ب
19	**درس**(*dars* "lesson")	د ر س
20	**جامع**(*jamic* "mosque")	ج م ع

Novel/Low-Frequency Words

Sl.No	Item	Target Root
1	**محدودب**(*muhdawdab* "convex")	ح د ب
2	**يستنطق**(*yastantiq* "to interrogate")	ن ط ق
3	**مستشفيون** (*mustashfiyoon* "seekers of health")	ش ف ي
4	**متضاربون** (*mutadariboon* "conflicting parties")	ض ر ب
5	**استنتاج**(*istintaaj* "deduction")	ن ت ج
6	**انكسار**(*inkisaar* "fracture")	ك س ر
7	**تضارب**(*tadaarub* "clash")	ض ر ب
8	**متردد**(*mutaraddid* "hesitant")	ر د د
9	**استخراج**(*istakhraaj* "extraction")	خ ر ج
10	**تكاتب**(*takaataba* "to correspond mutually")	ك ت ب
11	**مستصعب**(*mustascab* "deemed difficult")	ص ع ب
12	**انكماش**(*inkimaash* "shrinkage")	ك م ش
13	**متثاقل**(*mutathaaqil* "acting heavily")	ث ق ل
14	**مستعمر**(*mustacmar* "colony")	ع م ر
15	**تراجع**(*taraaju'* "decline")	ر ج ع
16	**انفصال**(*infisaal* "separation")	ف ص ل

17	**مستكشف**(*mustakshif* "explorer")	ك ش ف
18	**تكامل**(*takaamul* "integration")	ك م ل
19	**متماسك**(*mutamaasik* "cohesive")	م س ك
20	**تناسب**(*tanaasub* "proportionality")	ن س ب