Enhancing Handwriting Proficiency in Dysgraphic Students: Development and Validation of a Technology-Assisted Model

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Abstract—**Dysgraphia is a learning disability that makes writing and handwriting much more difficult. Traditional remediation methods that target only single aspects, such as motor skills or letter tracing, do not capture the multi-dimensional nature of this disability. This research aims to propose and validate a new intervention framework, the Dysgraphic Children Handwriting Model (DCHM), that consists of three principles: visualization, imagination, and automation. A mixed-methods approach was employed; the study focused on 50 dysgraphic students (age 8–12 years) whose handwriting quality was evaluated pre- and post-intervention through the Handwriting Legibility Scale (HLS). The DCHM is based on interactive, technology-assisted prototype applications that provide animated guidance on letter formation, timely feedback, and gamified activities to improve literacy engagement. Results revealed substantial improvements: 63.0% in alignment, 60.7% in letter formation, and 58.6% in overall legibility. Qualitative results included increased student motivation, decreased frustration, and greater confidence around writing tasks, backed up by positive teacher feedback validating the model's usability and scalability. These findings underscore the DCHM's efficacy as a comprehensive, scalable solution for dysgraphia. By bridging cognitive, motor, and visual strategies, this research contributes to the field of special education, paving the way for further exploration of adaptive technologies to support diverse learning needs.**

Keywords—**dysgraphia, handwriting proficiency, visualization, imagination**

I. Introduction

Handwriting is essential for students to express concepts, synthesize thoughts, and engage in learning. Despite the ubiquitous use of digital tools in modern education, handwriting plays a powerful function, particularly in early education, assessments, and note-taking. For students who experience dysgraphia, however, writing presents a real challenge. It reflects on their academic success and self-esteem [1–3].

Dysgraphia is a specific learning disability characterized by extreme challenges with the physical act of writing, such as poor handwriting, poor letter shapes, and an irregular writing speed. These are frequently caused by deficiencies in motor skills, memory, and cognitive processes that interfere with the seamless execution of the writing task. Dysgraphia impedes students from completing their schoolwork and academic tasks, leading to deflation of confidence, frustration, or withdrawal from social interactions altogether [4]. Although dysgraphia has a profound impact, its prevalence remains underdiagnosed, and many of the intervention strategies typically focus on isolated areas of the disorder rather than addressing the more global, interconnected problems [5, 6].

These approaches rarely use the kind of effective, individualized strategies that students with dysgraphia need. While technological advancements hold promise in supporting students with learning disabilities, solutions specifically developed to address the complexities of dysgraphia are limited [7, 8]. Current handwriting application solutions primarily utilize their own isolated component (such as letter tracing and writing in the air), ignoring the integrated process of cognitive, motor, and visual strategies necessary for skill mastery [9–11]. This disjointed method creates a major missing piece in properly combating dysgraphia.

In this scenario, the Dysgraphic Children's Handwriting Model (DCHM) was developed as a holistic intervention framework to provide a more comprehensive approach to handwriting difficulties in dysgraphic students. The model that consist of three components: visualization, imagination, and automation. Visualization helps students build a mental picture of the letters and how to write them. Bridging the use of imagination encourages students to be involved in construction, and creativity and automation enable fluency, reducing cognitive effort during writing acts. Combined, these components allow for a complete solution designed for the specific misunderstandings presented by dysgraphic students [12–14].

The findings of this study hold significant implications for special needs education. With these objectives in mind, the DCHM addresses many aspects of dysgraphia, promoting handwriting skills growth while also increasing students' confidence and engagement in otherwise challenging classrooms. Moreover, this study highlights the necessity of utilizing contemporary interaction design principles, theoretical frameworks, and models like Cognitive Load Theory to create beneficial learning tools [15–17]. This paper outlines the development, implementation, and evaluation of the DCHM in detail. It highlights the transformative capability of the model in helping students with dysgraphia and sets the ground for the subsequent development of assistive educational technologies. By bridging theoretical insights and practical solutions, this research offers a creative, unique, and holistic approach to addressing the challenges of dysgraphia in special education. It also contributes to developing innovative interventions that enhance learning experiences for dysgraphic children.

The Dysgraphic Children's Handwriting Model aligns with Cognitive Load Theory (CLT) by inheriting the cognitive overload involved in handwriting acquisition and optimizing the learning process for dysgraphic students. CLT focuses on

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key cognitive loads that affect effective learning, intrinsic, extraneous, and germane, and the desirable balance between them. Handwriting requires fine motor coordination, spatial awareness, and letter recognition as cognitively demanding, and they impose a high intrinsic cognitive load on children with dysgraphia. To address this problem, the model uses structured, guided learning strategies like tracing support and dividing letter formation into smaller tasks. Another factor to avoid cognitive overload is the reduction of extraneous cognitive load. Adapting technologies such as AI-based handwriting tools, which come with real-time corrective feedback for the students, allow them to rectify errors on the go, help students correct mistakes instantly, and reduce unnecessary cognitive strain. Handwriting tasks are complemented by multisensory feedback, such as visual overlays, auditory prompts, and haptic responses to strengthen the memory of writing correctly. Finger tracing on correct letter formed can help students build muscle memory that can help handwriting practice become more effective.

II. Literature Review

Dysgraphia is a learning disability that negatively impacts a student's ability to write by hand, such as handwriting legibility, handwriting fluency, or handwriting consistency. Motor coordination, cognition processing, and memory deficiency [18, 19] are some of the challenges that are often encountered. Consequently, students with dysgraphia often face severe academic hurdles and a decline in self-esteem because they struggle with tasks associated with handwriting [20]. Although theoretical models like Van Galen's Psychomotor Handwriting Model elucidate the cognitive and motor mechanisms of handwriting, none provide the methodological framework required to understand and design interventions specific to dysgraphic learners [21–23].

A. Conventional Tools for Dysgraphia

Conventional dysgraphia remediation methods often involve repetitive writing drills, motor-skill development, and tracing letters. Although these tools can provide some enhancements, they frequently do not address the complex challenges associated with dysgraphia holistically. For example, handwriting tracing worksheets provide for repetitive letter and number tracing but don't position students actually to engage in meaningful writing. These are often devoid of cognitive and emotional learning elements, providing little personalization to the unique needs of individual students [24]. Likewise, grip enhancers and special writing instruments are helpful in improving motor coordination and minimizing physical stress related to writing. Yet, these software are focused mainly on physical deficits and failure to incorporate cognitive and visual deficiencies, significant contributors to general handwriting performance [25, 26].

Another widely used intervention is touchscreen applications that provide visual prompts for letter formation and allow trace of letters. Although these applications serve beneficial visual guidance, the absence of adaptive feedback makes them less effective for accommodating diverse learning needs, thereby limiting potential individualized intervention [27]. While occupational therapy has proven very effective at building fine motor skills and muscle control, it is notoriously time-consuming and requires the individual attention of a trained professional. However, the curriculum requirement for occupational therapy is based on sessions from specialized professional centers, which reduces the applicability and scalability of information to the general population for large-scale implementation [28, 29]. While these conventional aids provide some level of progress, they do not meet the entirety of the requirement of dysgraphic students. Crucial elements, such as cognitive load, visual-motor integration, and sustained engagement, have yet to be sufficiently explored, leaving a gap that calls for more robust and adaptive solutions.

B. Emerging Holistic Approaches

New-century technologies highlighted the opportunity for a holistic approach to handwriting interventions by integrating visualization, imagination, and automation. Visualization enables students to create mental representations of the letter shapes, while imagination involves creativity coupled with cognitive processes, and automation fosters fluency through reduced cognitive load [30, 31]. Still, many of the tools implementing these strategies are ineffective because of their isolated components.

The DCHM unifies these components into a systematic model. The DCHM combines interactive exercises, animated feedback, and real-time error correction to parallel address cognitive, motor, and emotional dimensions. This makes it a game-changer in mitigating dysgraphia. Table 1 shows the comparison of the conventional tools with the DCHM.

Table 1. Shows the comparison of the conventional tools with the DCHM

Feature	Handwriting Tracing Worksheets	Grip Enhancers	Touchscreen Applications	DCHM
Focus	Isolated letter tracing	Motor coordination	Visual guidance for letter formation	Holistic (visualization, imagination, automation)
Feedback Mechanism	Absent	Absent	Limited	Real-time, adaptive feedback
Cognitive Load Consideration	Neglected	Neglected	Minimal	Explicitly addresses cognitive strain
Engagement	Low (repetitive tasks)	None	Moderate	High (interactive exercises, animations, gamification)
Scalability	High	High	Moderate	High (scalable and customizable for various contexts)
Outcomes	Incremental improvements	Physical strain reduction	Visual-motor integration enhancement	Comprehensive skill enhancement and improved confidence

Current handwriting tools have only been somewhat effective in addressing specific deficits of dysgraphia but do not offer a holistic approach that is required for meaningful and sustained improvement. These tools narrowly focus on physical and visual components, neglecting the cognitive and emotional aspects, which are key for handwriting development [32]. A major limitation of these systems is that they do not include adaptive learning mechanisms, real-time feedback, or gamified features that enhance student engagement and motivation [33].

The DCHM intends to bridge this gap based on the above insights by establishing a unified framework that amalgamates visualization, imagination, and automation. It draws on Interaction Design Principles and Cognitive Load Theory to offer an engaging learning experience that caters to users' needs without bombarding them with all the information. Notably, this holistic approach to learning handwriting promotes confidence and consistently incubates the curiosity to learn further. The model's scalability highlights its potential for usual adoption in educational settings.

III. Methodology

DCHM was developed and examined in this study using a mixed-methods research design. The study evaluated the handwriting proficiency of students with dysgraphia before and after the intervention using the Handwriting Legibility Scale (HLS). The intervention included animated letter formation demonstrations, activities for students to complete, and real-time feedback mechanisms.

A. Research Design

The research design was experimental, with pre-test and post-test treatment control groups. The quantitative aspect measured the difference in handwriting ability before and after the intervention using the Handwriting Legibility Scale (HLS) scores. The qualitative aspect includes collecting feedback from students and teachers to evaluate the DCHM's usability, engagement, and application in practice. A combination of quantitative and qualitative data was utilized to evaluate the intervention comprehensively. Numerical data ensured that tangible evidence provided reassurance, and qualitative feedback assured that the approaches taken resonated with students' lives, adding depth and meaning to how one considered results.

The study was conducted with 50 dysgraphic children aged 8–12 in special education programs, focusing on understanding their handwriting difficulties. The process for selecting the participants ensured that the children had a formal diagnosis of dysgraphia and a teacher's recommendation, excluding those with additional disabilities that could affect handwriting results. The participants were randomly allocated into two groups, the experiment group used the DCHM-based intervention with the prototype, and the control group continued conventional handwriting instruction. The design enabled a clearer analysis of the model's effect on handwriting fluency.The ultimate sample consisted of students diagnosed with dysgraphia using standard screening instruments and teacher referrals. Inclusion criteria were derived beforehand and included the requirement of no strong cognitive disabilities, and the ability to engage with digital learning tools.

The major phase of the study has three interconnected phases: categorisation and analysis of handwriting patterns, development of the DCHM prototype, and evaluation of the DCHM prototype. This is to capture a holistic view of the intervention's effect on dysgraphic students.

Phase 1: Categorisation and analysis of handwriting patterns

The first phase of the study involved categorizing and analyzing the children's handwriting patterns through standardized handwriting tasks: tracing, copying, and free writing, all done in a distraction-free environment to accurately capture their difficulties. Establish a baseline understanding of the students' handwriting difficulties. Students completed three standardized handwriting tasks: tracing, copying, and free writing. To limit distractions, these tasks were administered in a low-stimulus classroom setting. Samples were evaluated with the Handwriting Legibility Scale (HLS), measuring five handwriting quality dimensions:

- Letter Formation: Accuracy and consistency in shaping individual letters.
- Spacing: Uniformity of spaces between letters and words.
- Alignment: Adherence to baseline and proper alignment of text.
- Size Consistency: Proportionality and uniformity in letter sizing.
- Overall Legibility: General readability of the handwriting sample.

All dimensions were scored on a 5-point Likert scale scale between 1 (poor) and 5 (excellent). The sum score was an overall measure of each student's handwriting performance before the intervention.

Phase 2: Development of the DCHM prototype

The second phase was designed to develop the DCHM, an intervention framework for dysgraphic students. The architecture was based on three main elements:

- Visualization: Animated demonstrations of letter formation to enhance students' mental representations of correct writing patterns.
- Imagination: Interactive tasks prompt students to use creativity, fostering deeper cognitive engagement with the writing process.
- Automation: Repetitive exercises aimed at developing muscle memory and reducing cognitive load.

The DCHM prototype was delivered digitally through an application available on tablets and computers. The software had interactive features that gave immediate feedback to users, highlighting mistakes in how letters were formed and gamified aspects, such as progress badges that incentivized students. In order to identify usability issues and enhance functionality, a pilot study with 10 students informed the prototype refinement.

Phase 3: Evaluation of the DCHM prototype

During the last part, the impact of DCHM was assessed through an 8-week intervention trial. Students interacted with the application three times a week for 30 minutes per session. All sessions took place in a dedicated school computer lab, supported by trained research assistants who provided technical assistance and ensured students were consistently engaged.

The intervention was conducted over 8 weeks, as previous studies also suggest that handwriting intervention take at least two months in this group to produce measurable improvement [34]. This length allowed for ample exposure to the DCHM model but was within a time frame that could be reasonably implemented in an academic semester. Progress was assessed weekly, allowing constant visibility through the students' progress.

Furthermore, teachers were trained specifically on how to implement the DCHM model prior to the initiation of the intervention. The specialist teachers were given a workshop explanation guiding them on how to implement into their teaching the general principles of visualization, imagination and automation. The training focused on hands-on training sessions relevant to the prototype, techniques for delivering in-the-moment feedback, and ways to track student progress. This prevented variability in how the intervention was applied in classrooms.

This prototype allows dysgraphic children to practice penmanship with interactive tablet exercises. It increases motivation, self-competition, and confidence while also taking advantage of the growing use of tablets to get kids involved. This prototype is available for school use only. Learning letters by tracing with their fingers helps students develop visual perception, imagination, and motor skills. The system has three difficulty levels: (1) connecting points in texts, (2) connecting points in words, (3) writing words by oneself. It includes letter tracing for improved handwriting skills. This prototype enables teachers to customize exercises according to each student's ability level and assess the accuracy of a participant's writing through comparative results to a reference database.

The teacher will select the exercises and set the students' individual learning paths before they can work with the application. Students must follow instructions and complete the task before going to the next activity level. The system provides instant feedback in the form of marks by using statistical marks of the students for each activity. All tracing logs of each student are saved in a database separately as a reference of the individual student's performance. If a student struggles with the letter E, he or she can do the same activity repeatedly. Students can only see the interface that their teachers explicitly give them. This intervention addresses problems inherent in dysgraphic children based on the following principles: 1) Teacher can monitor progress in students' handwriting progress; 2) Helps identify each student's challenges and customize their learning path; 3) Offers immediate visual feedback; 4) Simple interface for rehabilitation exercise. Students performed the Phase 1 handwriting tasks again after the intervention. Handwriting samples collected after the intervention were scored again with the HLS to evaluate whether there was an improvement in handwriting quality.

B. Data Collection

In order to thoroughly assess the intervention, the study utilized both quantitative and qualitative data collection methods as detailed below:

1) Handwriting Legibility Scale (HLS)

- Purpose: To evaluate the quality of student's handwriting.
- Method: Student handwriting samples were collected before and after implementation. Using the HLS, these samples were evaluated across five dimensions at baseline and post-intervention for quantitative measurements of handwriting ability. A specialist teacher, researcher, and occupational therapist will assess the legibility of the student's handwriting by the Handwriting Legibility Scale (HLS). An LD expert will then validate this assessment to confirm the results of the assessment are accurate & reliable.

2) Observation field notes and checklists

- Purpose: To collect qualitative data based on student engagement, usability problems, and behavior changes in intervention sessions.
- Method: The researchers monitored students during the intervention, noting students' excitement and focus, as well as any challenges experienced when interacting with the interface or with the tasks. Based on verbal and nonverbal cues (such as willingness to participate), it was also observed that the students showed better confidence and motivation. Observers completed a structured checklist to maintain consistency of observations across sessions. Qualitative findings were investigated and used to expand the quantitative results emerging from key environmental observation themes.

3) Surveys and interviews

- Purpose: To collect student self-reported experience and teacher feedback on the potential classroom feasibility of the intervention.
- Method: Surveys for students: Students were given surveys to complete to mirror their personal experiences and perceptions of the intervention. Teacher Interviews: Teachers were interviewed using a semi-structured format to gather their perspectives on the effectiveness of the intervention and its implementation within the classroom context.

4) DCHM prototype

- Purpose: The main tool to engage students in the intervention is combining visualization, imagination, and automation.
- Features: Digital application that provides real-time feedback and gamified aspects. Through this application, students can see their progress in real-time, so they can improve their performance over time.

This study utilized multiple data collection methods to achieve a comprehensive understanding of intervention impact, capturing both quantitative outcomes and qualitative nuances of student and teacher experiences.

C. Data Analysis

In quantitative data, the authors utilized the Handwriting Legibility Scale (HLS), a validated scale of handwriting quality across five dimensions. Handwriting samples were collected from students pre and post-intervention, to identify significant differences in pre- and post-intervention performance. In qualitative data analysis, researchers documented student behaviors during the intervention sessions using structured checklists and fieldnotes, focusing on engagement, usability challenges, and behavioral changes. Surveys were administered before and after the interventions to the students that provided self-report data, and semi-structured interviews with teachers provided insights into whether the intervention was applicable in the classroom setting. Qualitative data were subsequently thematically analyzed, allowing us to derive further recurring themes related to usability, engagement, and practical application that complemented the quantitative results, providing a holistic view of the effect of the intervention.

The study employed various validation strategies to ensure the credibility and trustworthiness of the qualitative data obtained through observations, surveys, and interviews. First, triangulation was applied by corroborating findings across various data sources (observations, student surveys, and teacher interviews) to strengthen overall validity. Second member checking means having participants review the data collected from them to ensure its accuracy, offering them the ability to correct information while ensuring the findings truly reflect participants' perspectives. Moreover, reflexive journals were kept by researchers to be aware of and document their own biases and assumptions during the data collection and analysis phase to ensure that biases in the research process were minimized. Regular peer debriefing sessions were held to evaluate and discuss the findings, allowing for external scrutiny and improving the credibility of the results. Finally, an elaborative and rich description of the research context, participants, and findings allowed readers to grasp the setting and evaluate the transferability of the findings. These methods aimed to enhance the credibility of the qualitative data and ensure that it accurately reflected the experiences and perspectives of the participants in the study.

IV. Result and Discussion

The Dysgraphic Children Handwriting Model (DCHM) was evaluated using a pre-test and post-test experimental design to measure its impact on handwriting proficiency among dysgraphic students. The results demonstrated significant improvements across all assessed dimensions, confirming the effectiveness of the DCHM. The findings are detailed below, supported by quantitative data, qualitative insights, and visual analyses.

A. Quantitative Finding

The handwriting samples collected during the pre-test and post-test phases were analyzed using the Handwriting Legibility Scale (HLS). Five dimensions of handwriting performance were evaluated: letter formation, spacing, alignment, size consistency, and overall legibility. Each dimension was scored on a 5-point scale, with higher scores indicating better performance. The results showed substantial improvements in all dimensions following the DCHM intervention.

B. Letter Formation

Letter formation, one of the most critical dimensions of handwriting, showed a substantial improvement of 60.7% after the intervention. In the pre-DCHM implementation phase, students showed irregular and inconsistent letter shapes. Deficits in skills for producing accurate and consistent writing with correct syntax are needed due to motor coordination challenges and poor cognitive representation of letter structures [35]. For example, letters often look incomplete with inconsistent curves or disproportioned objects, hence producing illegible handwriting.

The post-test results showed great improvements in this dimension. The visualization aspect of the DCHM was vital, providing animated models of correct letter formation. These visual structures guided students toward learning to format letters through step-by-step breakdowns of complex shapes [36]. Also, because of the real-time feedback mechanisms, students could dynamically correct their handwriting techniques as well. This powerful feedback loop allowed students to internalize correct letter formations for execution with greater precision and consistency.

C. Spacing

The spacing dimension, which assesses space consistency between letters and words, increased by 53.3%. In the example below, prior to the intervention, students showed inconsistent spacing. When writing, some letters repeated each other, and some letters were separated from each other with distances that were too big, even so many, suggesting that they had issues with visual motor integration and spatial awareness. There was also inconsistency in spacing, which made it even more difficult to read their writing; it became less legible altogether.

With DCHM, students achieved equal spacing through letters and word spacing. The exercises in the model were structured for guided practice repeatedly, which helped students develop better spatial planning abilities. This model also offered error feedback mechanisms, which in turn prompted the users to change their writing on the fly, in this case, the spacing errors that were shown. These increased special elements helped with readability and the formation of appropriate writing forms [37].

D. Alignment

Alignment, which is a measure of the adherence of the text to the baseline, had the most marked improvement across all dimensions (63.0%). Without intervention, there was often a lack of alignment, with letters and words straying up or below the line. These misalignments signalled difficulties in visual tracking and fine motor control, which are both essential for writing. Another leading factor in students' illegible handwriting is misaligned text.

After the intervention, alignment became significantly better. This progress is due, in large part, to the real-time feedback tools inside the DCHM. Misalignment was immediately identified using these tools, encouraging students to re-adjust their position on the baseline throughout practice sessions. However, with repeated correction, students improved at self-correcting to stay aligned without me pointing out their mistakes. It was exciting to see not just an enhancement in their basic adherence, but also a remarkable transformation in the overall structure and flow of their handwriting [38].

E. Size Consistency

For size consistency, the ability to sustain proportional and uniform dimensions of letters increased by 51.6%. Before the intervention, the student often wrote too big or too small letters, demonstrating a lack of motor planning and control. Not only did this affect the look of their handwriting, but it also made reading their written text more challenging.

Post-test results highlighted significant progress in achieving proportional letter sizes. The imagination component of the DCHM encouraged students to visualize proper letter dimensions and replicate them accurately during writing exercises. This sort of creative approach helped students create a mental template of the sizes of letters, which they could apply in a consistent manner in different writing tasks. Thus, this led to a more ergonomic writing posture, which translated into better aesthetics of the letter shapes, supporting overall better legibility [39, 40].

F. Overall Legibility

The overall legibility, referring to the overall quality of handwriting, showed early evidence of a significant improvement of 58.6% based on the intervention. Before the introduction of the DCHM, most students had handwriting that was hard to read. These issues covered all assessed dimensions: variable letter formation, inconsistent spacing, poor level of pricked paper, and disproportionate letter sizes. In addition, these deficiencies in their delivery and reception rendered the writing illegible and further increased frustration for students and their educators alike.

The DCHM robustly met these challenges via its integrated visualization, imagination, and automation components. The visualization tools provided direct, structured instruction on how to write properly, and teachers reported that students could identify and imitate correct letter formations. In this way, the imagination exercises stimulated cognitive activity, nudging students to incorporate the principles of successful handwriting mentally and applying these principles in practice. On the other hand, the automation task focused on repetition, which facilitated muscle memory and reduced cognitive load within the handwriting process.

This multiple-pathway approach yielded significant enhancements in all individual dimensions, resulting in overall improved legibility of students handwriting [41–43]. At the end of the intervention, students were able to produce writing that was much more readable and also structured, and aesthetically more consistent than before. These findings emphasize the DCHM's effectiveness as a unitary approach for tackling handwriting difficulties among dysgraphic students.

The scores for five dimensions; Letter Formation, Spacing, Alignment, Size Consistency, and Overall Legibility were compared before and after the intervention as shown in Table 2.

Table 2. The scores for five dimensions

Dimension	Pre-Test Mean Score	Post-Test Mean Score	Improvement (%)	Key Observations
Letter Formation	2.8	4.5	60.7%	Enhanced clarity and consistency in letter shape due to animated visual guidance
Spacing	3.0	4.6	53.3%	Uniform spacing between letters and words achieved through guided repetitive tasks.
Alignment	2.7	4.4	63.0%	Better adherence to the baseline, supported by real-time feedback mechanisms.
Size Consistency	3.1	4.7	51.6%	Significant improvement in proportional letter sizing supported by visualization.
Overall Legibility	2.9	4.6	58.6%	Enhanced overall readability reflecting progress across all handwriting dimensions.

A line graph comparing each handwriting dimension's pre-test and post-test scores visually underscores the significant improvements achieved, shown in Fig 1.

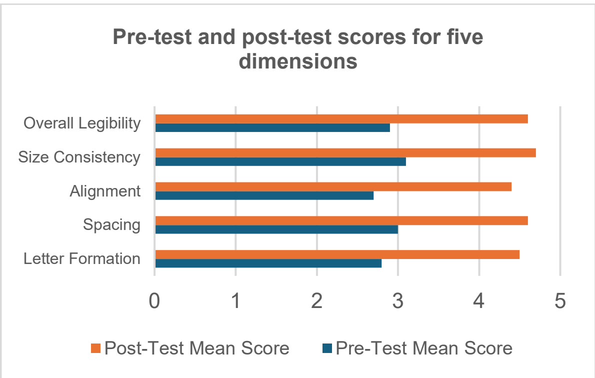

Fig. 1. Comparing the pre-test and post-test scores for each handwriting dimension.

These results strongly support the efficacy of the Dysgraphic Children Handwriting Model (DCHM) to address the various underlying aspects of dysgraphia. Integration of visual engagement, spatial motor experience, and cognitive representation of handwriting tasks in the model enhances fundamental components associated with handwriting, for example, motor coordination, spatial planning, and cognitive representation of handwriting tasks. These results highlight the model's capacity to address the motor, visual, and cognitive deficits that are typically associated with dysgraphia.

Alignment showed the greatest overall increase, with adherence rates to the baseline increasing by 63.0%. Even before the students used the system, there were non-alignments in the text, as letters and words jumped far up or down from the baseline, indicating that the students had trouble with visual tracking and fine motor control. These challenges were largely addressed through the integrated real-time feedback mechanisms incorporated in the DCHM. These mechanisms immediately flagged misalignments and gave students actionable feedback during practice episodes. The repeated exposure to these feedback loops allowed students to optimize alignment over time, leading to a substantial increase in baseline adherence. This not only improved the structural quality of the handwriting but also helped enhance overall readability.

Overall legibility of students' handwriting improved by 58.6%, demonstrating that the DCHM positively impacted all assessed domains. This is an aggregate of letter formation, spacing, alignment, and size consistency progression. In the DCHM, visualization tools were integrated to visually show students how to form each letter and write, leading them towards a correct path. The cognitive engagement from the imagination exercises allowed the students to visualize the correct techniques while practicing them. Also, the automation component focused on alphabet repeat practice, providing students with low cognitive load to work on composed text-to-text writing and line writing to promote a focus on written expression, accuracy, and fluency [44–46].

Overall legibility, which is the most meaningful measure of the effectiveness of the intervention, is significantly improved. Because the DCHM addressed several of handwriting's component parts at once, students' handwriting became more legible, consistent, and structured, improving functional communication and self-confidence in writing.

G. *Qualitative Finding*

Based on the qualitative findings, the Dysgraphic Children's Handwriting Model (DCHM) intervention affected student's motivation for writing, their confidence levels, and the development of new skills. Data obtained via structured observations during the intervention sessions showed remarkable behavioral and motivational changes among the students. Overall, students were able to maintain interest and attention through extended classes, especially through gamified activities that valued accuracy and consistency. These elements not only kept students' attention, but also supported students' active engagement with the material, which is a frequent challenge for children who struggle with dysgraphia. As students began, they hesitated more, but over time, they were less afraid and more open to trying new things, suggesting confidence in handwriting. There was also a decrease in repeated mistakes, as students learned from the feedback and implemented changes in subsequent attempts [47].

Students' examples further echoed these observations. Transformation of elementary handwriting practice activity, which is traditionally a frustrating task, to positivity and rewards despite students finding the DCHM pretty interactive and gamified. Students especially appreciated the real-time feedback feature where they could see mistakes and make corrections instantly [48]. By providing this immediate positive feedback, students could capitalize on their strengths while working on more targeted areas of improvement in a safe learning setting.

Teachers' comments further confirmed the effectiveness and utility of the DCHM. Educators said they saw notable improvements in students' handwriting quality, and many students produced more legible and consistent work. Most importantly, teachers noted the DCHM positively impacted the student's confidence, as they reported that many students approached tasks in writing with increased enthusiasm. As immediate negative consequences such as feelings of embarrassment and frustration were avoided, students found their confidence boosted in relation to handwriting exercises and better attitudes towards written communication as a whole [49, 50]. Moreover, teachers commented positively on the DCHM's design, which was easy to use, which allowed them to use it easily in diverting classroom routines. It was easily trained to apply, supplemented current instructional strategies, and was a cost-effective solution to hit handwriting on the head in the classroom.

These qualitative findings, taken together, underscore the role played by the DCHM as an effective intervention to improve students' handwriting and an agent for transformational change of increased student motivation, confidence, and classroom engagement. The findings suggest the model could potentially be more widely applied to support students with dysgraphia.

V. Recommendations

To enhance the effectiveness of handwriting interventions for dysgraphic students, targeted recommendations are proposed for teachers, researchers, schools, and government policymakers. Teachers can incorporate technology-assisted handwriting applications into their regular classroom activities, using gamified strategies to enhance student involvement and offer immediate feedback. Multisensory learning experiences like digital tracing tools, voice-guided instructions, and differentiated instruction that address individual needs can make a difference in handwriting proficiency. Also, the need to work with parents and specialists is necessary for being able to intervene consistently across both home and school environments.

For researchers, future studies should examine the long-term effects of technology-assisted handwriting interventions and explore the role of AI-driven adaptive learning systems in personalizing support. Exploring multimodal interaction techniques, such as haptic feedback and augmented reality, may provide additional insights into ideas for enhancing handwriting fluency. Research should also explore the model in diverse educational settings and cultural contexts to confirm the scalability of the model. Also, the number of items the user can write has been proven to be coined from the cognitive load as it may be effective and intuitive to the user depending on the user experience.

This means that using assistive handwriting tech in special education programs and providing teachers with professional training are two key ways that schools can support their dysgraphic students. Setting up dedicated handwriting support labs with interactive learning tools may help implement effective interventions. A multidisciplinary approach that involves occupational therapists, psychologists, and special education teachers can also improve student outcomes. Dysgraphic students must be known early so that appropriate interventions can occur early; therefore, early screening protocols should be introduced. Students with handwriting issues should also be included in classroom practices without stigma. Investigating why some students did not benefit from the intervention could provide valuable insights for refining the approach.

The government should establish educational policies incorporating assistive handwriting technology into the national special education system. Collaborative efforts should ensure that innovation is being directed toward handwriting support solutions by the educational sector, technology developers, and healthcare professionals.

VI. Limitations and Implications

Despite the promising findings regarding the effectiveness of the Dysgraphic Children Handwriting Model (DCHM) in developing handwriting skills in dysgraphic students in the current study, some limitations must be recognized. For one thing, 50 students are enough for preliminary analysis, yet not enough to fully capture the diversity within dysgraphic learners of varying cultures, languages, and socioeconomic status. To ensure the generalizability of results, future studies should consider recruiting a larger sample size as well as a diverse population. Second, this study was conducted over just a few weeks and focused on immediate effects on handwriting proficiency, so it is not known whether the effects will last in the long term. Long-term studies are needed to answer the question of whether students will hold on to their improved handwriting skills as others, and if not, how much more intervention perhaps needs to take place. This study primarily assessed handwriting outcomes through the Handwriting Legibility Scale (HLS), a common measure of handwriting proficiency, but may not encompass aspects like writing speed, cognitive load, or writing-related anxiety, all of which are related to writing proficiency

The study is highly useful for the areas of research in special education, instructional technology, and policy development. Highlighting the power of visualization, imagination, and automated process principles in special needs educational technology applications to solve handwriting challenges. Implications for educators, this research presents exciting opportunities for gamified learning strategies and real-time feedback mechanisms with handwriting engagement.

Specific recommendations were made for teachers, researchers, schools, and government policymakers that may enhance the effectiveness of handwriting interventions for dysgraphic students. Educators must incorporate technology-enabled handwriting applications into the regular classroom setting to support teaching interest and to deliver real-time feedback. It is also important to connect with parents and specialists to provide the same intervention at home and in the school environment. Researchers may further investigate the effectiveness of technology-aided handwritten interventions in longer-term settings and the potential of AI for emergence of adaptive learning systems that personalize such support. Dysgraphic students benefit from assistive handwriting technology applied in special education and corresponding professional preparation for school teachers. Collaboratively working with occupational therapists, psychologists, and special education teachers can also be beneficial to student outcomes.

VII. Conclusion

Many traditional dysgraphia solutions target either the motor skills required for handwriting or visual guidance but often overlook their potency individually or the interrelated nature of handwriting challenges. The significant improvement in alignment scores highlights the value of real-time feedback in helping students develop spatial awareness and motor coordination. Progress in size consistency and spacing is further evidence of the impact of practice, repetition, and cognitive engagement, as enabled by visualization and imagination components in the DCHM. This is consistent with previous studies highlighting the necessity for better, more versatile work in special education [51].

As exemplified by this study, the use of the Dysgraphic Children's Handwriting Model (DCHM) has effectively targeted the multidimensional difficulties experienced by dysgraphic students. Addressed across five dimensions: letter formation, spacing, alignment, size consistency, and overall legibility, the DCHM offers a multidimensional intervention framework that connects a visual aspect, representing what is desired; an imagined aspect, creating facilitated mental modeling; and an automated response leading to improvement. The quantitative findings show a significant uptrend for every factor: alignment, with an increase of 63.0%, returns the most improvement, and the most prominent one observes overall legibility let up by 58.6%. This added advantage highlights the model's capacity to comprehensively treat motor, visual, and cognitive impairments.

Qualitative findings further substantiate DCHM's effectiveness by reporting increased student engagement, decreased frustration, and greater confidence. Key features observed include gamified elements and real-time feedback mechanisms that were crucial in sustaining students' motivation and promoting a positive learning experience. According to teacher feedback, the DCHM was also highlighted as a practical, scalable approach with a significant impact on student's attitudes toward handwriting tasks and an ideal candidate for classroom implementation. Traditional tools for dysgraphia often focus narrowly on specific aspects, such as motor skills or visual guidance, neglecting the interrelated nature of handwriting challenges. In contrast, the DCHM addresses these gaps by combining theoretical frameworks like Cognitive Load Theory with modern interaction design principles, creating an adaptive and engaging learning environment.

Qualitative data provides further insight, showing that the DCHM changes the experience of practicing handwriting from something that usually generates frustration into something fun and rewarding. The model's gamified elements, including progress badges and interactive exercises, helped not only maintain students' concentration but also to boost their intrinsic motivation. Such results indicate that incorporating engagement-induced tactics in educational instruments can considerably elevate the learning outcomes for individuals with dysgraphia.

Overall, This study has developed and validated a technology-assisted model that integrates motor, cognitive, and visual strategies to enhance handwriting proficiency among dysgraphic students. The model illustrates how structured technological interventions can address the multifaceted challenges faced by learners with handwriting difficulties. By bridging these fundamental areas, the research not only contributes a novel approach to the field of special education but further highlights the significance of interdisciplinary frameworks in designing inclusive learning tools.

The main contribution of this study lies in its multidisciplinary approach, along with the empirical framework of a practical tool to promote personalized learning. This work is particularly valuable for educators, therapists, and educational software developers, as it provides the foundation for building adaptable and pedagogically sound interventions. Future work could expand this by investigating the scalability, long-term stability, and applicability to other learning environments and disabilities.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Norsafinar Rahim has reviewed the background and literature review including the discussion and conclusions, and Norizan Mat Diah has reviewed the methodology and interpretation of the results. Both authors had approved the final version.

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