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Write-rite: Enhancing Handwriting Visualization Proficiency in Dysgraphic Children

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ABSTRACT

Dysgraphia is a significant and age-inconsistent difficulty developing writing skills among students. To address this issue, various intervention methods for developing writing skills in dysgraphic students have been implemented. However, previous studies on these intervention methods do not encompass all stages of writing skills, from basic levels to automatization. This creates a research gap, especially the lack of support to enhance writing visualization aided by technology. The study emphasized the importance of offering instructional support to educators, thereby enabling the proficient utilization of technology-assisted resources to aid dysgraphic children. By integrating this application, the research endeavoured to augment both the productivity and enjoyment inherent in the teaching and learning processes. The functionality of dysgraphic students' writing support applications would be more effective with the presence of Interaction Design (IxD) guidelines that is crucial to developing user-friendly writing support software. Dysgraphic-customized application, Write-rite, integrates IxD to improve visualization, motor control, and letter memory. Write-rite utilizes tracing exercises, animations, and repetition to enhance letter formation. The study, involving five dysgraphic students aged 8-12, employs Handwriting Legibility Scale for evaluation. The prototype is evaluated before, during, and after an eight-week intervention. Results indicate significant improvements in letter formation, motor skills, and overall handwriting legibility. The efficacy of this intervention offers dysgraphic students a tailored approach to improving handwriting skills. It emphasizes the importance of early intervention and specific strategies in alleviating writing challenges, thereby positively impacting students' cognitive skills and handwriting automation.

1. INTRODUCTION

Dysgraphia is often associated with dyslexia, dyscalculia, or dyspraxia (a coordination development disorder), all of which can be classified as neurodevelopmental disorders (Fogel & Rosenblum, 2022; Asselborn et al., 2018). Dysgraphia and dyslexia are frequently linked because 30% to 47% of students facing writing difficulties typically encounter challenges in reading as well (Prunty & Barnet, 2020; Prunty & Barnet, 2017; Berninger et. al., 2015; Chung et al., 2020). The root of dysgraphia issues lies in the writing

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process rather than the mere outcome of the writing (Borghese et al., 2017). The process also occurs in stages based on their learning development. The pre-writing stage, which is the preparation period before producing correct and neat writing, is the most important stage. Dysgraphic students require specific approaches or strategies for writing process development. The challenges that dysgraphic students encounter can differ widely from one individual to another. Each student's experience is unique, adding layers to their journey in overcoming these hurdles.

In Malaysia, methods for confirming and categorizing dysgraphic students are based on the Dyslexia Screening Instrument (DSI), classroom activity books, interviews with parents, and feedback from occupational therapists. Medical experts make final confirmation. Although various programs help improve handwriting skills, a gap exists in identifying effective strategies through theories and models to assist dysgraphic students. The gap exists due to the lack of technological aid to measure its effectiveness systematically and firmly. This study also contributes to filling that measurement gap.

2. LITERATURE REVIEW

Handwriting involves graphomotor processing. At this stage, students need to master pre-visualization skills (visualizing letters), quickly and accurately recalling letter shapes, execution (following instructions to perform tasks), and feedback (knowing the position of the pencil while writing without looking at it). Reinforcing graphomotor skills can enhance phonological and orthographic processing as linguistic components referring to spelling. Furthermore, thoughts and ideas must be translated into written form involving information retrieval from both short-term and long-term memory.

The components involved in producing good handwriting are as follows: 1) writing with moderate pressure, 2) coordinating small muscles involving finger usage, 3) visualizing the letters to be produced, 4) coordinating motor movements, 5) using appropriate size and spacing, 6) using correct writing lines, and 7) maintaining suitable spacing between letters and words. Additionally, students need to have the skill of analyzing letters for storage in memory and future use. When these skills become fluent, students' cognitive resources can be directed toward generating more complex ideas and writing.

From the analysis conducted, most dysgraphic students face issues with visualization that affect their ability to depict letters and words (Suggate Pufke & Stoeger, 2019, Taverna et al., 2020; Veljanov et al., 2020). Therefore, visualization is crucial for automatization in writing. Visualization aids students in learning and memorizing each letter or word formation technique supported by memory and motor signals. Motor movements may be restricted if students struggle to depict each letter they want to produce. Consequently, they may produce handwriting that is difficult to read. This involves difficulties in depicting the required letter and motor patterns for producing the letter (Chung, Patel & Nizami, 2020; Chung & Patel, 2015; Boato et. al., 2022). Hence, contributing to the development of technology for dysgraphic students' writing skills with proper letter formation procedures needs to be strengthened to enhance long-term memory, motor skills and visualization.

2.1 Visual Interaction Design

Dysgraphic students struggle to visually depict the shapes of letters they intend to write, even though they can verbally identify them. This indicates that visualization constraints limit their writing, reducing their interest. This scenario underscores the need to develop Interaction Design (IxD) guidelines for dysgraphic students to enhance the functionality of writing support software to be more user-friendly and effective.

Well-designed IxD can positively impact the software interface for students with learning disabilities (No & Choi, 2021; Ramlan et al., 2022). Writing activities can be enhanced through an interactive user interface designed to accommodate students' motor and visual skills difficulties. Furthermore, IxD guidelines involve the arrangement of the User Interface (UI), delivering content, user experience, and user feelings. These guidelines facilitate minimal supervision when dysgraphic students interact with the UI.

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Learning content can also be translated into easily understandable instructions, providing a more effective learning experience.

The focused criteria aim to enhance visualization and facilitate student understanding. The three dimensions of IxD serve as guidance, namely form, content, and behavior (Poobrasert et al., 2023). The form dimension is crucial in compensating for dysgraphic students' visual processing deficits. Elements such as typography, color, and layout are considered to meet the needs of dysgraphic students. Screen displays should be organized to provide clear instructions for the main writing activities.

Reading limitations allow instructions to be translated into graphical or image formats to facilitate student understanding in the content dimension. Meanwhile, the behaviours dimension refers to easy navigation or illustration to facilitate interaction. Immediate feedback is also necessary to enable students to identify and promptly correct mistakes. The effectiveness of IxD design can engage students in learning, facilitate understanding, and positively impact the user interface for students with learning disabilities.

2.2 Technology-assisted

The contributions of the discussed Interaction Design (IxD) guidelines can be observed in developing the Write-rite prototype (Rahim & Jamaludin, 2019). The primary goal of this prototype is to enhance visualization and automation, subsequently impacting handwriting proficiency.

Activities involving guided letter formation are seen to affect visual-motor coordination positively. Proper letter formation fundamentals need prioritization, encompassing the overall depiction of letter positions, spatial orientation involving the use of lined paper, emphasis on crucial letter features (initial, middle, and final points), letter identification, and stroke initiation. Exposure to specific letter formation characteristics can enhance handwriting legibility and facilitate learning (De Vita & Schmidt, 2021; Laura Camille & Kera, 2021; Watanabe et al., 2020; Dutta & Gupta, 2020).

Handwriting requires continuous practice to achieve writing fluency. The readiness of the hand and mind must be emphasized to enable the quick production of the alphabet from memory through correct letter formation procedures. This learning process necessitates a more interactive approach through clear and engaging letter formation representations. Therefore, prototype support involving animated letters, numbered arrow animations, and guided letter formation prompts can be presented to students as a foundation for understanding the concept of proper letter formation.

Students need to visualize each letter before being able to produce it. Visualization and letter memory can be formed and retained in memory through finger-guided exercises. There is a correlation between finger-guided letter exercises and the mind's ability to retrieve memory (Hersh & Mouroutsou, 2019), besides enhancing hand strength and coordination (Gosse et al., 2021). Repetitive finger-guided exercises can improve motor control and can be referred to as a repetition component.

The primary purpose of these exercises is to enable lasting learning in long-term memory. Students should perform the same exercise at least five to ten times before progressing to the next activity (Dinehart, 2015; Martínez-García et al., 2021). This indirectly enhances automation in writing, reducing issues related to prolonged writing time, directional confusion, and letter formation memory.

2.3 Prototype

Dysgraphic students can engage in handwriting activities with varying difficulty levels using a tablet through a dysgraphic-customized application known as Write-rite. The increasing popularity of tablets among students can be leveraged for comprehensive engagement. This is attributed to the differing reception and processing of information among dysgraphic students, requiring specialized interventions. Implementing effective Interaction Design (IxD) can aid students in understanding essential letter forms to address challenges in traditional learning.

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The activities in Write-rite focus on the relationship between technology usage and the addressed issues. This interactive application allows students to actively participate in the entire learning process, enhancing visual ability, imagination, memory, and motor skills through conducted activities, subsequently achieving automation in handwriting.

Write-rite offers unique learning experiences, distinguishing itself from existing applications while also enhancing motivation and self-confidence. The primary emphasis of Write-rite is on letter formation activities with the correct procedure through manual exercises to reinforce the following three skills:

- Analyzing letter patterns for retention and recall in memory.
- Visualizing letters in the mind connected through the sequence of finger movements.
- Controlling hand coordination necessitates effective communication between the mind and hand.

Handwriting exercises are categorized into three difficulty levels: 1) Level 1: tracing with numbered lines; 2) Level 2: tracing without numbered lines; and 3) Level 3: writing from memory. These activities are adapted and modified based on the appropriateness of the study by Giordano and Maiorana (2014), utilizing a web-based application to assist students in word tracing.

Student activities involve manual exercises following the learning levels set by the teacher. These exercises enhance students' visualization and motor control by focusing on each movement to produce letters. The exercises that were performed were then compared with letter standards in the database for assessment purposes. Scores are obtained based on the accuracy of the exercises that were conducted. Students are motivated to strive for high scores in each exercise, indicating precise letter formation, and exercises are conducted within the designated area.

3. METHODOLOGY

3.1 Participants

The participants were selected using purposive sampling, with approval obtained from various authorities, including the Kedah State Education Department, two District Education Offices, the respective schools, and parents. These individuals participated in the Outreach Programme organized by the Education Department. A user-based evaluation involved five children aged 8 to 12, meeting specific criteria:

1. Experiencing writing difficulties
2. Diagnosed by experts with learning differences/learning disabilities and
3. Enrolled in remedial classes at schools.

The small number of participants limits the study, as it was challenging to gather a larger cohort that met the specified criteria and obtain parental consent. However, this can be considered a foundational study for research requiring an eight-week observation period, following the recommendations of Nielsen (2000).

3.2 Instrument

The Handwriting Legibility Scale (HLS) is utilized for assessing the handwriting of students aged between eight and 14 years old (Martínez-García et al., 2021; Pritchard et al., 2021; Wiley & Rapp, 2021). This instrument is adapted and modified to suit the context of assessing the handwriting of dysgraphic students in a holistic, fast, and easily interpretable manner concerning handwriting legibility. The HLS assessment criteria focus on the letter formation produced by dysgraphic students, involving the overall process of generating handwriting. The assessment employs a 5-point Likert scale, with 1 representing very poor performance and 5 representing excellent performance. Higher scores indicate excellent legibility, while lower scores indicate otherwise.

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3.3 Evaluation

Each activity aims to improve visualization, motor control, and letter memory and ultimately achieve automation in writing. The intended activities include finger-guided exercises, arrow animation, letter formation animation, and repetition. This intervention can contribute to the accuracy, fluency, and legibility of dysgraphic students' handwriting. The usability assessment process of the prototype involves three main phases: before, during, and after the intervention, as shown in Fig. 1.

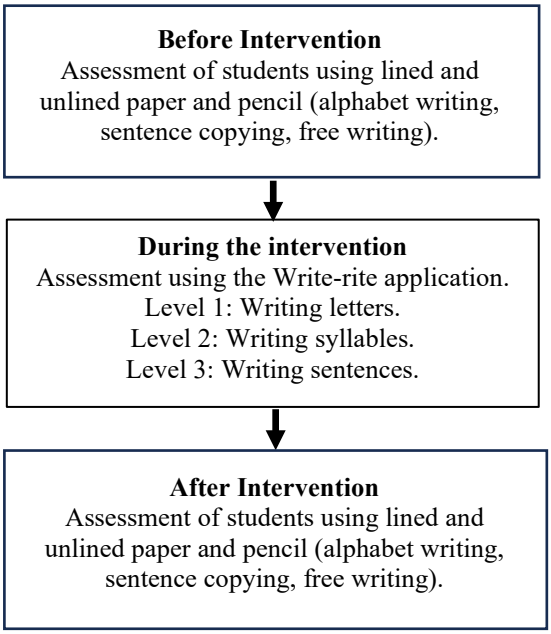

Fig. 1. Engaged activities for the assessment process

The prototype exercises are exposure and initial preparation for familiarizing students with the Write-rite application. Each student is equipped with an Acer or Galaxy SIII tablet. They are given a week to explore and familiarize themselves with the features of Write-rite. Teachers provide feedback to students based on observations during their interaction with the application. Each activity tailored to the student must be accomplished within a specific timeframe to demonstrate learning improvement before progressing to the next level.

The finger-guided letter formation exercise is the primary activity of the Write-rite application. Tracing and mimicking letters using fingers on the screen are suitable and can assist in understanding students with learning differences (Tonimoto et. al., 2015; Downing & Caravolas, 2020). Continuous practice enhances writing skills, directing attention toward spelling and punctuation (Palmis et al., 2017; Afonso et al., 2018).

3.4 Quality of letter formation

This criterion involves a detailed assessment of each produced letter. The quality of letter form is examined based on six elements of legibility: letter formation, size, proportion, spacing, slant, and alignment (Suárez-Coalla et al., 2020; Afonso et al., 2018). The focus on correct letter formation typically involves children aged between 5 to 7 years (Goirdano & Maiorana, 2014; Goirdano & Maiorana, 2015). The detailed quality of letter formation is assessed based on the following methods:

1. Incorrect direction of letter strokes: This occurs when the letter is formed, but upon examination, there are errors either in the direction of formation or the placement of strokes above the line.

2. Missed letter strokes occur when the required strokes are omitted, such as in the letter's 't' and 'f' without a middle stroke or in letters 'r,' 'n,' and 'u' formed with only one stroke.
3. Additional strokes in letters: Repetition of already formed strokes resulting in overlapping strokes.
4. Letter reversal: For example, the formation of the letter 'b' produced as 'd.' Many students struggle to form letters b, d, p, and q.

Therefore, proper letter formation procedures can reduce these errors. For instance, the production of the letters b and d can be differentiated; for the letter b, its starting point is at the top, while for the letter d, it starts in the middle. Emphasis on the starting point or key feature can enhance students' recognition of letter formation for smoother results. Based on the above criteria, the quality of letter formation is assessed, where a score of 1 is given if the letter formation is very poor, and a score of 5 refers to the score for correct letter formation.

4. RESULTS

A comparison of handwriting samples before and after the intervention is conducted to assess the exercises' effectiveness. The intervention primarily emphasizes letter formation, which is seen as a contributor to other issues. When letter formation becomes smooth, criteria for other problems can be addressed. Fig. 2 illustrates the comparison of correct letter formation after the intervention.

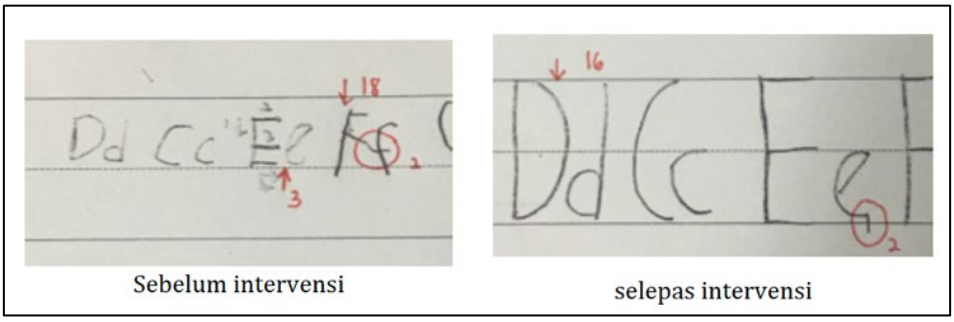

Fig. 2. Comparison of letter formation before and after intervention

Handwriting exercises are focused on as one of the learning activities to enhance motor and visual skills. A holistic assessment of the legibility of dysgraphic students' handwriting is necessary. This is because more emphasis is usually given to motor skills when dealing with writing difficulties. This issue should be viewed in a broader context involving linguistic and cognitive needs in producing writing. The detailed assessment for each criterion is explained as follows.

4.1 Letter formation

Letter formation is a crucial criterion for improving legibility and subsequently achieving automation in writing. Legibility should be prioritized first, followed by automation (Lifshitz & Har-Zvi, 2015; McCloskey & Rapp, 2017; Valdez, 2017; Grajo et al., 2020). The foundation of proper letter formation is essential for motor instruction implementation. Research conducted by Di Brina, indicates that dysgraphic students often struggle with proper letter formation, which can be linked to visual perception and motor coordination (Asselborn, Chapatte & Dillenbourg, 2020). Weaknesses in letter formation reflect a lack of knowledge about the correct letter formation procedures. Each letter has unique features that can be distinguished from one another for reference to assess the correct procedures. The analysis of data related

to letter formation quality indicates that these characteristics are considered when evaluating the criteria for letter formation.

For the letter formation criteria, the assessment scale is as follows: score 1 (less than 10 percent of formation features met), score 2 (less than 30 percent of formation features met), score 3 (50 percent of formation features met), score 4 (more than 70 percent of formation features met), and score 5 (100 percent of all features met). The assessment is based on a Task where students must rewrite the alphabet (uppercase and lowercase letters) from memory. Through this task, a detailed examination of each letter can be conducted. Fig. 3 illustrates a sample of dysgraphic student handwriting before intervention.

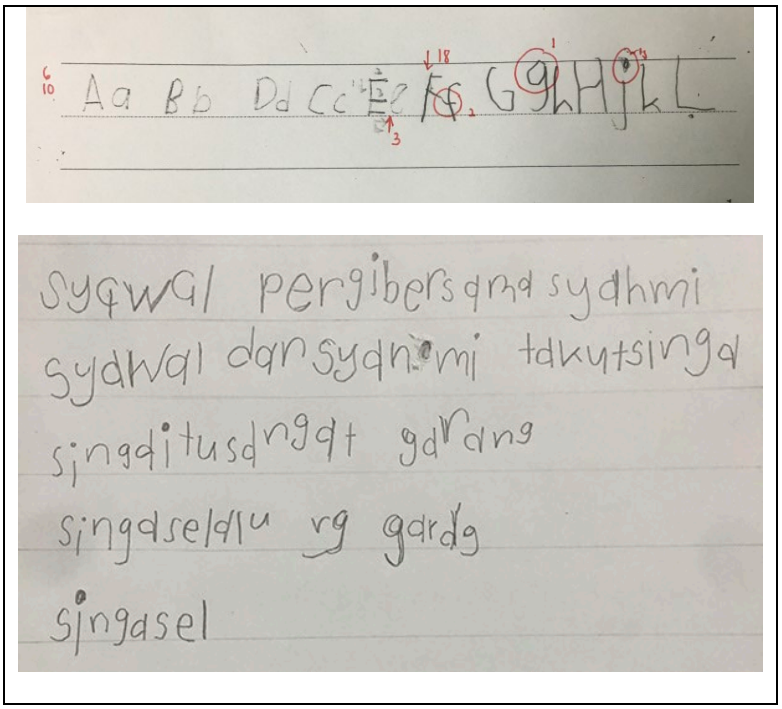

Fig. 3. Example of handwriting before intervention

The issue of letter formation emerges as a primary contributor to other problem criteria, especially global legibility, the effort required to read writing, and writing organization. As depicted in Fig. 4, it is evident that students face difficulties in letter formation, as they all obtained a score of 1 before the intervention was implemented.

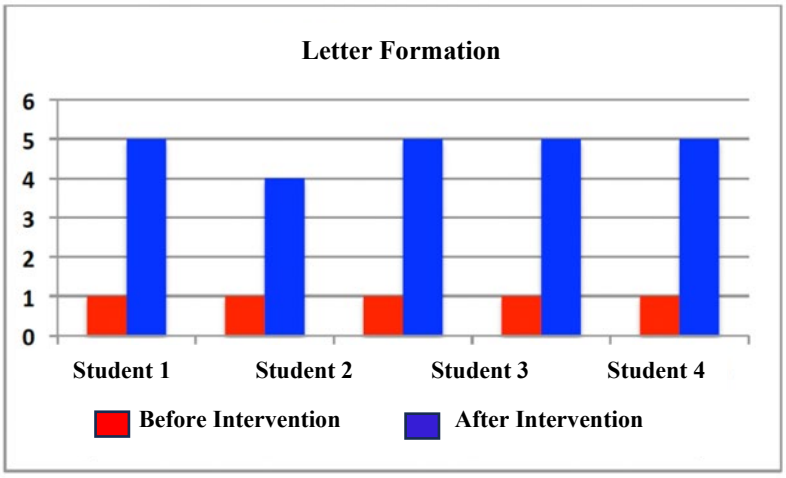

Fig. 4. Scores for letter formation criteria

All students were unable to produce the 26 alphabets in the correct sequence. Most of them could only generate half of the total alphabet and in the wrong order. Incorrect stroke procedures or sequences can make letter formation difficult. Another common mistake students make is related to the number of strokes for each letter. They either add or subtract strokes from the letters. For example, in producing lowercase letters 'a' and 'd,' almost all students struggled to distinguish them. Observations revealed that both letters were produced in the same form.

The intervention introduced key markers, sequences, starting points, the number of strokes, and essential strokes for each letter. Students could identify unique strokes for discrimination and differentiate each letter formation. After the intervention, through continuous exercises on basic letter formation, students were able to enhance their mastery of the correct letter formation procedures. As a result, four students scored 5, and one student scored 4, with an achievement percentage of 96. This indicates that through the exercises performed, motor memory and letter visualization could be improved to achieve automation in writing. Fig. 5 illustrates the results of letter formation after the intervention.

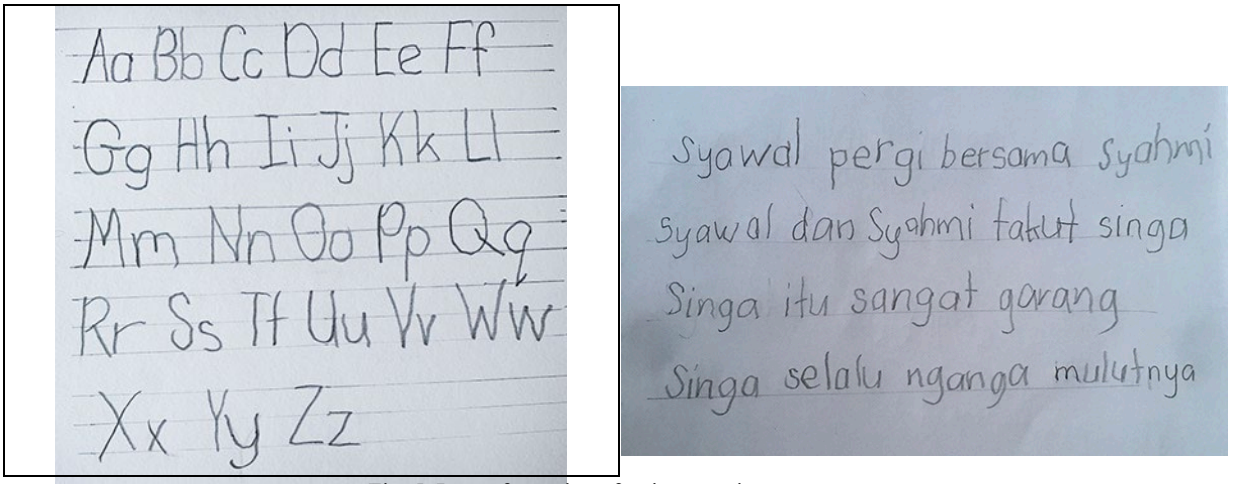

Fig. 5. Letter formation after intervention.

5. CONCLUSION AND RECOMMENDATIONS

After the intervention, students demonstrated a significant improvement in all criteria. The main improvement can be observed in the formation of uppercase and lowercase letters, where students could distinguish each production, and the size proportion was also consistent. This indicates that issues related to strokes in the wrong direction, missing strokes, additional strokes, incorrect stroke sequences, spacing, slant, and alignment could be overcome.

Efficiency in producing letters also showed positive progress, where the process of generating letters from memory became smoother and more organized. Overall, the positive impact on the handwriting of dysgraphic students can be observed after the intervention using the Write-rite application. Early intervention and specificity to the encountered problems can reduce students' pressure to produce handwriting. The process of generating letters from memory also became smoother.

Based on Figure. 3, a significant improvement can be seen in the criteria of letter formation is 96. This indicates that students can produce letters according to the correct procedures, words are modelled with consistent spacing between letters, the use of proper lines, and the produced letters are balanced and steady (uppercase and lowercase). The work produced by the students is also neat, and they can write confidently. Failure to achieve automatization in writing will hinder more complex writing tasks. Therefore, the developed application emphasizes improving students' cognitive skills and automatization in handwriting production. Consistently mastering the ability to produce letters quickly from memory is essential for the development of legible handwriting and the ability to complete various learning activities in the classroom. Students benefited greatly from exploring the Write-rite application within the allocated time and showed interest in completing tasks. Overall, the learning process became more engaging and easily understood.

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7. CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

8. AUTHORS' CONTRIBUTIONS

The sole author was responsible for all aspects of this paper, including conceptualization, methodology, data collection and analysis, and manuscript preparation.

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