Exploring the writing hypothesis using artificial intelligence

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ABSTRACT

This study investigates innovative approaches to recording and analyzing the early stages of literacy development, where children begin to graphically represent their oral expressions. The primary contribution is the development of an artificial intelligence (AI)-powered computational tool designed to identify and document students' writing progression. By leveraging machine learning techniques, the system provides educators with detailed, systematic, and frequent records, facilitating more informed instructional strategies. The research follows an experimental methodology, analyzing a dataset of 2,000 writing samples from early learners across diverse educational settings. To optimize the AI model's effectiveness, a specialized dataset of word images in Portuguese was developed, varying in syllable count and standardized to 224×224 pixels resolution for consistency in training. The study employs both quantitative and qualitative data analysis techniques, integrating statistical evaluation and pattern recognition algorithms to assess student writing proficiency. Findings indicate that the proposed system enables more precise and efficient tracking of literacy development, allowing for early identification of potential learning difficulties. This advancement in AI-driven assessment provides educators with actionable insights, enhancing intervention strategies and supporting personalized learning. Future research could explore expanding the tool's functionality to accommodate a wider range of educational contexts, further strengthening its role in literacy education.

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1. INTRODUCTION

Perception, visual-motor integration, and fine motor control are all necessary for handwriting, which is a complex skill. The literacy phase, which is critical to children's cognitive development, is when this ability develops [1]. A psychopedagogue, who tracks the psychogenesis of written language through different stages of language acquisition, is usually the professional in charge of monitoring this development. This process encompasses everything from the sensory-motor construction of writing to the development of mental imagery.

Teaching literacy is a top priority for early childhood educators. They play a critical role in teaching children to read and write, and in order to improve their teaching methods and foster student development, they must engage in ongoing professional development [2]. The literacy environment is crucial for knowledge acquisition because it fosters curiosity and encourages students to interact with the materials.

A classification system emphasizes distinct aspects of the cognitive journey in writing development. One approach focuses on the significant transitions from pre-syllabic to alphabetic stages, underlining the learner's active engagement in understanding the connection between letters and sounds. Another perspective expands the framework by including the early pictorial and scribbling phases while further dividing the syllabic stages [3].

This comprehensive approach considers not only phonetic values but also the visual elements and structural understanding of written language. Such a detailed perspective provides educators with a more refined tool to evaluate and support children's writing development, thereby enhancing the effectiveness of educational strategies informed by these theories. But because of the way educational systems are set up, the amount of work teachers have to do, and the emphasis on curriculum goals, teachers frequently put teaching written language above assessing students' cognitive or developmental progress [4].

Despite these obstacles, educators must acknowledge the value of literacy and their part in creating a stimulating learning environment that promotes students' overall growth [5]. Teaching writing and reading to large classes requires teachers to strike a balance while taking cultural and psychological aspects into account [6]. So, this study presents a tool that teachers can use to track and determine the writing development stages of students between the ages of six and seven. By leveraging machine learning and artificial intelligence (AI), the tool analyzes children's handwriting in an effort to classify it and detect potential cognitive or motor impairments. Its purpose is to support educators in their assessments.

2. CONCEPTUAL AND THEORETICAL FRAMEWORK

2.1. Stages of writing development

Various authors highlight that writing development is influenced by a child's native language and the cultural environment they are exposed to [7]. However, most agree that the first stage of a child's writing attempts is focused on directly representing the world in a non-arbitrary way, where the elements in their writing resemble what they represent. This is known as the non-alphabetic stage [8].

The next stage involves children understanding that writing is composed of symbols, and these symbols do not directly represent reality [9]. They begin to grasp the arbitrary nature of the writing system but still need to learn which symbols correspond to specific meanings. At this point, children often use the letters they are familiar with, usually those in their own name. This stage is called the pre-syllabic stage [10].

As they develop further, children realize that letters represent sounds, though they may still sometimes represent a syllable or a phoneme. This phase is known as the syllabic-alphabetic stage [11]. Once children understand that each letter represents a phoneme, they enter the alphabetic stage. In the alphabetic stage, children fully understand the alphabetic principle, allowing them to write words correctly. They recognize that letters represent sounds, and words are composed of syllables, and understand that letters can represent multiple sounds and that words can be written in different ways [12]. In this stage, children refine their writing and spelling skills and begin to use writing to communicate ideas and express thoughts [13].

The alphabetic stage marks a critical milestone, as children become independent writers capable of using writing for a variety of purposes [14]. Each child progresses through these stages at their own pace, with no fixed timeline. The essential element lies in the continued support and encouragement offered by parents, guardians, and teachers throughout the entire process of writing.

2.2. The identification and categorization process

When a child enters the Lettering stage, they go through the stages already described, and the teacher, trained to identify which stage the student is in, adapts the activities to help the student overcome the current phase and move on to the next stages, such as literacy [15]. The method traditionally used for this assessment is the writing hypothesis test. As shown in Figure 1, identifying the children's writing level is crucial for teachers to plan meaningful activities and propose cognitive conflicts that will help children progress in the literacy process.

Traditionally, children practice handwriting through exercise sheets in the classroom, starting with letter recognition. At this stage, the form of the letter is associated with sound (perceptual and linguistic knowledge). Then, children trace and copy the letters (motor skills), a process that involves cognitive skills such as planning and motor execution [9]. Recently, technological resources have been changing some teaching methods. For example, several schools have started using tablets to complement existing written work in the classroom [16]. Technology has proven to be an effective solution for facilitating handwriting learning and engaging children in the practice process [17]. However, more information is needed about the results of using these applications, especially in fine motor skills development, such as handwriting.

In the realm of educational technology, understanding the developmental stages of writing is critical for crafting effective interventions that enhance literacy acquisition. Writing encompasses intricate processes involving fine motor coordination and visual-motor integration, skills that are honed during the early literacy stages.

Writing quality is closely linked to a student's ability to segment words and sentences, which helps with text comprehension. Therefore, it is crucial for educators to closely monitor the psychogenesis of written language to recognize potential difficulties early on and offer timely pedagogical interventions-such as gamified learning experiences and writing activities tailored to each student's needs.

Various researchers have proposed distinct classifications for the developmental milestones of writing. Among them, Shepherd [1] stands out for introducing a valuable framework that traces the evolution of writing from early symbolic marks to the full acquisition of alphabetic principles. In contrast, our approach presents a more granular classification, comprising eight distinct stages of writing development. Emphasizing the importance of pedagogical flexibility, this model is designed to support children's progress at each phase, beginning with initial scribbles and culminating in conventional alphabetic writing [2], so this classification unfolds across the following eight levels:

- Iconic (level 1)
- Scramble (level 2)
- Differentiated writing (level 3)
- Syllabic without phonetic value (level 4)
- Syllabic with phonetic value (level 5)
- Syllabic-alphabetic (level 6)
- Alphabetic (level 7)
- Orthographic (level 8)

2.3. Evaluation strategy

Assuming that identifying the student's writing hypothesis can help educators develop more efficient educational strategies, we began researching the development of a computational tool that could assist literacy teachers in conducting writing hypothesis assessment (WHA) activities. WHA is a common activity in early childhood education (ECE) classrooms and is part of the "Mais Alfabetização" program established by Brazilian Ministry of Education (MEC-BR) ordinance nº 142/2018. Given that understanding children's early writing behaviors can help educators design more effective instructional strategies, we began investigating the development of a computational tool to support literacy teachers in assessing emergent writing activities [18]:

- Preparation and organization: the teacher review the evaluation criteria and organizes the classroom environment.
- Choosing the moment: the teacher selects an appropriate time for the evaluations, usually during less distracting periods.
- Calling the children: children are called individually to take the evaluation.
- Conducting the evaluation: the child writes and reads a word, and the teacher observes and records the child's gestures while reading.
- Analysis and recording of results: the results are recorded and analyzed to identify patterns and difficulties.
- One of the main challenges of this approach is the time required for evaluations, which can take approximately 30 minutes per student. Given that, according to MEC-BR data, early elementary school classes in Brazil average around 25 students, the process can become quite demanding.

The WHA activity uses exercise sheets, which may vary in format. The proposal involves incorporating mobile devices that minimally alter the usual routines, enabling teachers to photograph the exercise sheets and quickly obtain an analysis using AI, offline, that indicates the student's writing level. This analysis could provide suggestions and changes made by the educator and allow them to record the students' activities for later analysis of their progress.

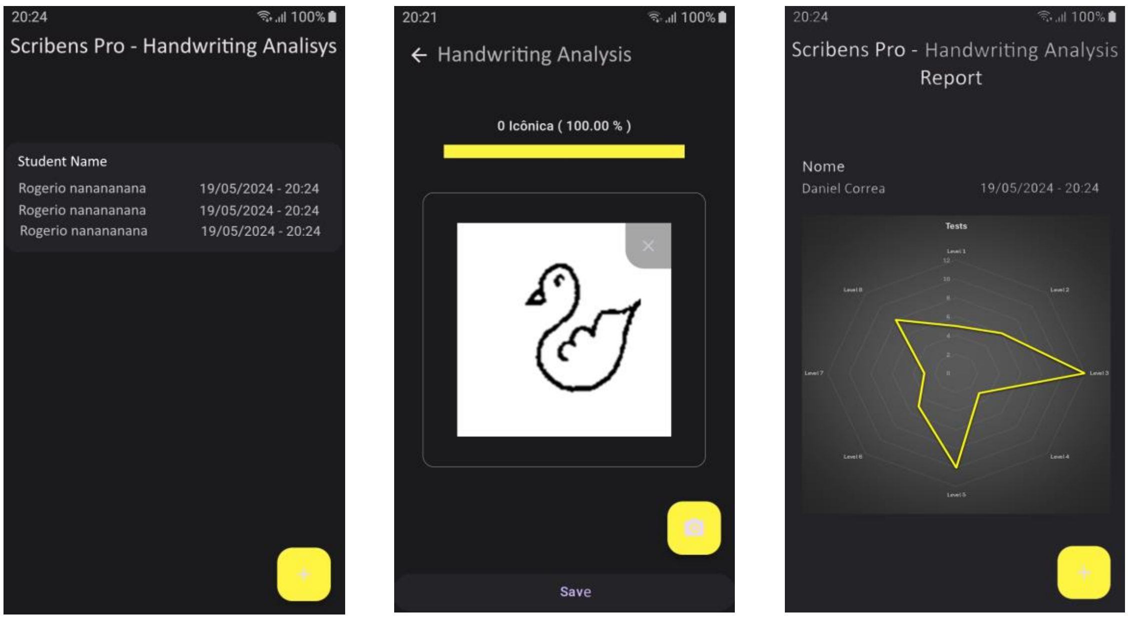
This approach not only aims to facilitate the initial writing evaluation process but also seeks to optimize teachers' time, providing an effective tool to identify patterns and difficulties in children's writing learning. Given all these factors, the proposal is for the app to support teachers throughout the process, enabling more frequent evaluations and helping them monitor the results of their interventions more accurately, addressing the specific needs and stage of each student.

School organization and the teachers' workload can limit their ability to identify and intervene in learning difficulties [19]. It is important for educators to understand the significance of literacy and receive continuous training to create environments conducive to student development. The challenge lies in teaching classes while considering variations in writing and the cultural context of each student.

2.4. The prototype

The prototype developed by the team at the Visual Computing Laboratory of the Federal University of Paraná comprises a software solution with two main components: a mobile application for devices and a web-based environment for managing usage records. This dual architecture is intended to facilitate an integrated and efficient system for collecting, storing, and analyzing data on student writing hypotheses captured by the mobile app. Figure 1 provides an illustration of this setup, initial app page, image capture, and report.

Figure 1 illustrates the user interface of the educational application developed by our team, which is tailored for monitoring and enhancing student learning experiences through writing analysis. Panel a display the main dashboard for educators to start analysis of student submissions as shown in Figure 1(a). In Figure 1(b), the application guides the user to activate the device's camera functionality, enabling them to capture images of student handwriting. This feature is pivotal for integrating real-time data into the system, which then processes the handwritten content. In Figure 1(c) presents the analytical outcomes, providing users with a comprehensive overview of the assessments conducted during the application's usage.



(a) (b) (c)

Figure 1. Mobile app interface (in Portuguese): (a) initial app page, (b) image capture, and (c) report

It explicitly showcases a radar graph charting eight developmental levels of writing that align with learning and literacy acquisition stages. These levels were trained on an algorithm using segmented image datasets, representing distinct stages of writing skill progression. The radar graph in the image visually maps a specific student's performance against these eight levels, with a yellow line connecting the scores achieved. The graph evaluates writing skill development across these categories, identifying strengths and potential areas for growth.

This visual presentation underscores the power of AI-enabled tools like Scribens Pro in assessing and supporting educational progress. By leveraging a robust training regimen based on diverse image datasets, the tool facilitates a nuanced understanding of writing development, enabling targeted interventions and personalized learning strategies. This visual feedback is crucial for educators to understand and interpret the progression and performance of students in their writing tasks, thus facilitating targeted instructional strategies.

The mobile app component is designed for installation on smartphones and tablets, serving to gather usage data by capturing interactions, preferences, and activities relevant to the app's function. It functions as the principal user interface, facilitating data entry and providing an engaging, interactive experience for users. The web environment functions as a centralized platform for the management of usage records collected via the mobile application. It provides a secure repository for data storage and facilitates comprehensive analysis, potentially offering advanced visualization tools and reports for interpreting usage patterns and user behavior.

Secure communication is established between the mobile app and the web environment to ensure data integrity and confidentiality during transmission. Mechanisms for authentication and authorization are implemented to restrict access to the usage records within the web environment to authorized users only. This software solution is designed to offer a comprehensive system for tracking and managing usage data, seamlessly combining the mobility of a mobile application with the centralized analytical power of a web-based platform. This integrated structure enables a deeper insight into user behavior and fosters data-driven decision-making in the software development process.

Based on the theories of children's writing development and how professionals conduct WHA, we conceptualized the "Scribens Pro" app, which uses AI to detect the writing level of students and track their progress. Concerning the teachable machine (TM) within the web-service, this study is centered on the recognition of handwritten characters to aid document analysis and transcription, and to develop automated systems for identifying writing stages. Handwriting recognition methods are examined to address the challenges in creating efficient algorithms for character, symbol, and sketch identification in written material.

Deep learning (DL), a technique in AI, is noted for its effectiveness in recognizing handwritten characters despite variations in style, size, and clarity [20]. DL models have been trained to achieve recognition success rates between 75% and 98%, marking it as a valuable method for enhancing character recognition accuracy. The effectiveness of character recognition is influenced by the quality of training data, preprocessing and segmentation methods, and the chosen recognition model. To prepare the AI model for its intended educational application, our team developed a specialized dataset featuring word images in Portuguese, varying in syllable count [21].

In our software each image was captured at a consistent resolution of 224×224 pixels to ensure uniformity in the training process. The dataset was meticulously curated to include words at different stages of complexity, such as "*Pato*" (duck), "*Macaco*" (monkey), and "*Brigadeiro*" (Brazilian chocolate truffle), reflecting the diversity of student writing samples. The algorithm's training regimen was structured around segmented image classes that correspond to distinct stages of writing development, as follows:

- Iconic (level 1): 239 images representing the initial stage where children's drawings begin to show intentionality in representing written language.
- Garatuja (level 2): 243 images capturing the scribbling phase, characterized by random strokes that may start to suggest letter-like forms.
- Pre-syllabic differentiated writing (level 3): 238 images where the writing begins to differentiate from scribbling but do not yet correspond to syllabic representation.
- Syllabic without sound value (level 4): 231 images illustrating attempts at syllabification without accurate phonetic correspondence.
- Syllabic with sound value (level 5): 233 images showing a progression where syllables begin to be represented with some phonetic accuracy.
- Syllabic-alphabetic (level 6): 238 images depicting a transitional stage between syllabic writing and the alphabetic principle.
- Alphabetic (level 7): 250 images indicating a more advanced level where children write words using a one-letter-for-one-sound correspondence.
- Orthographic (level 8): 230 images showcasing writing that conforms to conventional orthographic norms, indicating a higher level of literacy development.

Each class was instrumental in enabling the AI model to learn and distinguish between the nuanced expressions of written language development. By training the model with these diverse classes, we aim to provide an educational tool that can accurately assess and categorize student writing, thus supporting educators in tailoring interventions that meet students at their current level of writing proficiency.

The procedural sequence for implementing the DL program to identify handwritten images captures images through the camera or from the device's album. The image detection module then identifies specific coordinates and the area size for recognition, minimizing external interference. In the subsequent Image Detection module, images undergo normalization to reduce the impact of angles and lighting. Key features are located, and the image is transformed to align with standard coordinates, requiring conversion to grayscale.

The feature extraction module utilizes parameters from a TM training model, performing forward propagation on the input images and extracting feature vectors from the last hidden layer [22]. The image matching module uses cosine similarity on feature vectors to check if images belong to the same character class. TM utilizes the mobilenet architecture and allows adjustments to parameters such as epochs and batch size, facilitating the training process with transfer learning (TL). The model was exported in TFLite format for use on mobile devices [23].

2.5. AI algorithmics training methodology

Training was performed with 75 epochs, a batch size of 16, and a learning rate of 0.00115. Real-time results were analyzed using the under the hood function, which provides a detailed visualization of the model's performance [24]. The use of TM provided an intuitive interface for training ML models. By following the configuration steps, it was possible to upload images from different early writing classes and train a classification model with adequate accuracy. The analysis of performance metrics such as accuracy per class, confusion matrix, accuracy per epoch, and loss allowed for the identification of the model's strengths and areas for improvement.

The choice of parameters such as the number of epochs, batch size, and learning rate was crucial in balancing the model's complexity and training time. The under the hood function was essential for monitoring the model's performance during training, offering valuable insights for future adjustments. The result was a model capable of classifying various early writing hypotheses with high accuracy, demonstrating the feasibility of using machine learning tools to support educational assessment and facilitate teachers' work [25].

In developing the software, an AI model for handwriting analysis was used, applying TM algorithms. A comprehensive evaluation of its performance metrics was carried out to assess its suitability for use in everyday teaching. The analysis explored key metrics such as precision, recall, classification accuracy, and loss values, offering insights into the model's ability to distinguish between different stages of handwriting development. These metrics revealed how effectively the model identifies and classifies handwriting features, as well as its overall reliability and learning efficiency.

3. METHOD

In this study, we used the design research approach because it is a method that facilitates the generation of knowledge in a research context. Design science research (DSR) aims to examine, investigate, and research the artificial and its behavior from both an academic and organizational perspective [26]. In this sense, DSR is established as a rigorous process of designing artifacts to solve problems, evaluating what has been designed or is in operation, and communicating the results obtained.

3.1. Warranties and ethics

The research project was submitted to the ethics committee of the Federal University of Paraná for analysis. After being reviewed, we were authorized to begin research involving human subjects. It is important to highlight that the research aims to verify whether the computational tool facilitated or not the teaching work based on real cases of its use.

In design science, "problem classes" and "artifacts" play a central role in the generation and application of knowledge. The conceptual definition of these elements is crucial for understanding and advancing in this field of study. Thus, "problem classes" represent the categories or challenges that design science seeks to solve. These problems can vary widely and encompass issues related to technology, organization, and human interaction. Identifying and understanding problem classes is essential for guiding research and developing innovative solutions.

Conversely, artifacts are tangible or conceptual outcomes—such as products, systems, or solutions—developed through the application of DSR methods to address specific classes of problems. These artifacts may encompass physical and technological tools, conceptual frameworks, and organizational strategies. The development and evaluation of such artifacts constitute core elements of the DSR methodology. Within this approach, the relationship between problem classes and artifacts is inherently interdependent: problem classes inform the identification of needs and challenges, while artifacts embody the proposed responses to those issues. Accordingly, a thorough understanding of the problem space is essential to ensure the design and implementation of artifacts that are both relevant and impactful. Table 1 presents a summary of the identified problem classes alongside their corresponding artifacts, serving as a foundation for the subsequent analysis.

Table 1. Problems and artifacts category

No.	Problem class	Artifacts
1	Technical problems of image capture, analysis, and recognition	Functional and structural system tests
2	Image processing	Performance test of the recognition algorithm
3	Interaction with the system user	Usability test of the system
4	Interpretation of results	Semiotic tests of meaning

3.2. Subjects

This study investigates the performance of a mobile application designed to capture and recognize handwriting images, utilizing a sample of 25 subjects to assess its efficacy. This analysis provides a detailed understanding of how the application accommodates diverse handwriting abilities and styles, which are particularly relevant in educational settings.

The sample of 25 subjects was intentionally diverse, encompassing a wide range of writing proficiency. Participants included early learners at the iconic and garatuja (scribble) stages as well as more advanced students with developed orthographic skills.

Handwriting samples were collected using the app's camera interface, which reliably captured high-resolution images for AI processing. The AI model then classified these images into developmental writing stages. The study reported that the app can be used for diagnostic purposes, allowing educators to assess developmental stages and identify areas where students may require additional support. It also offers progress tracking capabilities for longitudinal monitoring of individual development and evaluation of teaching strategies. Additionally, the findings highlight the importance of enhancing model customization through more diverse training datasets to improve AI generalization.

4. RESULTS

Figure 2 provides a detailed evaluation of four critical features of an educational technology system: user interface usability, real-time processing, image capture quality, and error handling. These features were assessed using a five-point Likert scale ranging from "strongly disagree" to "strongly agree". The data offers valuable insights into these features' performance, highlighting strengths and areas for improvement.

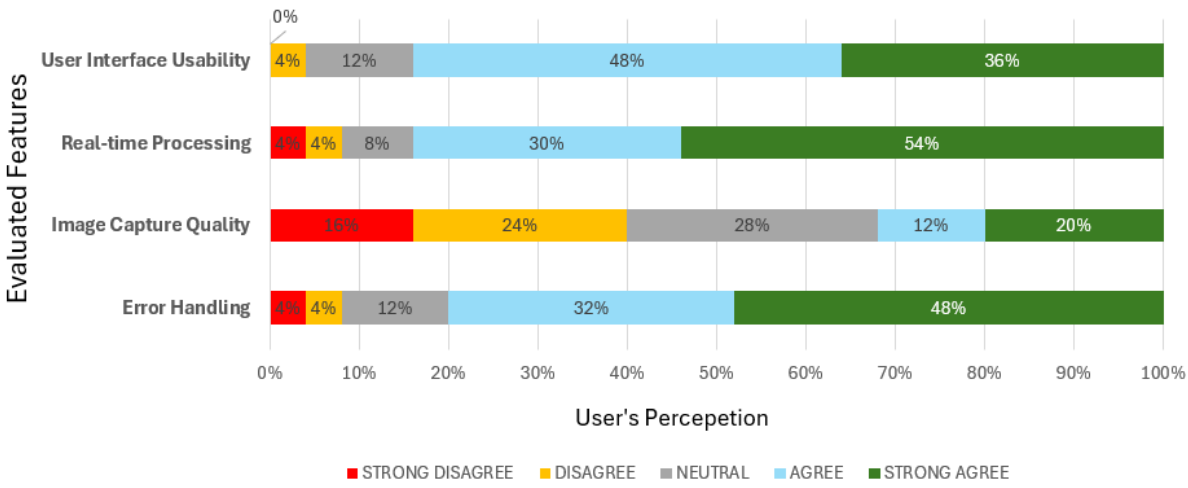


Figure 2. Functional and structural system test

Starting with user interface usability, the results reveal that most respondents perceive this aspect positively. A combined 84% of participants either agree or strongly agree that the system's interface is user-friendly and efficient, with 48% falling into the "agree" category and 36% in "strongly agree". We think that implies that the interface design meets user expectations regarding accessibility and ease of navigation. However, a small proportion, accounting for 12%, remains neutral, indicating potential areas for refinement, while 4% express dissatisfaction. Despite these minor concerns, the overall sentiment reflects a robust endorsement of the interface's usability.

Real-time processing emerges as the highest-rated feature in this evaluation. 54% of respondents strongly agree that the system performs well in this domain, and an additional 30% agree, resulting in 84% expressing positive feedback. Neutral responses comprise only 8%, while disagreement is negligible at 4%. The overwhelmingly positive reception of this feature underscores the system's reliability and efficiency in handling real-time tasks, which are often critical in educational technology applications. This capability enhances the user experience by ensuring smooth and immediate interactions, a key requirement in dynamic learning environments.

Conversely, image capture quality stands out as the most problematic feature, with significantly lower satisfaction levels than the others. While 20% of participants strongly agree that the image capture functionality meets their expectations, and 12% agree, these figures are overshadowed by the substantial percentages expressing dissatisfaction. Notably, 16% strongly disagree, and 24% disagree with image capture quality. Moreover, 28% of respondents remain neutral, signaling uncertainty or inconsistency in their experience with this feature. These results indicate a critical area that demands immediate attention from developers. Enhancing image capture quality could significantly improve user satisfaction and system performance, mainly if this feature is pivotal in the platform's intended applications, such as remote assessments or interactive content creation.

On the other hand, error handling is another area of strength for the system. Nearly half of the respondents, 48%, strongly agree that the system effectively handles errors, while 32% agree. This combined positive response rate of 80% suggests that the platform is reliable in managing issues that arise during usage, ensuring minimal disruptions to the user experience. Neutral responses are relatively low at 12%, and only 8% of respondents express any disagreement. These findings indicate that the system's error management protocols are robust, contributing to its dependability and usability in educational settings.

In summary, the graph comprehensively shows the system's performance across key features. Real-time processing and error handling are clear strengths, demonstrating the platform's capability to deliver consistent and reliable performance in critical areas. User interface usability also receives strong approval, though minor refinements could further enhance its effectiveness. However, image capture quality presents a notable challenge, with significant user dissatisfaction. This issue should be prioritized for developers aiming to improve the system's overall performance and user satisfaction.

5. DISCUSSION

The hypothesis that drove our study was that a mobile application designed to capture and analyze children's handwriting could significantly improve the identification of written language disorders [1]. Our findings supported and highlighted the potential of our application to serve as an innovative tool to assist novice teachers, bridging the gap between traditional handwriting assessment and advanced technological solutions [22].

Although the data analysis showed that the user experience of the interface was a strong point, we addressed some interferences that may directly affect this good experience. This positive reception highlights the application's ability to meet user expectations regarding accessibility and ease of use [6]. Nevertheless, a minor fraction of neutral and somewhat dissatisfied feedback highlights opportunities for enhancement, particularly in addressing the needs of younger users or individuals who encounter challenges navigating the interface. One of the key strengths of our application lies in its ability to assist educators in promptly identifying language disorders. It facilitates interactive analysis and engagement, enabling the delivery of timely and precise interventions [27].

Our study also revealed that image capture quality is a key factor for improvement. We found that teachers (the subjects of this research) did not have modern devices with high-resolution cameras. This is why some responses were false negatives, meaning it was not the app's fault but the devices [19]. The feature received lower satisfaction ratings, with notable dissatisfaction expressed by participants. Therefore, this requirement must be improved to ensure more meaningful analytical results.

Addressing these limitations is vital to realizing the app's full potential in detecting writing difficulties and providing personalized educational insights [28]. Error handling emerged as a key strength of the application, with many participants indicating that the app effectively manages errors [23]. This capability ensures that when issues arise during usage, the app can recover gracefully without interrupting the overall experience. This resilience is important in educational settings because it enables consistent interactions for students and educators and supports the application's dependability [14]. A dependable system builds user smoothmizes frustrations, allowing educators to focus more on the learning objectives and less on technical disruptions [15].

Overall, the findings underline the app's strong performance in areas such as usability, real-time processing, and error management while emphasizing a critical need for improvement in image capture quality [17]. Addressing this issue will enhance the app's utility and user satisfaction [27]. This ability to personalize learning activities and adapt to various language and skill levels aligns with the multidimensional nature of literacy development [29], addressing both technical and behavioral aspects of learning.

6. CONCLUSION

This study emphasizes the importance of aligning writing skill development with a child's cognitive and emotional growth. Writing reveals socio-emotional and behavioral traits, necessitating tools that help teachers address challenges effectively. In response, an AI-powered mobile application was developed to analyze handwriting, using a diverse sample of 25 children across various writing stages, from iconic to orthographic. The findings underscore the app's potential to personalize learning, offering flexibility for activities across languages and skill levels.

The app demonstrated strengths in usability, real-time processing, and error handling, which were widely praised for enhancing the user experience and enabling immediate, actionable feedback. However, some users, particularly younger students, highlighted challenges in navigating the interface. Image capture quality emerged as the primary area needing improvement, highlighting the need for better reliability across diverse conditions to ensure accurate analysis. This innovative approach blends mobile technology and AI, empowering educators to identify subtle literacy-related developmental patterns. Its language-independent design promotes inclusivity, supporting various educational needs. The app modernizes teaching practices and fosters equity by enabling early detection of writing issues and offering personalized interventions. Future research should expand its application across diverse contexts, maximizing its transformative potential in educational technology.

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This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

ETHICAL APPROVAL

In Brazil, ethical approvals provided by committees such as the Federal University of Technology of Paraná are designated with a unique identifier referred to as the "CAAE" (Certificado de Apresentação para Apreciação Ética). The CAAE identifier assigned to this research is 43754821.6.0000.5547.

DATA AVAILABILITY

The authors confirm that all data supporting the findings of this study are contained within the article and its supplementary materials. Derived data supporting the findings of this study are available from the corresponding author, [EFD], upon request.

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