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Preventing Dysgraphia: Early Observation Protocols and a Technological Framework for Monitoring and Enhancing Graphomotor Skills

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Abstract: Writing is first-order instrumental learning that develops throughout the life cycle, a complex process evolving from early childhood education. The identification of risk predictors of dysgraphia at age 5 has the potential to significantly reduce the impact of graphomotor difficulties in early primary school, which affects handwriting performance to such an extent that it can become illegible. Building on established scientific literature, this study focuses on screening processes, with particular attention to writing requirements. This paper proposes a novel prevention and intervention system based on new technologies for teachers and educators or therapists. Specifically, it presents a pilot study testing an innovative tactile device to analyze graphomotor performance and motor coordination in real time. The research explores whether this haptic device can be used as an effective pedagogical aid for preventing graphomotor issues in children aged 5 to 6 years. The results showed a high level of engagement and usability among young participants. Furthermore, the quality of graphomotor traces, respectively executed by children after virtual and physical training, were comparable, supporting the use of the tool as a complementary training resource for the observation and enhancement of graphomotor processes.

Keywords: specific learning disorders; dysgraphia; graphomotor skills; dysgraphia risk predictors; dysgraphia early identification; handwriting; haptic training; decision support system

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1. Introduction

The period between the conclusion of kindergarten and the start of primary school is widely acknowledged worldwide as a critical phase for the progressive refinement and consolidation of reading, writing, and mathematical skills [1]. Within the Italian context, according to the latest data from the Italian Ministry of Education [2], the number of students with dysgraphia certification has significantly and consistently increased, rising from 30 to 99.8 thousand over the last seven years. A similar situation is registered in the Spanish educational context, where there is a high prevalence of students diagnosed with specific learning difficulties [3]. Given this situation, schools face the challenge of identifying, attending to, and appropriately including students with learning difficulties, specifically those diagnosed with dysgraphia. In this context, this paper aims to conceptualize new technological tools to support the early identification of predictors of dysgraphia in early childhood education in the context of two European countries with common cultural, linguistic, and educational characteristics: Italy and Spain. Starting from an analysis of the Italian and the Spanish educational systems, it provides an international perspective to identify both commonalities and differences in how each country's legislation addresses the rights of children and young people with dysgraphia to equitable and inclusive education.

Inclusive education appears as a paradigm that promotes the development of educational policies, cultures, and practices aimed at the inclusion of all students, regardless of their individual characteristics and potential [4,5]. In this framework, Specific Learning Disorders (SpLDs), such as dysgraphia, among others, pose significant challenges for education professionals, who must ensure equitable and inclusive quality care for all learners. It is essential that teachers have adequate training to enable them to effectively address the needs of all students [6], with an approach to the process of teaching and learning based on scientific evidence, didactic innovation, change, and improvement; in other words, consistent multidisciplinary training so that all teachers are promoters of educational inclusion [7–9]. Similarly, this preparation is essential to identify, eliminate, and/or minimize the barriers that hinder the presence, participation, and progress of students in the classroom. In this line, it is also crucial to consider, in both initial and ongoing training, beliefs and attitudes, norms, and school functioning (e.g., leadership, established culture, educational project). These are some of the main barriers for schools to provide adequate responses to student diversity [10–13].

2. Motivation and Objective for a New Pedagogical Prevention Model

In the educational context, writing is considered a crucial skill, acting as a link between the acquisition of knowledge and its expression; and it is so because it is a very complex process of encoding and decoding. In this sense, students with dysgraphia show difficulties in producing legible and coherent texts [1,14]. Between the end of preschool and the beginning of primary school lies a crucial phase in the progressive refinement and consolidation of foundational reading, writing, and arithmetic skills. The relevant scientific literature [15–17] indicates that the two most significant developmental periods are the ages of 5–6 years (high precocity) and 6–7 years (low precocity). This finding underscores the importance of identifying early predictors of risk for potential Specific Learning Disorders (SpLDs) within these "developmental windows". In particular, for the 5–6 age group ([18,19], it is recommended that early screening practices should be widespread and well-organized [20] to aid in identifying and/or monitoring challenges that may interfere with the natural progression of reading and writing skill acquisition [1]. It has been demonstrated that the timeliness and promptness of intervention are essential indicators that can significantly influence the trajectory of the disorder [1]. Early intervention reduces the severity of the disorder and the risk of secondary comorbidities, benefiting the individual's overall functioning profile [21,22]. Systematic observation, the activation of corresponding enhancement training, the documented monitoring of developmental progress, and shared educational responsibility in the transition from preschool to primary school are, therefore, key pillars of effective educational and instructional practices. Early intervention allows students to minimize behavioral difficulties that may arise, such as a tendency to avoid participation and a desire to go unnoticed, due to a possible disadvantage in writing tasks compared to their peers, by participating in classroom activities [23]. The distinction between learning difficulties and Specific Learning Disorders (SpLDs) is well-established in the literature [24–26]. Learning difficulties are often temporary and can be addressed through appropriate interventions, while SpLDs, diagnosed through specialized evaluation, are persistent conditions that impact specific skills and significantly affect both academic performance and daily life. In the preschool setting, this distinction serves as a fundamental guideline for shaping the perspectives and actions of educators, helping them to avoid two common pitfalls: the risk of overlooking a potential case of SpLDs, or, conversely, the tendency to interpret all children's difficulties as potential SpLDs [1]. For this reason, teacher training and shared educational responsibility are essential in preventing late identification. Delayed recognition cannot only hinder the prognosis and progression of the disorder but can also foster a tendency to view SpLDs as a lens through which to interpret all school-related difficulties [1]. Given this distinction, schools and teaching staff play a central role in proactive interventions and initial screening. A broad-based assessment across entire sections or classes enables the early detection of behaviors that, collectively, may indicate the potential development of

SpLDs [1]. The scientific lines that we have just discussed have motivated the experimentation of a technological device to support a new pedagogical model of prevention. In this paper, we focus on screening processes, with particular attention to writing requirements, through a comparative analysis of standardized prevention protocols in Italy and Spain. The protocols currently used in Italian and Spanish schools are perceived by teachers as too complex or not very functional to the school context. For this reason, the paper aims to propose a new prevention and intervention system based on new technologies for teachers and educators or therapists. Specifically, this study introduces a system that incorporates a Decision Support System (DSS) with intelligent tutoring capabilities. This system is designed to assist teachers and therapists/educators in identifying early motor issues related to handwriting and in crafting personalized interventions to enhance students' graphomotor skills. The proposed system offers a comprehensive analysis of children's writing performance, emotional responses, and motor coordination, enabling educators to design individualized strategies to strengthen graphomotor abilities. It is designed to be adaptable for use in both Italian and Spanish classroom settings, as well as in distance learning contexts. Furthermore, we outline an enhancement program, developed under the umbrella project PRIN 2022 "E-Hand. Empowering middle childhood Handwriting", for early childhood education aimed at improving handwriting skills regarding accuracy and fluency.

3. Research Background

Authors such as [27,28] conceptualize dysgraphia as a functional disorder that prevents the correct execution of writing, in addition to difficulties in reading and calculation. For the focus of this paper, we will concentrate on dysgraphia as a Specific Learning Disorder, starting with a review of the physiological processes involved in writing. It should be noted from the outset that writing "is a complex skill that develops over time and depends on various components" [29] (p. 128), constituting a multidimensional competence that includes executive and cognitive functions that mutually interact and influence each other [30]. On the graphomotor level, writing competence relies on the joint and integrated maturation of various kinesthetic, visual-perceptual, motor, and cognitive abilities, allowing for controlled and fluid manipulation. The coordinated and visually monitored movement pattern, supplemented by sensorimotor feedback [31] that enables fluent writing, requires the exercise of fine motor skills [32] as well as gross motor skills for posture control during writing tasks [33]. These skills are essential for reproducing letter shapes with accurate sizes and proportions, arranging them in a serial order on a specific spatial plane, while maintaining linear orientation and overall spatial organization [34]. Handwriting, on an executive level, is thus "a complex perceptual-motor skill that involves a combination of visuomotor coordination, motor planning, cognitive and perceptual skills, as well as tactile and kinesthetic sensitivity [. . .]. The motor and perceptual components related to writing performance may include fine motor control (in-hand manipulation, bilateral integration, and motor planning), visuomotor integration, visual perception, kinesthesia, sensory modalities, and sustained attention" [35] (p. 313). An uncertain acquisition of the motor schema underlying movement coordination and action organization, poor fine motor skills, undeveloped lateral dominance, or difficulties in hand–eye coordination, along with challenges in visual discrimination or sequential visual memory, may affect writing activities as early as the final year of preschool. Difficulties in these areas can result in slow and inconsistent handwriting, challenges with directionality and spatial management on the page, and weak or excessive pressure on the page, all of which may signal potential difficulties in acquiring writing skills. It is, therefore, crucial to identify the components involved in writing performance "as a means to target effective intervention strategies" [35] (p. 313). Focusing on the peripheral and executive processes [36–38] involved in the acquisition of graphomotor skills, the literature consistently identifies a set of recurring processes implicated in the automated production of written strokes. As the reference literature highlights [39], key processes include kinesthetic, visual-perceptual, spatial, fine motor, sensorimotor integration, movement planning, and proprioceptive awareness. According to [40], the fundamental processes for learning to write can be identified as visuomotor perception and integration, spatial-temporal organization and integration, body schema knowledge and representation, right/left orientation, motor coordination, lateral dominance, memory, and attention. At four years old, these processes are still in an emerging developmental phase, meaning observed performance "seems to have transient and spontaneously recoverable characteristics, while by five years old, it is characterized more as a stable condition, generally less compensable by the child alone" [24] (p. 18). By this age, further learning should already be underway [41], making the final year of preschool an optimal period for identifying reliable predictors. Risk indicators are defined as "personal and social factors whose presence increases the likelihood that an individual may develop a specific disorder over time" [22] (p. 39), and could, therefore, become focal points in prevention programs. In light of these scientific considerations, prevention becomes a central strategic action for promoting inclusive processes from the early stages of preschool, where it is essential to train educators to create learning environments rich in facilitators and tailored to the characteristics and needs of all students. Inclusive planning begins with intentional observation, and in this regard, the scientific literature provides a range of validated protocols. Consequently, in the following section, we will outline the current state of available tools for first-level assessment during the high-predictability developmental window (ages 5–6), focusing on assessments that enable the observation of reliable predictors within the processes underpinning writing development. In terms of personality and psycho-affective factors, when students face writing difficulties at school, they may experience emotional conflicts, such as effects on feelings and self-esteem. Therefore, the methodologies used by teachers must be oriented towards minimizing these impacts [23]. It is essential to highlight the comorbidity of dyslexia with other disorders, among which difficulties in writing (dysgraphia) may be frequent [42]; according to this author, each disorder has its own identity, although it may appear with dyslexia. Hence, there is a significance in making a proper diagnosis and, on the other hand, detection and care at an early age [14]. Pérez-Caina et al. [43] distinguish between two types of dysgraphia: specific and motor dysgraphia, identifying evolution, phenology, or superficial factors as possible origins. On the other hand, Beltrán [44] classifies dysgraphia into two categories: developmental dysgraphia, which affects pupils in the process of learning to write, and acquired dysgraphia, which arises as a result of a brain injury that causes difficulties in writing. It has already been mentioned above that early detection contributes to the improvement of later learning in primary education. This detection can be carried out by teachers by observing the pupils' productions. To this, we should add the importance of acting early in the Response to Intervention Model (RTI), i.e., as soon as we detect some signs, as well as the importance of assessing pupils for possible difficulties. Alonso et al. [45] conducted a study on dysgraphia in children from 2nd to 4th grade of primary education, focusing on the psychomotor component of writing to analyze the type of graphic errors. They highlight these as such: "anomalous lines, irregularity, zones, interlineation, curves and superimpositions" [45] (p. 23); they also state that before the age of 6 or 7 years, it is not possible to speak of dysgraphia. All of this must be based on scientific evidence for decision making when deciding on writing methods and intervention targets. In this direction, starting from the state-of-the-art review of validated protocols in both countries, it is clear that there is a need to explore future observation protocols capable of detecting predictive development indicators, or indicators of risk, in the acquiring process of handwriting from the age of 5.

3.1. Early Detection of Dysgraphia: Current Italian Screening Practices

The relevant scientific literature [15–17], establishes that the most crucial developmental periods are around the ages of 5–6 (high earliness) and 6–7 (low earliness). This underscores the importance of identifying risk factors for SpLDs during these critical developmental stages. In particular, for children ages 5–6 years, Law n. 170/2010, Art. 3

c. 3 [18] and the SpLDs Guidelines 2011, 4.1 [19], recommend early screening to identify and monitor potential difficulties that may hinder the normal development of reading and writing skills [1,20]. Early and timely intervention has been shown to significantly impact the course of the disorder [1]. It is crucial to prioritize teacher training and shared responsibility in education to prevent delayed identification that may negatively affect the prognosis and progression of the disorder. This approach also helps to prevent Specific Learning Disorders from being viewed as the sole cause of all school difficulties [46]. For these reasons, the scientific literature returns several scientifically validated protocols for a first-level assessment in the highly predictive developmental window (5–6 years). In light of the purpose of this paper, we report below on the tools in the national literature in which specific focuses emerge about screening protocols on writing requirements from 2000 to the present [46]:

- IPDA— Questionario Osservativo per l'identificazione precoce delle difficoltà di apprendimento [47];
- Test SR 4–5 (School Readiness 4–5 anni)—Prove per l'individuazione delle abilità di base nel passaggio dalla Scuola dell'Infanzia alla Scuola Primaria [48];
- CMF—Valutazione delle competenze metafonologiche [49];
- PAC-SI—Prove di Abilità Cognitive per la Scuola dell'Infanzia [50];
- SPEED—Screening Prescolare Età Evolutiva Dislessia [51];
- Mano alla forma—Prova Grafica di Prassia Costruttiva [52].

Various protocols include tests related to writing requirements and offer insights into the Predictive Indicators of Dysgraphia. It is worth noting that, as of 2000, the only observational questionnaire documented in the literature is the IPDA Questionario Osservativo [47]. This questionnaire is designed to identify learning difficulties early, covering general and specific skills related to reading, writing, and mathematics. It comprises 43 items and can be completed by a trained teacher in no more than 10 min, following a minimum observation period of one week. For this discussion, our focus will be on the reading–writing requirements assessed by the questionnaire, including visual and auditory discrimination, eye–hand coordination, visual–verbal association, rapid lexical access, and anticipatory semantic processing. Additionally, phonological short-term memory and metaphonological skills are observed. A more recent tool, the Mano alla forma [52], has been developed specifically to detect writing disorders proactively. It involves a constructive praxis graphic test to identify potential SpLDs from the final year of kindergarten onward. This instrument evaluates underlying motor-visuo-spatial functions and provides differentiated information on the graphic gesture. It takes approximately 10 min to administer and explores three areas with eight parameters. The first area, "space", examines shape, size, and general spatial organization. The second area, "graphomotor organization", assesses conjunctions, reference lines, and prolongation/no closure. The final area focuses on "motor quality" and investigates stroke safety. An analysis of the screening instruments has revealed several pedagogical issues that educational and teaching research has yet to address. Firstly, several tests in the screening instruments are still closely aligned with the clinical-diagnostic domain, making integrating them with kindergarten teaching activities challenging. Secondly, in line with the Guidelines: Management of SpDLs [53], screening pathways should consider sensitivity, specificity, cost-effectiveness, speed, reliability, and ease of administration.

3.2. Early Detection of Dysgraphia: Current Spanish Screening Practices

Current Spanish legislation, in particular the Ley Orgánica de Modificación de la Ley Orgánica de Educación [54], guarantees the right of students with dysgraphia to receive personalized attention and provides support measures. However, the effectiveness of these measures depends on the specific context of each school and the level of teacher training, which can lead to inequalities in the quality of the attention offered to students with learning difficulties. In this regard, teachers need to be equipped with pedagogical tools, specialized resources and appropriate training to respond effectively to the needs of these students and facilitate their inclusion [55]. The lack of specific competences in the field of learning difficulties may compromise teachers' ability to effectively implement the adaptations envisaged by current regulations. According to [56], teachers in Spain have significant deficits and misconceptions about specific learning difficulties, regardless of their years of experience in the teaching profession. This lack of knowledge is particularly notable among teachers in compulsory secondary education, which may be attributed to the initial training received [57]. It is therefore necessary to improve teacher preparation to ensure equitable and quality educational intervention in schools, promoting the effective inclusion of all learners. The diagnosis of dysgraphia in Spain is generally carried out in the first years of schooling, at around 6 or 7 years of age. The screening usually begins with observation by teachers and is later complemented by specialized assessment by pedagogues, educational psychologists, speech therapists, and occupational therapists. Furthermore, students with learning difficulties are often not identified until the first or second year of primary education, which may delay appropriate intervention. The systematic learning of written language is also formally introduced after the pre-primary stage, which underlines the need for early attention for these students [3]. Regarding the assessment instruments available in the Spanish educational context, several screening protocols specifically designed for the identification and assessment of learning difficulties stand out [58]. On the other hand, there are non-standardized tests that use activities and procedures that analyze the following processes interacting in writing and writing composition [59]:

- Motor: compare spontaneous writing with dictation or copying and perform tasks for visual–motor coordination;
- Lexical: naming tasks, pseudoword dictation, and word segmentation tasks;
- Morphosyntactic: constructing sentences from given words, ordering sentences in disorder, and punctuating a text;
- Planning: describing a drawing, writing a story.

Thus, the analysis of handwriting and spelling must be taken into account in the diagnosis, without forgetting the elements of writing [60]. Educational interventions aimed at writing difficulties must address two fundamental areas. Firstly, from a neuropsychological perspective, the aim is to stimulate basic psychological processes and sensory channels, such as motor skills. Secondly, from a psycholinguistic perspective, work is conducted on the development of graphomotor skills, which are necessary for written production [61]. The use of digital tools is also essential to facilitate writing, using technologies such as voice recognition, among others. Finally, in Spain, raising awareness has been promoted among families and associations of people with learning difficulties, with the aim of informing society and advocating for their rights. Even in the Spanish context, the protocols presented have critical issues when used in school contexts. For example, they are often too long to be applied in the school context; sometimes, they are also considered by teachers to be mainly clinical. Therefore, as we will see in the next paragraphs, it is necessary to design a pedagogical prevention system that is more responsive to the needs of the school context and more motivating from the point of view of student participation.

3.3. Technologies to Monitor and Empower Graphomotor Skills

Technologies currently allow us to collect and digitize an important number of parameters and indicators during handwriting, such as acceleration, pressure [62], the inclination of the pen [63], and to focus on micro-movements [64], in particular grip, finger position, fine coordination, hand and shoulder movement, posture, pressure on the sheet/tablet, instead of on macro-movements [34]. For instance, smart pens (e.g., Livescribe or Neo smartpen) can capture handwriting data in real-time, recording key factors such as pressure, speed, and angle while also digitizing handwritten notes. These pens are particularly useful for measuring fine motor movements. Additionally, graphic tablets (e.g., Wacom tablets or iPads) with a stylus (e.g., Apple Pencil) offer the advanced tracking of pressure sensitivity, tilt, and micro-movements. These devices provide high-resolution input, enabling the precise recording of grip, finger positions, and hand coordination. Haptic technology is gaining rising interest for collecting dynamic and spatial information during the drawing task, and is useful for detecting and determining the early dysfunction of motor skills. Affordable and portable haptic systems could be a valid solution to deliver information and complement school-based therapist-directed interventions to improve functional handwriting outcomes [65–67]. However, these devices have been evaluated mostly on simple motor tasks (for a review, see [68]), while their effectiveness in supporting more complex tasks like handwriting remains to be confirmed. Moreover, the same haptic devices, used in passive mode, could enable dynamic and spatial information to be collected during the drawing task and used to detect and determine motor skill dysfunctions early. At the same time, to better understand and assess a handwriting pupil's performance, monitoring the students' posture and their engagement (or interest) in accomplishing the learning task is of paramount importance [69]. Moreover, information related to students' emotional behavior should also be collected, as emotional intelligence may support students in the development of more self-awareness and self-management skills [70], impacting on the timing of training for children who present indicators of risk in the development of dysgraphia. To this end, the use of body and hand tracking systems based on RGB cameras (e.g., Ref. [71] seems particularly suitable for monitoring student posture during the handwriting activity, due to their low intrusiveness and low cost). Engagement prediction and emotion recognition systems can be based on various kinds of data. Among them, systems that take advantage of implementing deep learning algorithms to monitor user's behavior and emotions from the video captured by RGB cameras are the least invasive and probably the most suitable to be used in a learning context. They enable the acquisition of facial expression, eye gaze, and head posture (e.g., [72,73]). The vast majority of these systems are based on Convolutional Neural Networks (CNN) (e.g., Ref. [74]) and allow the identification of the "Big six" of Ekman's emotions [75] by tracking the movements of the face muscles. Usually, these systems refer to trained models using datasets built in controlled environments, where it is possible to obtain the best accuracy scores, or, trained with data obtained by crawlers on the web, with a low accuracy but mostly reflecting real contexts. Data from all these different sources can be correlated with learning indicators, through data multimodality allowing personalized teaching [76]. Several systems have been proposed to support teachers in evaluating and monitoring students' graphomotor skills (e.g., [77]) or in training handwriting skills through haptic devices (e.g., [78]). However, no system has yet been developed that integrates both training and evaluation/monitoring capabilities. Additionally, most studies focusing on the evaluation and monitoring of graphomotor skills have primarily analyzed the kinematics and dynamics of graphical strokes. Only a limited number of studies have considered postural information (e.g., [79]), and none have incorporated emotional behavior into their assessments. In this context, this research seeks to develop a new technological framework that offers personalized training for students while supporting the monitoring and selection of the most effective teaching practices. The framework aims to enhance graphomotor skills by considering both students' performance and behavioral factors, including body and hand posture as well as emotional responses. In summary, this work, while sharing the scientific research that recognizes the risk indicators at the basis of screening protocols, presents an innovative perspective in the design of a technological system more functional to observation and intervention in the school context.

4. Monitoring and Enhancing Graphomotor Skills: The Proposed Technological Framework

The proposed system integrates a DSS with intelligent tutoring features to aid teachers and therapists in the early detection of student graphomotor issues affecting handwriting performance. By analysing writing performance, emotional responses, and motor coordination, the system is capable of supporting the handwriting learning process both in classroom and remote learning environments. Through its interactive, personalized, and adaptive functionalities, it enhances the ability of educators and therapists to provide timely and effective interventions, fostering improved handwriting and overall motor development in children. In classrooms, teachers can monitor and support multiple students simultaneously, while in distance learning, features like haptic training and tailored interventions help children to continue developing writing skills with guided support. This adaptive system blends machine learning and data analytics with evidence-based teaching and therapeutic techniques to offer a comprehensive approach for identifying and addressing handwriting-related motor issues. As described in Figure 1, during the writing task, the system can collect several source data, including student's emotions, hand and upper body posture, and information related to handwriting gesture dynamics and hand micromovements, in a non-intrusive way.

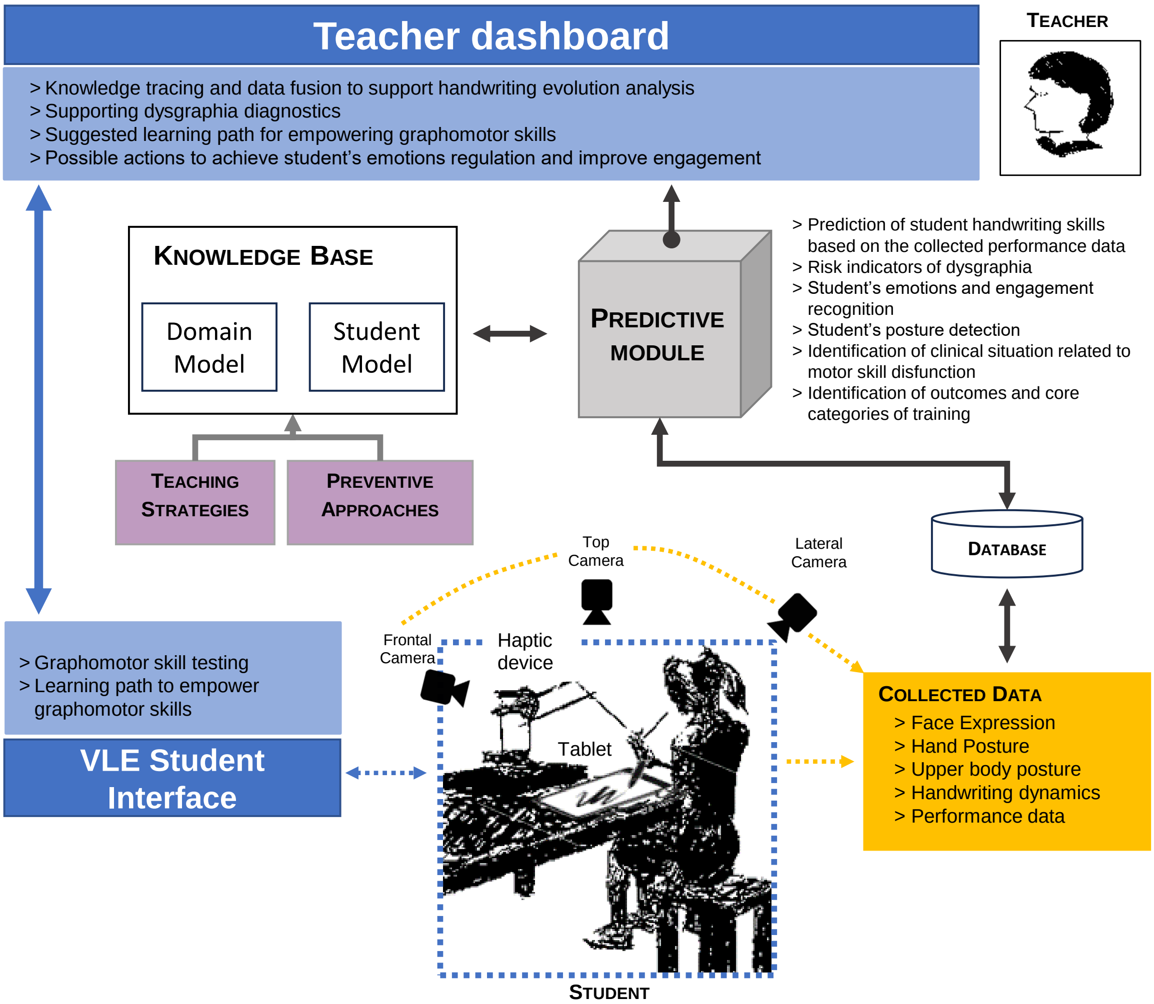

Figure 1. The proposed technological framework.

In particular, data related to the kinematics and dynamics of graphical strokes can be captured and recorded through a Wacom tablet (e.g., Wacom Intuos Pro M tablet) and a smart pen (e.g., Wacom KP13300D Ballpoint Pen) and exported thanks to the Wacom SDK. In this way, for each time event, it is possible to acquire information related to pen coordinates (X, Y, Z), orientation, rotation, and normal and tangent pressures. As stated before (see Section 3.3), such information currently represents the most considered parameters to monitor graphomotor skills [62–64]. To capture hand and upper body posture, the system implements a motion analysis tool similar to that described in [80]. To maximize the tracking accuracy of upper body segments angles, it requires the installation of three RGB cameras, positioned parallel to the student's transverse plane (top camera), to the coronal plane (frontal camera), and the sagittal plane (lateral camera), respectively. Based on the predicted joint angles, the system is capable of detecting the five postural patterns identified by [79] as relevant phenotypic characteristics of the graphomotor gesture, useful for assessing the level of development of motor control in handwriting (i.e., pattern 1: hand rotation at the wrist; pattern 2: wrist movement in flexion–extension; pattern 3: lateral movement of the trunk; pattern 4: forearm lateral movement; and pattern 5: forearm rotation at the elbow). Moreover, it can discriminate hand posture by exploiting deep learning algorithms based on CNN, similar to that proposed by [81]. To analyze the emotional behavior of the student, the system implements the tool described in [73]. This tool can distinguish Ekman's emotions (i.e., joy, surprise, sadness, anger, disgust, and fear), along with a neutral state that indicates no expressed emotions, through analysing the student's facial expressions captured by the frontal camera. Additionally, it evaluates the emotional valence (i.e., positivity or negativity of the emotions [82]) of each recognized emotion through a specific algorithm. Emotional valence is measured on a scale from -100 to +100, where 0 signifies emotional neutrality, positive values indicate positive emotions (such as happiness and surprise), and negative values reflect negative emotions (like anger, sadness, disgust, and fear). As previously discussed (see Section 3.3), monitoring students' emotional behavior provides valuable insights that support developmental processes, helping to enhance self-awareness and self-management skills [70]. Additionally, such information can be useful for the effective timing of training interventions for children exhibiting risk indicators for dysgraphia. The system is built on two key models:

- Student Model: using data mining and machine learning, the system creates a detailed profile of each child. This model analyzes writing performance (e.g., handwriting legibility, speed, pressure), information related to upper body and hand postures, and emotional reactions (e.g., frustration or engagement). The system identifies gaps in motor coordination, postural issues, and preferences for learning activities based on emotional responses, which are then used to provide suggestions to teachers to personalize interventions.
- Domain Model: focused on handwriting and motor skill development, this model organizes key concepts, such as fine motor control, pencil grip, and stroke formation, into a hierarchy. It ensures that learning tasks are introduced in a logically coherent way, starting from basic motor skills to more advanced graphomotor tasks. The system uses knowledge ontology to represent the relationship between different skills and prerequisites.

The system can be used both to test students' actual writing skills and to monitor students' progress following the intended learning path. To test writing skills, the system proposes a battery of exercises to the learner through its user interface, which are visualized on the tablet screen. As the system monitors a child's progress, it can offer a large amount of information to teachers or therapists useful for adjusting the learning path or offering emotional support if the child is showing signs of frustration: continuously monitoring the child's motor coordination and emotional state while writing enables the collection of data useful to the objective's points and tailors the difficulty and type of exercises provided. For example, if a child struggles with fine motor tasks, the system may suggest that the teacher should provide simpler exercises or additional haptic feedback. In the same way, the system can detect subtle signs of graphomotor difficulties early on, such as poor grip or inconsistent pressure, and provide insight to the teacher to set the proper interventions aimed at empowering students' handwriting performance, ensuring that they stay engaged and motivated through appropriately challenging tasks. As is well known, young children's graphomotor skills develop rapidly, and temporary delays may resolve naturally. To account for this, the system provides educators with trend data rather than one-time assessments, enabling longitudinal monitoring to differentiate between transient issues and persistent challenges. Importantly, teachers play a central role in interpreting and utilizing the system's outputs. Their professional judgment is essential for contextualizing the data and recommendations provided by the system. While the system offers valuable insights, final decisions are left to educators or therapists to ensure balanced reliance on automated analysis and professional expertise. Consequently, the system is designed as a supportive aid, complementing rather than replacing established teaching practices. The system can provide haptic training to empower graphomotricity skills. To this end, it exploits the Geomagic Touch X haptic device by 3D Systems, offering six Degrees of Freedom (DoF) and high-fidelity force feedback. The associated Virtual Learning Environment (VLE) application is built in Unity 3D using the OpenHaptics Unity Plugin from 3D Systems and displayed on a PC monitor. The interface allows users to manipulate virtual objects using a virtual probe, which is controlled by the handpiece of the haptic device and acts as a stylus in the virtual environment. These objects are presented in an orthogonal view on the screen, facilitating precise interaction with the surface features. When the tip of the virtual stylus touches the virtual object, the Touch X device provides force feedback to the user through its electro-mechanical actuators. This feedback simulates the "collision" between the stylus and the virtual surface, allowing the user to feel the resistance of the virtual material in accordance with the action–reaction principle. The virtual objects are designed to replicate wooden graphomotor boards and have a flat surface with grooves. Such objects are modeled using parametric 3D modeling techniques. This enables the adjustment of geometric characteristics of the grooves, such as width and depth, allowing for precise control over the level of haptic support provided during the gesture.

5. Haptic Training to Support the Acquisition of Graphomotricity Skills: A Pilot Study

This study introduces a novel prevention and intervention system utilizing advanced technologies designed for teachers, educators, and therapists. Specifically, it presents a pilot study testing an innovative haptic training system aimed at supporting the acquisition of graphomotor skills. The research explored whether a haptic device could effectively assist preschool children in developing these skills, with a focus on the following:

- The ease of learning of this technology by children of preschool age;
- The engagement duration demonstrated by the children in using this technology compared to that shown during activities with wooden graphomotor tablets.

Activities tests were performed within the Research Center on Teaching and Learning, Inclusion, Disability and Instructional Technology (TIncTec) at the University of Macerata. They were led by a multidisciplinary team composed of experts in pedagogy and special education and experts in human factors and human–computer interaction. The TIncTec organizes workshops in schools and gives students the opportunity to participate in innovative research that takes place within the center. Teachers and families of students fill out a form to freely participate in research activities of the greatest interest. For this pilot study, five families filled out the participation form. Therefore, the tests involved five children (three females and two males) aged five who were attending the last year of preschool.

5.1. Experimental Procedure

Students were asked to participate in three experimental sessions on non-consecutive days during one week. During each test session, they performed a preparatory handwriting exercise, which involved completing a graphomotor path chosen from three options, each requiring varying levels of motor control and graphomotor skills (Figure 2). During each session, participants practiced drawing one of three designated patterns in a specific sequence: first battlements, followed by waves, and finally cycloid loops.

Each experimental session consists of two activities:

1. Activity A: interaction with a virtual object on a VLE application with haptic feedback—reproduction of the digital trace by hand on paper.
2. Activity B: interaction with a wooden board for graphomotricity—reproduction of the carved trace by hand on paper.

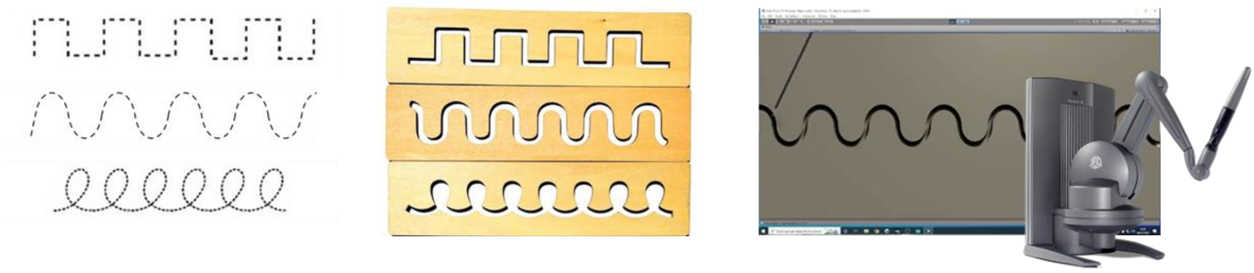

Figure 2. Example of considered graphomotor paths (on the **left**). Example of wooden graphomotor boards (in the **middle**). An example of a virtual object used for haptic training (on the **right**).

The order of the activities has been counterbalanced between subjects. Before starting Activity B, each student was instructed on how to interact with the VLE application through the haptic device. During the training sessions with the boards and haptic device, students were introduced to each exercise and then allowed to repeat it as many times as they wished. They were then instructed to draw the pattern on a sheet of paper affixed to a Wacom Intuos Pro M tablet, using a Wacom KP13300D Ballpoint Pen, following the dashed guide printed on the paper. Data collection was conducted through direct observation and audio and video recordings of activity sessions. A team of experts in special pedagogy and human factors analyzed the videos, focusing on handgrip accuracy, posture maintenance, interaction style with the virtual object, exercise execution, level of autonomy, and the duration of engagement. Drawing-related data were captured and exported using Wacoom SDK. The observation specifically addressed the following aspects:

- Autonomy in interacting with the virtual object/wooden board;
- Duration of engagement, measured by the number of exercise repetitions completed by the student;
- Student's interest and satisfaction, as expressed through comments;
- Accuracy in drawing execution, measured as the percentage of trace contained within a tolerance range of ±5 mm from the dashed guide pattern.

5.2. Results and Discussion

The results showed that the haptic device was straightforward and manageable for typically developing children after a brief training period. Observational data indicated that all five children without disabilities were able to perform the graphomotor exercises on the haptic device independently after an average of one introductory session, achieving a high level of autonomy (average of 90% independent interactions per session). In particular, they achieved an average of 4.8 independent exercise repetitions per session on the haptic device. During the sessions, they demonstrated a high level of engagement with the haptic device, averaging 5.2 repetitions per session, compared to 3.4 repetitions with the wooden graphomotor tablet (Figure 3).

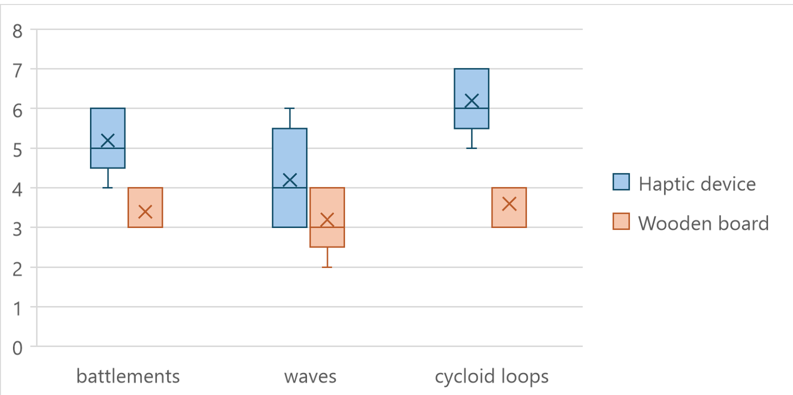

Figure 3. Exercise repetitions performed with haptic device and wooden board.

The preference for the haptic tool was reflected in their comments, with all students expressing enthusiasm for the virtual environment and the haptic feedback. In terms of graphomotor tracing quality, expert visual analysis showed no significant differences between the tracings produced by students after training with the haptic device and those completed using the wooden tablets. The evaluations showed an average accuracy of approximately 87% for tracings completed after exercises on both the haptic device and the wooden tablets (Figure 4), suggesting no measurable differences in performance quality between the two tools. Overall, these results suggest that haptic devices can be a feasible and engaging tool for graphomotor training among preschool children.

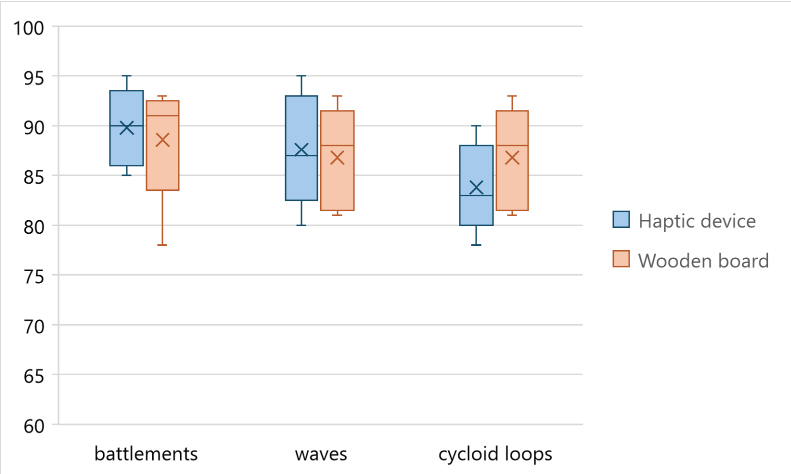

Figure 4. Accuracy of the drawing of the three patterns achieved after haptic and wooden tablet training.

6. Conclusions

Starting from kindergarten, prevention plays a strategic role in promoting a more harmonious development of learning, which in turn enhances school performance, and supports meaningful inclusion initiatives. This point was also reiterated by the European Agency for Special Educational Needs and Inclusive Education when, in a document titled "Five Key Messages for Inclusive Education", it emphasized the positive impact of early diagnosis and intervention and the importance of proactive measures within the school context [83]. A difficulty that is not identified early and not compensated educationally tends to lower the student's self-esteem and motivation to study. These factors may lead to further school failures, triggering a spiral of negative emotions that will impact the student's future, including socially, potentially resulting in low self-esteem, depression, and sometimes at-risk social behaviors [84]. Therefore, the early identification of individuals considered "at risk" aims to reduce the likelihood of school failure and/or dropout and to encourage, primarily in the child, awareness and understanding of their difficulties. In this way, the potential guilt and chronicity of any disorder are countered, and through early intervention by qualified experts, it is possible to bring writing (and reading) parameters closer to average levels. Conversely, if intervention is delayed, students with SpLDs will continue to face difficulties throughout their life [85]. Thus, early intervention reduces the impact of disorders and lowers the risk of developing secondary conditions, ultimately benefiting the individual's overall functioning [21,22]. Consequently, equipping teachers with the skills and tools to create supportive learning environments tailored to each individual's characteristics and needs is essential. Systematic observation, targeted training for reinforcement, documented progress monitoring, and shared educational responsibility (between teachers, families, and external experts) during the transition from kindergarten to primary school are fundamental aspects of inclusive educational practice [86]. Thus, aiming to prevent disorders and enhance handwriting learning, this research project pursues a broader goal of inclusive education, intending to compensate for the child's difficulties (potentially stemming from personal and neurobiological characteristics or extrinsic factors such as the sociocultural environment or educational poverty to which they may be exposed), improve their self-esteem, and support a positive emotional approach to learning. Hence, there is a commitment to developing and testing a new technological educational tool to intervene early in potential dysgraphia problems, improve handwriting, and, ultimately, support students from disadvantaged backgrounds and contexts. This technological aid will provide an intervention methodology to assist various educational professionals in identifying, case by case, the specific characteristics of each child's difficulties and the different ways to overcome them. Technologies utilizing virtual and/or augmented reality, tablets, and smartphones with specific apps or compensatory technologies are recognized as highly strategic approaches for designing educational interventions focused on developing social, academic, and metacognitive skills, as well as promoting students' motivation. Through the designed tools, students with dysgraphia will, from a young age, become more aware of their learning process and cognitive style. With these metacognitive skills, they can actively and consciously participate in their change process, engage actively in school life, experience learning more peacefully, and achieve educational benefits and goals that otherwise would be out of reach. Moreover, thanks to the proposed technological framework and its related technological aids (designed to be used not only within school walls but also beyond), the principle of shared educational responsibility between school, family, community, and third-sector services, which inclusive education promotes, will be pursued [4]. The dimension of networked collaboration among multiple stakeholders becomes central to creating effective alliances aimed at empowering students with Specific Learning Disorders. At the same time, involving and networking with the community will provide an opportunity for educational institutions to foster cultural and social maturation processes that engage the entire community. The proposed system adopts a modular architecture, ensuring scalability and adaptability to a wide range of technological contexts. This design supports diverse educational environments while remaining inclusive and flexible. For instance, well-resourced schools can fully utilize advanced tools such as smart pens, haptic feedback devices, and multi-camera setups. Conversely, schools with limited resources can rely only on tablets and styluses to access the system's essential functionalities. This flexibility enhances accessibility and enables the system to accommodate cultural and regional variations in technology use, allowing for gradual adoption and seamless integration tailored to specific needs. However, the results gathered from the preliminary trial, though promising, come with several limitations. The trial involved a small sample of children, and the observation period was very short. To comprehensively assess the system's potential and limitations, extensive longitudinal studies involving a larger cohort of students are necessary. Furthermore, to evaluate the tool's suitability for supporting inclusive teaching practices, it is crucial to include students with disabilities in future studies. In brief, the research presented in this article represents a strategic starting point for the implementation of the early screening of dysgraphia. Among the main reasons that have moved the two nations involved, Italy and Spain, towards the implementation of the joint implementation practices that we mention is that in both countries early childhood education (3–5 years) is not compulsory, but it is part of the education system, and compulsory schooling begins at the age of 6 [87,88], when the educational curriculum establishes the formal start of teaching reading and writing. On the other hand, in Spain, the education system is multilingual in some areas, such as in the Balearic Islands, where Catalan is the vehicular language of instruction, coexisting officially with Spanish, which implies that both languages are taught in the education system. This linguistic diversity may influence the development of writing skills. In contrast, in Italy there is no such multilingual situation at school level. These differences provide an ideal context for analyzing how the particularities of the educational environment affect the predictors of dysgraphia, considering that both Italian and Spanish are Romance languages originating from Latin. In terms of educational provision, Italy has a more established track record in terms of school inclusion compared to Spain. In Italy, the education system promotes inclusion in ordinary classrooms, while in Spain two modalities still coexist: the ordinary system and the special system in specific centers for students with special educational needs [88]. Furthermore, the linguistic characteristics of the official languages in both contexts (Spanish, Catalan, and Italian) are a relevant factor to consider. As they are Romance languages, there are similarities between them that facilitate mutual understanding [89]. Spanish is a language with a more transparent orthography than Italian, similar to that of Catalan, which may influence the ease with which children acquire writing skills and thus the manifestation of dysgraphia. Comparing how these orthographic differences affect writing development may offer valuable clues as to the specific predictors to be considered in diagnosis and intervention in each context. Finally, this study has important practical implications. Identifying predictors of dysgraphia in both countries will allow the development of more accurate diagnostic tools adapted to the needs of each context, as well as the design of more effective intervention strategies tailored to the specific characteristics of the Spanish and Italian education systems. In addition, the exchange of good practices between the two countries could contribute to improve teacher training with regard to the development and learning of writing both in the initial phase (in infants) and in the primary education stage, favouring a more inclusive and effective attention for children with specific learning difficulties. To this we should add the common interest in the use of technological tools that facilitate the early detection of difficulties as a preventive measure, thus preventing children from failing later on in their compulsory school career.

7. Future Outlook

Even though the system promises significant benefits for the early detection of graphomotor issues and dysgraphia risk, further research is essential to ensure its practical and reliable implementation. Key areas for future studies include the following:

1. Development of machine learning algorithms for the early detection of graphomotor issues. Advanced machine learning algorithms must be developed to reliably identify early predictors of graphomotor developmental issues and dysgraphia risk. Studies should focus on improving the accuracy of these algorithms to detect subtle motor skill deficits and non-standard hand postures, as well as patterns in emotional engagement that may signal early handwriting difficulties.
2. Ensuring data collection reliability across different environments. The system relies on tracking hand and body posture, gesture dynamics, and emotional cues. Research will be needed to optimize the camera setup and data collection methods, testing the accuracy and stability of posture recognition across a range of real-life environments and student behaviors.
3. Construction of a proper knowledge base to implement DSS capabilities. Studies are needed to define proper AI algorithms to enable the system's ability to provide suggestions regarding personalized and adaptive learning interventions based on each student's motor skill and emotional profile. Several experiments should be carried out to develop and test how the system should dynamically adjust the complexity of handwriting tasks or provide haptic feedback based on real-time assessment of student performance, with a focus on reducing frustration and fostering engagement. The reliability of machine learning models fundamentally depends on the quality of their training data. To ensure the system's predictions achieve the highest levels of accuracy and reliability, it is essential to gather comprehensive data that capture a diverse range of developmental trajectories, backgrounds, and graphomotor skills.
4. Validation of haptic feedback for motor skill training. Testing the haptic feedback component is essential to verify its effectiveness in developing fine motor skills related to handwriting. Comparative studies should assess how haptic support impacts the learning curve for students with different levels of graphomotor skills.
5. Long-term studies on predictors of dysgraphia and graphomotor development. To confirm the system's effectiveness in early detection, longitudinal studies should track motor skill and emotional development over extended periods. These studies should monitor any long-term improvements in handwriting performance, emotional

resilience, and motor control, analyzing how early indicators evolve and what factors are most predictive of dysgraphia.

6. Developing specific training modules or guidelines for educators on implementing and using these technologies in real classroom settings could enhance usability and ensure effective integration into daily teaching [90].

Following this perspective, which outlines a long-term research path, a large-scale trial, including a longitudinal study on a pool of more than 150 students, conducted in parallel by the University of Macerata and the University of the Balearic Islands, will be launched in the next months to gather essential data and create robust datasets to support the development of the system's predictive modules. The knowledge gained from this comprehensive study will be invaluable in shaping a responsive and adaptive tool that enables educators and therapists to provide timely and individualized support, ultimately improving the motor skill development and handwriting proficiency of at-risk students. The study will also consider whether to include additional indicators of children's attention and engagement with peers and teachers (e.g., eye tracking) and social and psychological impact in order to assess, for example, how dysgraphia affects peer interactions, self-esteem, and general social learning contexts [91,92].

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Abbreviations

The following abbreviations are used in this manuscript:

SpLDs	Specific Learning Disorders
ICTs	Information and Communication Technologies
DSS	Decision Support System
VLE	Virtual Learning Environment
CNN	Convolutional Neural Networks
TIncTec	Research Center on Teaching and Learning, Inclusion, Disability and Instructional Technology

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