

From Early Detection to Lifelong Inclusion: Artificial Intelligence-Supported Identification and Intervention for Dysgraphia

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Abstract—Dysgraphia, characterized by persistent difficulties in handwriting fluency, spelling, and written expression, continues to be among the least systematically identified learning disabilities within mainstream and inclusive educational settings, especially in India, where delayed identification exacerbates academic disadvantage and undermines learner confidence. This study systematically reviews the research literature and emerging technology platforms worldwide to explore AI based technologies for the early detection and structured intervention of dysgraphia. This study reviews AI powered assessment systems such as machine learning models, smart pen sensors, deep learning diagnostics and handwriting analytics as well as AI supported intervention ecosystems providing adaptive learning environments, real time feedback and personalised skill development pathways using a qualitative, review based methodology. The results indicate that AI identification tools can improve the objectivity, accuracy and timeliness of dysgraphia detection, moving from reactive deficit assessments to proactive, evidence-based screening embedded in educational routines. AI-assisted interventions also demonstrate consistent promise in improving writing outcomes, engagement, and self-efficacy, via developmentally calibrated learning pathways. The study points out major lacunae in the use of AI in the Indian educational context and the importance of culturally responsive, multilingual and ethically-grounded tools that are in alignment with the RPwD Act, 2016 and NEP, 2020. Responsible AI integration has huge potential for reducing educational exclusion and for promoting equitable, sustainable participation across the lifespan.

Index Terms—Artificial Intelligence, Dysgraphia, Early Identification, Inclusive Education, Handwriting Analysis, Specific Learning Disabilities, Adaptive Learning, India, National Education Policy

1. INTRODUCTION

The first decades of the twenty-first century have been marked, to a large extent, by the unprecedented acceleration of digital and computational technologies. Of these, Artificial Intelligence (AI) is one of the most impactful and transformative innovations that can redefine entire sectors — from healthcare and finance to governance and education. We are in an era where AI-based systems can diagnose medical conditions with more accuracy than trained clinicians in certain domains, predict individual behavioral patterns from complex datasets, and generate nuanced language outputs that are indistinguishable from human authored text. These capabilities have enormous transformative potential in the field of education, especially for learners with specific learning disabilities (SLDs), who have often been underserved by traditional educational systems.

Dysgraphia is a specific and often under-recognized member of the spectrum of specific learning disabilities. In contrast to dyslexia, which has been the subject of a great deal of research and public awareness, dysgraphia is relatively unrecognized and often misunderstood, even among professional educators. Clinically, dysgraphia is defined as "persistent difficulties with the fluency of handwriting, letter formation, spelling, and written expression in the absence of intellectual disability or inadequate educational opportunity" (American Psychiatric Association, 2013). But in many classrooms, especially those with limited resources, a child with dysgraphia is more likely to be seen as lazy, unmotivated or not trying, than as a learner with neurological processing differences that present specific, solvable challenges.

The effects of this misperception are profound and cumulative over time. Early identification of dysgraphia during the initial years of formal education does not allow learners to benefit from early access to appropriate educational support. The subsequent cascade of academic challenges—including avoidance of writing tasks, reduced classroom participation, poor academic outcomes, and psychological distress—not only hinders current educational achievement but also influences learner identity and self-concept in ways that persist into adulthood (Berninger & Wolf, 2016; Graham et al., 2015). Thus, early identification is not simply a formal diagnosis; it is a foundational act of educational equity.

Traditional methods of identification of dysgraphia have been heavily dependent upon standardized tests, administered by specialist practitioners, typically only when serious academic difficulties have become clearly evident. This reactive model is inherently limited, creating diagnostic delays, consuming finite specialist resources, and failing to capture the subtle, dynamic nature of handwriting difficulties as they manifest across different writing tasks, conditions and developmental contexts. AI-powered tools are a real game-changer. The combination of machine learning algorithms applied to handwriting data, smart pen sensor technologies that capture real-time motor execution, and neural network models trained on large-scale handwriting datasets enables a precision, continuity, and scalability in dysgraphia identification that was not previously achievable (Asselborn et al., 2018; Bublin et al., 2022; Govindaraju & Srihari, 2020).

This study looks at how new technologies from around the world fit into India's education system and its rules. India has a big challenge with learning disabilities, and it does not have good ways to spot them early. India's policies, like the 2016 Rights of Persons with Disabilities Act and the 2020 National Education Policy, strongly support education that includes everyone, is fair, and uses technology. However, it has been slow and inconsistent to turn these policy goals into real-world practices for finding and helping with dysgraphia early on. This study suggests that AI can help bridge the gap between what policies hope to achieve and what actually happens in schools. But for this to work, AI needs to be used in a way that respects different cultures, is ethical, and truly pays attention to the varied situations in Indian classrooms.

Let me tell you how this paper is set up. First, Section 2 will explain the main ideas behind our study. After that, Section 3 goes over relevant research from around the world. Section 4 will lay out why we are doing this and what we aim to achieve. Then, Sections 5 to 9 dive into analyzing dysgraphia in inclusive learning environments, why spotting it early is so important, how AI is being used in education, the AI tools available globally for identifying and helping with it, and the ethical questions involved. Section 10

specifically looks at a research gap here in India. The paper wraps up by discussing what this all means for making education more inclusive and sustainable.

2. CONCEPTUAL FRAMEWORK

The research is grounded in a multi-dimensional theoretical framework, drawing on Inclusive Education Theory, Cognitive and Neurodevelopmental Science, Learning Analytics and AI-Driven Assessment, and Lifelong Learning. The four dimensions are not viewed as discrete, competing lenses, but as interlocking perspectives that together shed light on how AI can most responsibly and effectively support children with dysgraphia across educational settings.

2.1 Inclusive Education as the Normative Foundation

The theory of inclusive education on which this study is based is that of leading scholars and international organizations (Ainscow, 2020; UNESCO, 2020). Inclusive education is not simply the physical placement of learners with and without disabilities in the same classroom; it is a holistic orientation towards equity, participation and belonging that requires the active removal of barriers to learning. Viewed this way, dysgraphia should be understood not simply as a neurological deficit in the individual child, but as a learning difference that becomes disabling in the absence of educational settings that expect and adjust for it. What this means is that early identification and appropriate intervention are not optional extras to inclusive practice but constitutive elements of it.

2.2 Cognitive and Neurodevelopmental Theories of Writing

Writing is one of the most cognitively and neurologically complex activities required of school age children. Contemporary models of writing development emphasize the need to simultaneously incorporate fine motor coordination and visual-perceptual processes (including hand-eye coordination and spatial orientation), phonological and orthographic language processing, and executive functioning capacities such as working memory, planning, and cognitive flexibility (Berninger & Richards, 2010). Disruption of any one of these component processes, whether due to developmental variation, neurological difference, or environmental factors, can produce the pattern of difficulties characteristic of dysgraphia. This multi-factorial understanding of dysgraphia informs the study's emphasis on assessment approaches that capture the product and the process of writing, rather than on evaluation of handwriting legibility as a static end-product.

2.3 Learning Analytics and AI-Driven Assessment

The framework is based on learning analytics theory (Luckin et al., 2016), which considers education as a data-rich environment that can be subject to continuous, dynamic and formative assessment. The role of AI systems here is not to replace diagnosticians but to be used as intelligent monitoring and decision-support tools that increase educator capacity by identifying patterns and anomalies in learner behavior that would be imperceptible through conventional observation alone. For instance, handwriting data contain variables such as stroke velocity, pen pressure variation, motor rhythm consistency, and spatial organization, which can be analyzed using learning analytics frameworks in order to identify patterns associated with dysgraphia with a granularity and objectivity that standardized, product-focused assessment tools cannot offer.

2.4 Lifelong Learning and Policy Alignment

The lifelong learning framework points to the significance of flexible, personalized and constantly adapted learning pathways that help people not only in their formal schooling but throughout the entire spectrum of their learning lives (UNESCO, 2020). The aim for this population is full participation in academic and social life, and for this early identification of dysgraphia and timely and appropriate intervention is the foundation, as learners who receive sufficient support during the critical years when they develop their writing skills are better able to develop the skills, confidence and adaptive strategies to participate in sustained academic and social participation. The framework is explicitly situated in the Indian policy context and aligns its recommendations with the RPwD Act, 2016 and the National Education Policy, 2020, which together articulate a national commitment to inclusive, accessible and technology-enabled education systems.

3. REVIEW OF RELATED LITERATURE

The following review discusses the key empirical and theoretical contributions that inform the analysis of AI-supported identification and intervention of dysgraphia in the study. Methodological approaches, key findings and implications for the development of AI-based tools in inclusive educational settings are reviewed.

3.1 AI-Based Handwriting Analysis and Early Identification

Asselborn, Chapatte and Dillenbourg (2018) conducted a landmark study in Switzerland with a dataset of some 300 school-age children who performed structured handwriting tasks on digital tablets. The researchers applied machine learning and neural network-based handwriting analysis, examining stroke dynamics, writing speed, spatial organization and pressure variation to create an automated classification model for handwriting quality assessment. The study showed that AI-based analysis could reliably detect subtle handwriting irregularities related to a risk of dysgraphia, with high predictive accuracy. It was concluded that data-driven handwriting assessment enables earlier and more objective identification than conventional observational methods. This study provided an important empirical basis for the use of computational modeling for dysgraphia screening in educational settings.

Building on this line of research, Bublin, Mohr and Schneider (2022) conducted a study in Germany with sensor-embedded smart pens with primary school children. Motion-capture analytics recorded pressure sensitivity, acceleration, stroke timing and fine motor coordination during writing tasks. Then, quantitative data were processed with pattern recognition algorithms to discriminate between typical and atypical handwriting development. Results indicated that sensor-based measurements were able to successfully identify motor irregularities associated with dysgraphia prior to academic failure being evident, highlighting the value of objective, continuous monitoring compared to relying on subjective teacher judgment. This study is particularly important in demonstrating that meaningful early identification is possible in naturalistic classroom contexts without the need for specialist clinical assessment.

A significant foundational study was completed by Rosenblum, Weiss and Parush (2003) who conducted a mixed-methods evaluation of handwriting difficulties in elementary school students comparing children with identified handwriting difficulties and typically developing peers. Both the products of handwriting, such as legibility, spacing and alignment, and the processes, such as speed, motor execution and fatigue, were analyzed by the researchers. They found that the students with dysgraphia wrote

significantly slower, their letters were inconsistently formed and they required greater physical effort. The study confirmed the multidimensional nature of handwriting problems, including motor, cognitive and perceptual components, and laid the theoretical foundations for subsequent AI-based analytics approaches that simultaneously capture multiple writing parameters.

In their piece "AI-Based Handwriting Recognition and Analysis: A Review," Govindaraju and Srihari (2020) present an extensive overview of the field, establishing how advances in machine learning have made it possible to move from subjective observations to objective, data-driven assessments. Recent work produced by Govindaraju, Kim, & Srihari (2025) has mapped the development of predictive models at the National AI Institute for Exceptional Education in the USA; these models achieved high accuracy in the identification of writing difficulties using large handwriting databases. The authors evaluated five parameters that were identified as critical to determining diagnostic insight regarding the development and/or disorder of writing, including stroke order, velocity, pen pressure, spatial arrangement, and motor rhythm.

The research of Robaa, Hassan, and Ibrahim (2024) represents a major methodological advancement in Explainable AI (XAI) technology development focused on detecting handwriting problems. The authors built transparent algorithmic frameworks so that educators could comprehend the creation of diagnostic decisions due to the lack of transparency of traditional deep learning models, ultimately reducing barriers for educators to trust and use these technologies. The impact of this contribution towards the ethical implications of utilizing AI in Education cannot be overstated as it demonstrates the need for algorithmic accountability and interpretability are not secondary considerations in the responsible use of AI within educational settings, but rather, they are essential components of socially responsible use of AI within educational contexts.

3.2 Intervention Research and AI-Supported Writing Development

According to Feder and Majnemer, who conducted a systematic review of multiple clinical/educational studies, children experiencing difficulties with handwriting and motor coordination can benefit from early intervention. Their research supports that early intervention can positively impact handwriting fluency, academic involvement, and psychological health, while late identification can add to academic difficulties and reduce the child's sense of confidence as a learner. The findings also provide strong empirical support for the principles of proactive identification and early intervention, which are the primary purpose of AI-based systems.

Luckin et al. (2016), presented a broad theoretical and practical perspective on integrating AI into education with their pivotal report "Intelligence Unleashed." Through extensive research and case studies of educational technologies, they showed that AI-based systems allow for continuous assessment through learning analytics to identify early signs of learning problems which would go undetected using standard assessment tools. They also argued that AI should serve as a decision-support system for teachers rather than independently diagnosing learning issues, providing greater personalization and early intervention while maintaining the dominance of the teacher's professional judgment. This conceptualization of AI as an augmentation rather than a replacement provides the normative frame for the current study's approach to AI integration.

Dillenbourg (2021), explored the challenges and opportunities that AI may bring to education from a perspective of sustainable learning, noting the importance of developing adaptive learning environments that are able to continuously adapt to the immediate needs of individual learners. He subsequently analyzed several AI based assistance systems, highlighting the importance of three primary design characteristics necessary to develop enhanced writing skills by providing real time feedback, adapting the level of difficulty as needed, and developing systems based upon a learner centred design. In addition, the review of the literature on the use of AI for identifying and intervening with respect to dysgraphia has illustrated the potential benefits and complexities associated with the implementation of AI based methods. The review has illustrated the need for establishing empirically based, ethically accountable, and contextually relevant frameworks within which AI can be implemented.

4. RATIONALE AND OBJECTIVES OF THE STUDY

4.1 Rationale

Early identification is increasingly understood as a fundamental component of inclusive education and lifelong learning, and this growing recognition is the primary driver of this research. While there is increasing global evidence on the ability of artificial intelligence (AI) to improve both the accuracy and timeliness of dysgraphia identification, translating that evidence base into practice is not consistent, particularly in the context of Indian education. As a result, most children with dysgraphia in India have no identification and support during their early years of schooling, with their difficulties typically attributed to either effort deficits or attitudinal problems rather than recognised as signs of a discrete, addressable learning disability.

Several intersecting factors compound this challenge. Very large class sizes in public and government-aided schools considerably restrict the ability of individual teachers to notice, document, or respond to subtle individual differences in students' writing behaviour. A lack of trained special education teachers and educational psychologists at the school level means that formal assessment procedures are usually conducted only after the issues have become significant, further reducing the timeframe for the most timely and effective early intervention. There is an unequal distribution of technological infrastructure and digital literacy across urban and rural communities, leading to additional barriers for the implementation of technology-based screening instruments.

At the same time, India's policy environment is increasingly conducive to the integration of technology-enabled inclusive practices. The RPwD Act, 2016, enshrines the right of persons with disabilities to quality inclusive education and mandates the removal of barriers to participation and access. The National Education Policy, 2020, similarly articulates a vision of foundational literacy and numeracy support, early identification of learning needs, and the strategic use of technology to enhance educational equity. These policy imperatives create both the justification and the urgency for developing AI-based approaches to dysgraphia identification and intervention that are contextually appropriate, linguistically responsive, and ethically grounded.

4.2 Objectives

The study is guided by the following specific objectives:

- (1) To examine AI's role in early dysgraphia identification through a review of global AI-based tools, focusing on methodology, diagnostic accuracy, and implementation.
- (2) To analyze AI-supported interventions for dysgraphia, including cognitive, adaptive, motor, and therapeutic tools aimed at improving writing and academic outcomes.

(3) To explore AI integration in inclusive and lifelong learning frameworks, focusing on equity, participation, and sustainable academic development.

(4) To identify gaps in dysgraphia identification and intervention in India and propose culturally responsive, policy-aligned AI solutions.

5. DYSGRAPHIA IN INCLUSIVE EDUCATIONAL CONTEXTS

5.1 Defining and Understanding Dysgraphia

Dysgraphia is a Specific Learning Disability in DSM-5 (American Psychiatric Association, 2013) defined as persistent difficulty in writing and evidenced by poor handwriting legibility, poor handwriting fluency, misspellings, and difficulty with punctuation and grammar. Dysgraphia occurs despite having sufficient intelligence, sensory abilities, and educational opportunities. Dysgraphia is recognized by the World Health Organization's International Classification of Diseases, 11th edition (ICD-11) as a developmental learning disorder; it is accepted as a neurobiologically based disorder that does not depend on the general cognitive ability of the individual.

Writing is complex because it combines both cognitive functions (the processes involved) and motor functions (using your body's motor systems). The multiple neurocognitive systems involved in writing require coordination and processing at the same time (Berninger & Richards, 2010). Below are the five neurocognitive systems that are coordinated when a person is writing: Phonological processing — how we think about sound-letter connections; Orthographic processing — storing and retrieving a specific word's spelling; Fine motor coordination — controlling your fingers to create each letter and manipulate a writing instrument; Visual spatial processing — the way we perceive how letters are made and where they are on the page; Executive functioning — includes working memory, planning, monitoring, and switching between tasks. Any of these systems, when disrupted, can create the behaviors associated with dysgraphia; therefore, dysgraphia is experienced by children differently. Some kids experience mostly problems with producing letters using their fingers, whereas others will experience major deficits in the other systems.

5.2 Identification Challenges in Inclusive Classrooms

Classifying individuals with dysgraphia in an inclusive educational environment can be challenging because of a number of structural and perceptual characteristics. Perceptually, the difficulty a child may have with handwriting is often mistakenly attributed to motivation (e.g., lack of effort or care), or not having practiced enough, or not trying very hard, rather than to neurologically based processing differences (Berninger & Wolf 2016). This is true not only for parents/caregivers, but also for classroom teachers. In educational systems that have limited knowledge about specific learning disabilities and do not include these areas as part of pre-service teacher preparation programs, this problem is even more acute.

The difficulty in identifying students at risk for having learning disabilities is made worse by a lack of established and systematic methods of routine screening of children within the early primary education setting. Schools across India, as well as many schools around the world, do not provide formal assessments of children's literacy impairments (dysgraphia is an example) until a teacher or parent makes the necessary referral to have a child assessed for possible learning disability. Because teachers in most classroom settings have large amounts of students to teach, the number of specialist personnel available to help teachers further identify students with disabilities in the school, and how much time teachers have to refer students for assessment, teachers will generally require that the students have been exhibiting very severe difficulties prior to referring them for a possible learning disability (Sharma & Sokal, 2016). Such children with mild to moderate dysgraphia very rarely receive assessments to confirm such an impairment.

The identification failures outlined in this paper are not insignificant and/or short lived. Longitudinal research repeatedly shows that children with unaddressed handwriting difficulties face cumulative academic disadvantage: they tend to generate shorter written outputs, score poorly on written assessments across the curriculum, avoid writing-based assignments, and develop a negative self-perception towards writing, all of which continue throughout their educational journey (Graham et al., 2015). Beyond the academic impact, it is possible that there are also significant long-lasting emotional and/or psychological effects resulting from being placed in an educational system where the student's cognitive capabilities do not match the curriculum demands.

5.3 The Imperative for Systemic Early Identification

Evidence and ethics both support the need for early intervention for children with dysgraphia. The evidence is clear: The earlier a child receives the appropriate intervention for their dysgraphia, the better their success will be in a variety of ways (examples: improvement in handwriting fluency, quality of writing, academic performance, and psychological well-being) (Feder & Majnemer, 2007). Additionally, research on neuroplasticity shows that children's brains are most able to respond positively to targeted interventions when they are developed during the early years of school; therefore, identifying children with dysgraphia as early as possible is not only better than identifying them later, but it is much more effective than identifying them later in terms of how the child will develop over time.

From an ethical standpoint, failing to accurately identify and assist students who suffer from dysgraphia represents an infringement on the tenets of inclusive education that the vast majority of present-day educational systems profess a commitment to. Inclusive education represents a commitment on the part of education systems, not individual learners, to identify and alleviate barriers to the learning process. The systematic use of AI-based screening instruments utilized in conjunction with daily instructional practices within general education classrooms provides a distinctly tangible and scalable method of discharging this obligation.

6. ARTIFICIAL INTELLIGENCE IN EDUCATION: AN OVERVIEW

AI in Education (AIEd) describes the broad use of computational systems that can analyze learner data and recognize patterns in how learners learn within different environments. They are also capable of adapting instructional processes based on the requirements of individual learners as well as their developmental pathways (Holmes et al., 2019). There are many types and degrees of AIEd available, from basic automated feedback applications to highly complex intelligent tutoring systems (ITS) that simulate each student's knowledge state and modify instructional sequences to match that knowledge state.

Examples of categories of AIEd applications in the educational arena include ITS (intelligent tutoring systems) that provide students with individualized and real-time instruction and feedback on any curriculum area; automated essay scoring and writing feedback applications that evaluate a student's writing in relation to structural, grammatical, and content features; predictive analytic systems that utilize longitudinal data on an individual student to help identify those who are most likely to be academically challenged;

and handwriting recognition and analysis systems that utilize the kinematic, spatial features, and characteristics of an individual student's handwriting to provide an objective measurement of handwriting development and/or disorder (Govindaraju & Srihari, 2020).

Handwriting recognition technologies play a critical role in identifying dysgraphia. Such systems use micro-level analysis of handwriting characteristics such as: stroke order, speed of writing, pressure variation, spatial alignment, and timing of writing movements to detect writing motor planning and cognitive processing mechanisms that are non-visible to even the most observant human, yet provide essential information to diagnose dysgraphia (Govindaraju & Srihari, 2020). Writing characteristics can be captured using digital tablet or smart pen devices and analyzed using machine learning (AI). Patterns associated with dysgraphia at much greater levels of detail and objectivity than traditional assessment methods can be identified using AI analysis of captured handwriting.

AI systems also provide the opportunity for ongoing, real-time formative assessment of students, which gives teachers the chance to determine how to best support learning. This is unlike standardized assessments, where the data only provides a set point in time for a child's performance in a particular way that is only assessed in an artificial manner. In the case of writing, an AI-based assessment tool collects data on a variety of writing tasks in different writing contexts over time and will create a much broader and more real-life-based profile of how writing is developing for that particular child. It can also identify variations in the development of writing within and beyond to indicate potential areas of difficulty or developing strength; therefore, ongoing tracking would be a direct connection to the recommendation from existing, contemporary research on formative assessment and learning analytics (Luckin et al., 2016) as providing the foundations for developing responsive, personalized approaches to teaching and learning.

AI must be framed pedagogically. Educators assist with context, relationships and experience; therefore, the way we conceptualize AI, ethically and productively, is as an augmenting tool to support an educator's judgement. AI provides data; the person who educates gives those data meaning through context, relationships and experience. For AI to work in inclusive education, it requires resources for technology and training, as well as resources for developing educators and developing a school system that can support inclusivity.

7. GLOBAL AI SYSTEMS FOR THE EARLY IDENTIFICATION OF DYSGRAPHIA

During the last two decades there have been a large number of AI based systems developed and empirically evaluated to identify dysgraphia early on. All these systems take a data driven approach to analyzing handwriting behaviours although the technical architecture of the system, what handwriting parameters are targeted, for which populations they were designed and validated, and whether they are to be used in clinical, research or classroom settings are all very different between the various systems.

7.1 Smart Pen-Based Identification Systems

The smart pen technology is a very valid eco-friendly method to identify dysgraphia; they create "real-time" data that documents the motor production process while students use writing in real-life situations at school. This technology consists of multiple motion-sensor types, like pressure sensors, accelerometers, gyros, etc. inside the pen; thus, you can collect very rich information about kinematics (including grip force, velocity of stroke, pen acceleration and angular orientation) without any artificiality that typically occurs in the lab when conducting assessments.

The SensoGrip Smart Pen (designed in research labs in Germany) is proof that this type of device can support both basic research and applied clinical work. The Smart Pen collects data regarding multi-dimensional force and motion as they occur during the accomplishment of handwriting actions, and the collected data are processed through pattern recognition algorithms that can recognize the differences between typical and atypical handwriting development profiles. Studies that have used the SensoGrip to assess handwriting have found that the Smart Pen is effective at identifying motor irregularity patterns due to digital expression of dysgraphia prior to the motor difficulties becoming significant enough to warrant teacher referral or parental concern (Bublin et al., 2022). Therefore, the ability to identify children prospectively or preventively with this type of assessment is a substantial improvement to the traditional form of assessing children reactively after they exhibit significant amounts of difficulty.

7.2 Machine Learning and Neural Network Diagnostic Models

Controlled empirical research has demonstrated that machine learning and deep learning approaches can achieve high accuracy when identifying dysgraphia. The systems that were developed employed large annotated databases containing handwriting examples collected from children with and without dysgraphia; therefore, these systems learned how to extract and weight diagnostic features in an iterative optimization process.

Table BHK AI Model built by BOLD Group in France, as well as CNN Dysgraphia Detector developed through university studies in Malaysia are two examples of deep learning approaches used by businesses to identify children who write poorly. In both cases, convolutional neural networks (CNN) trained on handwriting databases from tablets were used to find atypical ways that children write with both sensitivity and specificity. Similarly, studies using Europe's neural network models for tablets have also shown good predictive accuracy identifying dysgraphia risks of young children (Asselborn et al., 2018).

An important and emerging area in artificial intelligence (AI) research is Explainable AI (XAI) models developed by AI Research Labs in Egypt. These models provide interpretable reasoning behind the algorithmic decisions made by neural networks for deep learning diagnostic systems instead of simply providing an answer in "black box" format. Therefore, traditional models produce accurate diagnostic outputs for teachers and other practitioners, however, there is little understanding of what features the diagnostic outputs actually rely on. The introduction of explainable AI (XAI) creates interpretability of the reasoning process behind the diagnostic outputs which aids in increasing trust from educators, accountability from professionals, and better informed decision making (Robaa et al, 2024).

7.3 Handwriting Analytics and Screening Platforms

The neuropsychological/psychological group of tools for identifying handwriting is represented by handwriting analysis and diagnostic software that allows for quantitative assessment of handwriting characteristics over multiple dimensions. Examples include the MovAlyzeR and ScriptAlyzeR systems from NeuroScript (U.S.) and the CEDAR Handwriting System developed at the University at Buffalo (N.Y.). All three utilize modeling based on advanced computational techniques for examining the spatial organization, speed of writing, formation of strokes, and temporal patterns in writing (e.g., in terms of timing) relative to a given writing task.

These tools are generally used in clinical and research settings to provide the quantitative information necessary to complete a professional assessment of handwriting problems and develop a treatment plan. More importantly, the output from these tools provides a profile of individual children's writing difficulties (i.e., the specific nature, severity, and configuration of the difficulties), which provides valuable data for developing the most appropriate, individualized interventions.

Platforms designed for screening purposes, such as the AI Handwriting Screener (developed by the National AI Institute in the USA) as well as EarlyMind AI (developed by researchers from Canadian universities), can be deployed at scale within a classroom setting. They have been designed to be scalable and user-friendly by providing automated risk screening outputs and enabling the efficient administration of such assessments across all children within an entire year group as part of universal screening protocols.

TABLE 1: GLOBAL AI TOOLS FOR DYSGRAPHIA IDENTIFICATION

#	Tool Name	Country	Developer	Technological Approach	Primary Application
1	AI Handwriting Screener	USA	National Institute AI	ML screening algorithms	Classroom-based early screening
2	SensoGrip Smart Pen	Germany	Research Labs	Motion sensor analytics	Motor analysis, early detection
3	MovAlyzeR	USA	NeuroScript	Writing analytics	Clinical/research evaluation
4	ScriptAlyzeR	USA	NeuroScript	Handwriting evaluation	Clinical/research evaluation
5	Tablet BHK AI Model	France	BOLD Group	Neural network prediction	School-based diagnostic screening
6	CNN Dysgraphia Detector	Malaysia	University Research	Deep learning CNN	Automated pattern detection
7	Explainable AI Model	Egypt	AI Research Labs	XAI transparent diagnosis	Educator-facing diagnostic support
8	CEDAR Handwriting System	USA	Univ. at Buffalo	Statistical pattern analysis	Research and clinical assessment
9	EarlyMind AI	Canada	University Research	Automated screening	Classroom-based early identification
10	OCR Dysgraphia Analyzer	Global	Research Consortium	OCR and anomaly detection	Large-scale assessment remote

These global developments collectively signal a decisive shift in the paradigm of dysgraphia identification: from reactive, specialist-dependent, product-focused assessment toward proactive, data-driven, process-sensitive screening that can be embedded within everyday educational practice and scaled across diverse educational settings.

8. AI-SUPPORTED INTERVENTION SYSTEMS FOR DYSGRAPHIA: A GLOBAL OVERVIEW

As advances made in identification technology have grown and the demand for AI-supported intervention systems for dysgraphia has increased, the overlap of the two fields has continued to expand as advocates for early identification continue to stress that timely, appropriate, and effective supports must be available concurrent with the identification process. The incorporation of AI-based intervention platforms has several key advantages over traditional remediation strategies: they allow for the development of individualized learning profiles that personalize learner progress; they provide timely, specific, and actionable feedback that would not be possible for a classroom teacher to give simultaneously to multiple students; and they continually assess and modify the learner's intervention trajectory based on data that becomes available as learning occurs, rather than establishing an intervention plan based on data obtained at scheduled time points throughout the intervention process.

8.1 Cognitive Training and Neurological Strengthening Programs

Cognitive training programs relate dysgraphia to writing using the cognitive and neurological processes necessary for writing completion rather than handwriting production as the primary focus. The most fully documented instance of a cognitive training approach is the Arrowsmith Program developed at the Arrowsmith School in Canada. The foundation of the Arrowsmith Program is based upon neuroplasticity research, and it accomplishes its goals through structured cognitive exercises designed to develop the neural circuits necessary for attention, processing speed, working memory, and executive functioning (cognitive abilities necessary for successful writing). Although primarily intended to assist school-aged children with significant learning challenges, the Arrowsmith Program contains many case study examples with significant evidence of improvement in performance on both underlying processing capacities and academic achievement (Arrowsmith School, 2024). While additional randomized controlled trial research would help to strengthen the empirical support for this intervention, the Arrowsmith Program's foundation in well-established neuroplasticity research and its focus on improving cognitive function as opposed to only correcting observable behaviours contribute significantly to the intervention options available.

8.2 Intelligent Writing Tutoring and Instructional Support

The category of artificial intelligence (AI) intervention tools for representing intelligent tutoring systems that assist learners with writing is an emerging area of rapid development and expansion. These platforms use natural language processing (NLP) and machine learning algorithms to evaluate samples of a learner's written output and offer feedback that is individualized and automated across multiple dimensions; this includes letter formation, spelling accuracy, syntax, composition coherence, etc. Specifically, both the Intelligent Writing Tutor created by AI Education Labs (US) and the Writing Assistance AI platform used worldwide in education represent this approach and offer an additional layer of continuous instructional assistance for learners outside of the traditional face-to-face (i.e., teacher-to-student) instructional periods.

For learners with dysgraphia, intelligent writing tutors can provide immediate, objective, and specific feedback based on the current level of performance for the learner. Compared to the social context of receiving feedback in a classroom setting, where a learner with dysgraphia may have an emotionally charged reaction to receiving feedback (due to the emotions associated with the challenges learners who have dysgraphia experience), the level of psychological involvement associated with engaging with AI-delivered feedback is less severe, potentially resulting in increased willingness to engage with the feedback and to try to revise.

8.3 Motor Skill Training and Real-Time Handwriting Correction

A new and different way to improve fine motor skills of children with dysgraphia is being created. It is being created by using new technology of a digital stylus and a haptic feedback system to help develop equal and fluid handwriting movements. The Digital Handwriting Trainer from EdTech Labs (EU) and a Smart Stylus Feedback system from Human-Computer Interaction laboratories (Japan) use digital stylus technology to give immediate corrective feedback on grip pressure, stroke direction, letter proportion and writing rhythm. Another product that also uses the new technology and gives real time performance feedback through the use of structured practice exercises is the Tablet Writing Coach developed by the Learning Science Labs (South Korea).

These tools are based on motor learning principles, which indicate that immediate, specific and frequent feedback is necessary for developing fine motor skills (Dillenbourg, 2021). The frequency and specificity of the practice that these tools can provide is much greater than the experience of traditional methods of getting help with cursive handwriting, because they can provide this type of correction without the constraints to which human tutors are subject, i.e., monitoring the motor performance of every child in a classroom at one time.

8.4 Adaptive and Personalized Learning Applications

Adaptive learning software designed for use in the context of intervention for dysgraphia utilizes AI algorithmic technology to provide dynamically individualized learning experiences through real-time adjustments in task complexity and type, pacing, and motivation based upon continual evaluation of data regarding the learner's progress.

In general terms, adaptive writing applications that have been produced by Finnish educational technology organizations represent an established example of this use of artificial intelligence and machine learning to create unique personalized learning paths for learners based upon both their level of skill and ability (as demonstrated in the case of an individual learner), thus preventing both frustration caused by the innate difficulty involved in completing the written task and/or being disengaged from the learning process due to lack of challenge in completing the task.

The importance of adaptive personalization for students with dysgraphia cannot be overemphasized. Dysgraphia is not only a unique disability but its presentation also varies greatly from student to student in terms of their unique profile as evidenced by the substantial variation of each of the specific motor, orthographic, phonological and executive function challenges presented in this disability.

Thus, it is impossible to provide all dysgraphic students with a "one-size-fits-all" method of intervention. An adaptive learning system that responds to the unique learning characteristics of each individual can provide differentiation from instruction as required by inclusive education, which is often difficult for human teachers to provide consistently due to the restricted amount of time and large student-teacher ratios they are required to work with every day.

8.5 AI-Supported Therapeutic and Occupational Intervention

Artificial intelligence (AI) tools are being used more in clinical and rehabilitation settings to help with occupational therapy and specialized education for children with dysgraphia. AI Occupational Therapy Tools developed by Clinical AI Labs in the UK and AI Guided Therapy Systems developed in conjunction with research institutes in Australia support therapists in creating data-informed intervention plans, tracking participant improvement over time, and assisting in determining optimal therapeutic goals based on continuous performance analytics. While these tools do not replace the judgment of an experienced therapist, they do provide larger and more detailed performance data than what is possible through traditional means of observation so therapists can create evidence-based, customized interventions tailored to the unique needs of each participant.

8.6 Learning Analytics and Progress Monitoring

Learning analytics platforms are the last and a growing category of AI intervention support as they do not directly provide instructional materials. Instead, they use long-term learner writing performance data collected from many previous interventions to evaluate trends, produce progress reports, and make predictions about future performance.

AI learning analytics platforms developed by universities in the USA also provide teachers/therapists with individual and group writing development dashboards, which help them adjust intervention strategies and identify students who are struggling with their current approaches early on.

TABLE 2: GLOBAL AI INTERVENTION TOOLS FOR DYSGRAPHIA

#	Tool Name	Country	Developer	Intervention Approach	Target Population
1	Arrowsmith Program	Canada	Arrowsmith School	Cognitive-neurological training	School-age learners with SLD
2	Intelligent Writing Tutor	USA	AI Education Labs	NLP-based writing feedback	Upper primary and secondary
3	Digital Handwriting Trainer	EU	EdTech Labs	Motor practice with feedback	Early and middle primary
4	Smart Stylus Feedback	Japan	HCI Labs	Real-time motor correction	Early primary learners
5	Adaptive Writing Apps	Finland	EdTech Groups	Personalized adaptive learning	Inclusive classroom learners

6	AI Occupational Therapy Tools	UK	Clinical AI Labs	Analytics-informed therapy	Clinical/rehabilitation settings
7	Tablet Writing Coach	South Korea	Learning Science Labs	Guided motor skill practice	Primary school learners
8	AI Learning Analytics	USA	Universities	Progress monitoring	Educator/therapist support
9	Writing Assistance AI	Global	Education Platforms	Writing support and feedback	Broad age range
10	AI Guided Therapy Systems	Australia	Research Institutes	Data-driven intervention planning	Clinical settings

9. ETHICAL CONSIDERATIONS AND ALGORITHMIC JUSTICE

When using Artificial Intelligence (AI) in the education of students with disabilities, there are many important ethical questions (e.g., how do we address issues concerning algorithmic bias, data privacy/protection and the way in which responsibilities are shared among teachers (as professionals) and AI systems? All of these factors should be taken into consideration when deciding how best to use AI.

9.1 Algorithmic Bias and Representational Equity

Data is the basis for AI systems. The quality of AI outputs is determined by the representativeness, as well as quality and accuracy, of the training datasets. This presents an equity issue when it comes to identifying students with dysgraphia; if training datasets are primarily composed of specific demographic, linguistic, cultural or socio-economic groups, then there will likely be inequitable outcomes across the various groups due to differential accuracy in identification of dysgraphia — that is, the model will likely accurately identify dysgraphia in those student samples that are well represented in the training dataset and yet misidentify, under-identify, or have false positives for those student samples that are not well represented (European Commission, 2022).

In the Indian context, this issue takes on an even greater degree of urgency because the multiple and divergent scripts exist (22 official languages; many different writing systems) along with dramatically different socio-economic status and educational backgrounds mean that the data landscape with regard to scripts from which AI dysgraphia tools have been trained, developed and validated is drastically different than that used in the European and North American contexts in which most of the existing AI dysgraphia tools have been created and trialed. Therefore, the use of AI dysgraphia tools that have been trained using only Latin-script handwriting samples is fraught with the potential for significant and systematic misidentification and the potential for inequitable outcomes for children writing using Devanagari, Tamil, Bengali, Telugu, etc.

9.2 Data Privacy and Child Protection

The collection of children's handwriting and behavioural data is a significant data privacy issue that requires careful legal and ethical scrutiny. Handwriting data can be very personal to children: it captures not only how well they write, but also how well their fine motor skills function, how their development is progressing, and indirectly, how well their brains are functioning. The storage, processing and potential commercial use of children's handwriting data will raise questions about informed consent, ownership of data, security of data, and the potential uses of data beyond those that were originally anticipated or not authorised upon collection by tech companies.

The General Data Protection Regulation (GDPR) adopted by the European Union and other data protection frameworks in various countries provide a minimum amount of protection for the collection of children's educational data, but how they apply in the context of different countries with different priorities will vary significantly, and therefore will require a consistent case-by-case review of issues. In addition, while the Digital Personal Data Protection Act (2023) is a data protection law specific to India, the application of this law to the use of educational AI tools and the collection of performance data from children will continue to require further regulatory refinement.

9.3 Human-AI Authority and Professional Accountability

In AIED ethics literature, there is a significant amount of discussion regarding how to delineate clearly the roles of authority between AI systems and professionals in education. This issue becomes even more critical when examined within the context of identification for disabilities and intervention planning. Professionals in education should use AI systems as decision-support tools because they provide data-informed insight to aid professional judgment. AI systems should not be designated as stand-alone diagnostic systems that provide results without having gone through any type of critical professional evaluation. Professionals must be aware of the dangers of relying too heavily on the results generated by AI systems using algorithms or of considering AI-generated results to be the sole decision-making factor when concluding if a student has a disability. As such, this concern must be made part of teacher training, professional development, and institutional policies related to the use of AI systems to support the screening and identification of children with disabilities (Luckin et al., 2016).

Furthermore, accountability must also be established. Human educators must be accountable and have the ability to resolve issues when students experience negative outcomes as a result of using AI systems for identification and intervention. To that end, all AI systems must be developed and governed with appropriate oversight mechanisms, audit procedures, and opportunities for students, families, and educators to understand and challenge the decisions made by AI systems using algorithms.

9.4 Ethical Implementation in Inclusive Education

An ethical approach to using AI in inclusive education calls for a number of basic principles: Transparency (ensuring stakeholders understand how AI works and its limitations); Accountability (ultimately holding humans responsible for decisions made using AI); Accessibility (ensuring the tools will not create new barriers to learner/practitioner access); Cultural Responsiveness (ensuring AI systems are created and used in ways that reflect the cultural, linguistic, and socio-economic diversity of the communities served by AI). The European Commission (2022), OECD's AI Principles, and UNESCO's Recommendation on the Ethics of AI have identified these principles as basic design requirements; therefore, their inclusion in any educational context must be seen as essential rather than secondary.

10.1 Current State of Dysgraphia Identification in India

Dysgraphia identification within the Indian education system occurs primarily in clinical settings or by specialists, so the majority of students with dysgraphia are diagnosed only after they have had several years of poor academic performance or failure. Many of these students are children in the primary grades and may have close contact with primary grade teachers, who are best positioned to identify students for special education services; however, many of these teachers lack specific training in recognizing learning disabilities, therefore making it difficult for primary grade teachers to distinguish between developmental variation in students and the disability-related writing problems in students with dysgraphia.

The availability of professional resources for students with disabilities varies considerably across India's educational landscape; wealthy private schools in urban areas may have access to trained special education teachers and psychologists, while the majority of children who attend public schools, most of whom come from low-income families, do not have any access to professionals qualified to provide assistance. Because of this discrepancy in the availability of professionals to assist students, children who would benefit most from early identification of AI-related intervention services are the children who have currently not received services.

10.2 Policy Framework and Technology Readiness

In India, most children with dysgraphia are diagnosed only after they have experienced failure in school or had below average grades due to their writing difficulties because they are diagnosed primarily by medical professionals or educational specialists in a clinical environment. The majority of children with dysgraphia are in elementary school and have had many opportunities to interact with elementary-school teachers, who are generally better able to identify children for special education services. However, the majority of those who work in elementary schools do not have training in identifying children with learning disabilities, thus making it very difficult for them to differentiate between developmental variation and the writing problems in children with dysgraphia.

The availability of qualified professionals outside of schools to assist children with disabilities varies greatly throughout India's education system; for example, wealthier urban private schools generally have access to a fair number of professionals qualified to assist students with disabilities (trained special education teachers and psychologists), but the vast majority of children enrolled in public schools in India (who are generally from low-income families) do not have any access to such professionals. Because of this disparity in the availability of qualified professionals to help assist children, the children who would be most positively affected by identifying children with AI-related intervention services early on are currently the same children who do not have access to those types of services.

10.3 Directions for Culturally Responsive AI Development

Developing AI tools for identifying and intervening for children with dysgraphia in India involves several important aspects of cultural and linguistic responsiveness. One critical factor is that the tools must be created and validated for the languages and scripts that Indian children write in, such as Devanagari, Tamil, Bengali, Gujarati, etc. The way letters are created in these various scripts is different in terms of how they are formed kinematically and spatially; therefore, models developed for Latin-based scripts will not necessarily generalize to these other script contexts without a sufficient amount of validation research that has been done in those respective contexts.

A second aspect is that the training datasets used to create AI tools for identifying and intervening with students with dysgraphia must include handwriting samples from all types of school-age children in India (e.g., children living in rural areas, children living in urban areas, children from low-income backgrounds, children from affluent backgrounds, children attending different educational systems, etc.), since without adequate representation across all demographic dimensions in the training dataset, it is likely that these AI tools will produce results that differ for different demographic groups, thereby reinforcing existing educational inequities between them.

It is necessary for AI intervention tools to have a culturally appropriate, as well as linguistically appropriate interface design and instructional content in each site where they are being used. This means re-designing how to teach the material includes revising the process for how to motivate a student or measure a student's success, and not simply taking existing materials used in the western world and translating them.

10.4 Teacher Education and Institutional Capacity

For successful integration of AI based educational systems into Indian Inclusive Education Practice, significant resources must be allocated to teacher training and increasing Institutional Capacity Building. Pre-service teacher training programs must provide both theoretical knowledge regarding specific learning disabilities, including dysgraphia, along with opportunities for in-class practice using AI based screening and intervention tools. Practicing teachers must also have access to adequate in-service professional development programs including both theoretical and practical training needed to effectively integrate AI based educational tools into their practice.

At an institution level, Education Departments and Schools must establish clear protocols for managing the use of AI Screened Data, including guidelines related to parental communication regarding AI based screening data, At-Risk Child referral pathways, and a mechanism for connecting identification outcomes to the appropriate support services. Without establishing these institutional frameworks, even well-designed AI tools could generate identification data that may not lead to effective action being taken on the behalf of identified learners.

11. IMPLICATIONS FOR INCLUSIVE AND SUSTAINABLE SOCIAL TRANSFORMATION

The impact of early identification and intervention for children with dysgraphia, particularly when integrated with artificial intelligence (AI) technology, extends beyond the educational domain. From a lifelong learning perspective, providing timely and effective support to children with dysgraphia during their initial years of schooling can substantially influence their future trajectories. Children who acquire adequate writing skills through appropriate support, such as accommodations and assistive technology, are more likely to access a full range of educational and employment opportunities. The broad social and economic benefits of enabling children with dysgraphia to access these opportunities across the entire population underscore the importance of investing in AI-supported early identification and intervention at both institutional and policy levels.

The use of AI-based universal screening tools in an inclusive education approach has the potential to shift the institutional culture of early childhood and primary education from a reactive response to clear difficulty to a proactive and universal approach to support. Universal screening of all children for potential writing difficulties, rather than only those who raise concern of the teacher or parental advocacy, results in a more equitable identification process and aligns more systematically with the values of inclusive education. Universal screening approaches are more likely to identify and support children whose difficulties might otherwise go unnoticed, perhaps because they are quiet and compliant rather than disruptive, or because their difficulties are masked by compensatory strategies.

From a teacher professional development perspective, the arrival of AI-based tools into educational practice is a challenge and an opportunity. It is a question of digital literacy and professional confidence: many teachers, particularly those earlier in their careers or working in under-resourced settings, may not be sure they can use AI tools effectively and read the data they produce. The opportunity is for professional enrichment: AI tools which provide rich and nuanced data on the development of writing in individual learners can help teachers develop a richer understanding of the writing process and of learning disability, thereby increasing their professional capacity in ways which go beyond the use of any particular tool.

Finally, from a research perspective, the systematic collection of handwriting and learning data using AI-based tools in Indian educational settings — subject to appropriate ethical safeguards and data protection frameworks — is an invaluable resource for the development and validation of India-specific AI models for dysgraphia identification and intervention. Longitudinal studies that track the developmental trajectories of children identified through AI screening and compare outcomes between children who receive AI-supported interventions and those who do not would provide the high quality of evidence needed to inform policy decisions about the scale and mode of AI integration into inclusive education systems.

12. CONCLUSION

In this study, we have explored the transformative potential of Artificial Intelligence in early identification and intervention of dysgraphia within inclusive educational frameworks, with specific focus on the particular challenges and opportunities emerging from the Indian educational context. The review of global research and technology development provides strong evidence that AI-based handwriting analytics and intervention platforms are at a level of maturity and empirically validated to be taken seriously for inclusion in mainstream educational practice.

AI-based identification systems (smart pen technologies, machine learning diagnostic models, deep learning neural networks, handwriting screening platforms) provide unparalleled ability to objectively, continuously, and scalably identify dysgraphia-associated handwriting patterns at developmental time points when intervention is most effective. AI-enabled intervention platforms encompass cognitive training programs, intelligent tutoring systems, adaptive learning applications and motor skill training technologies. They offer personalized, data-driven and continuously responsive support, complementing and enhancing the work of skilled educators and therapists.

The study has also brought to light the huge gaps between the world state of the art and the ongoing practice of dysgraphia identification and intervention in Indian educational settings. But the disparities are not just about technology. They reflect deeper structural issues, such as unequal access to resources, poor teacher training, lack of specialists, and the absence of systematic early screening procedures. To bridge these gaps, it is not enough to use existing AI tools but to create new culturally responsive, linguistically appropriate and ethically grounded tools for the Indian context.

The path forward demands concerted effort across multiple dimensions: investment in the development and validation of India-specific AI tools for dysgraphia; integration of learning disability awareness and AI literacy into pre-service and in-service teacher education; development of institutional protocols for the use of AI-based screening and intervention data; strengthening of data protection frameworks for children's educational data; and sustained research investment to build the evidence base for AI-supported inclusive education in Indian contexts.

Most fundamentally, this study affirms that the case for AI-supported early identification and intervention for dysgraphia is not merely a technological argument but an ethical one. Every child who navigates years of educational difficulty without recognition, support, or accommodation — not because appropriate tools do not exist but because the systems responsible for their education have not invested in deploying them — represents a failure of the inclusive education commitments to which educational systems increasingly aspire. AI offers a powerful, scalable, and increasingly affordable means of making good on these commitments. The challenge is not whether to adopt AI in the service of inclusive education but how to do so responsibly, equitably, and sustainably.

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