Designing an AI-Based Solution for Teaching Handwriting

Alexandra Neagu, Erwin Li, Tim Tian, Thomas Kuiper, Vanessa Timmer
Delft University of Technology

ABSTRACT

This paper explores an AI-based solution for the teacher shortage and declining handwriting skills, an increasingly prevalent problem in the digital era. The paper focuses on the design and evaluation methods of an application capable of analyzing handwriting based on the Minnesota Handwriting Assessment metrics, providing child-friendly AI feedback for handwriting, and creating an evaluation method for this application. The solution results in an AI-based handwriting application, with four different difficulty levels: *Tracing an expert, following an expert, copying an expert, writing without an example.* Additionally, it immediately provides personalized AI generated feedback on the words written, based on the five metrics from the Minnesota Handwriting Assessment: *legibility, spacing, size, form, and alignment.* Finally, this application makes use of gamification to keep children motivated, engaged and challenged. To test the effectiveness of our application, compared to traditional methods, we have designed a year-long experimental study comparing the two.

1 INTRODUCTION

Digital technology has been the rising star of the past few years, especially with AI getting so much traction with **OpenAI**. Everyone loves the convenience that our mobile phones, computers, and tablets provide, as we are slowly getting addicted to this 'convenient technology' that we use so much in our daily lives. However, this 'convenient technology' is also one of the primary reasons that handwriting skills are declining in our digital age. Although the prevalence and frequency of handwriting has declined, these skills are nonetheless important, as they are readily used in academics, where children are taught how to write and need to take exams on paper. These handwriting skills are becoming increasingly illegible [1], while at the same time, fewer and fewer qualified teachers are capable of teaching children properly. The Netherlands has faced a shortage of qualified teachers for many years now, leaving children vulnerable and with limited education. To address the problem of declining handwriting skills and the teacher shortage, an AI handwriting app will be realized, which teaches elementary school children proper handwriting skills on their tablets in a fun and competitive way.

Even though the need for handwriting skills have declined in this digital era, handwriting remains a timeless skill promoting academic success, development of fine motor skills, and cognitive development [2–4]. Due to the dexterity required, improving handwriting impacts the fine motor skills, which are crucial for various activities such as drawing and utilizing tools [5]. Additionally, it is vital to one's cognitive development, such as memory retention, comprehension and creativity [6]. Finally, handwriting goes hand in hand with academic performance, where studies have shown a bidirectional connection between the two [4].

While existing applications for learning handwriting exist, all of them are a supplementary tool for enhancing children's handwriting skills, rather than a replacement for actual teachers [7, 8]. These applications either provide lackluster feedback, or target the wrong demographic. As we are creating an application with the goal of being able to replace teachers, we aim to answer the following research question: ***How does AI-generated personalized feedback for handwriting improve children's learning outcomes versus traditional methods?***

To ensure that the children are being engaged and challenged, the application offers a wide range of exercises with increasing levels of difficulty. These exercises include the tracing of expert handwriting, following expert handwriting, copying expert handwriting and finally writing without an example, so users can practice without a reference. Additionally, by adding gamification, such as achievement badges, leaderboards, and progression levels, the children can stay engaged and would be more likely to improve [9–11]. This would turn handwriting from a tedious task, to a fun gamified method of education.

To create proper personalized feedback, a neural network combined with image recognition will be used to evaluate the user's writing, offering feedback and scores based on five metrics: legibility, spacing, size, form, and alignment. These metrics are based on the Minnesota Handwriting Assessment [12], and are used to provide feedback with the LIME Image Explainer, proposed by Bhoi et al. [13]. As the application is intended for younger children, the feedback needs to be adapted to properly explain how to improve in a child-friendly manner.

The main contribution of our research consist of the following: The creation of an application which teaches children handwriting skills. The steps for creating the evaluation for the AI-generated feedback provided by the application. Finally, possible real world integration, creating a possible solution for the current teacher shortage.

2 BACKGROUND

2.1 Learning Objectives

To achieve our learning objectives of fostering fine motor skills' development, enhancing cognitive abilities, and improving educational outcomes, we are assisting users by improving their handwriting. Handwriting skills have proven, throughout the years, to be a critical factor for cognitive development and cognitive functioning, as well as reading skills in younger children [6]. However, improving your handwriting skills is not the only component of achieving our learning objectives.

2.2 Theoretical Background

Fine motor skill is the ability to control and coordinate small muscle movements, which are crucial for conducting various tasks and activities [2]. According to Syafril et al., the development of fine motor skills in younger children involves the appropriate tools, direction and practice, and allowing enough opportunity for practice [2]. Additionally, the study suggests that fine motor skills can be developed by performing activities that require small muscle movements, such as writing and drawing. Developing these motor skills are necessary, as they are linked to cognitive, social-emotional, self-regulatory, and academic development [3].

Cognitive abilities are skills that are involved in all aspects of life. Some examples are: perception, memory, and processing ability. Studies have suggested that there is a bidirectional relation between academic achievements and cognitive abilities [4]. Their findings mention that direct academic instruction positively affects the development of certain cognitive abilities, and that fostering both children's academic and cognitive development may indirectly influence academic and cognitive development with this bidirectional relation [4].

The acquisition of handwriting skills is thus crucial for multiple facets of a child's development. In order to facilitate the learning process, we combine aspects of constructivism [14] with deliberate practice [15]. Constructivism posits that people create their own knowledge by engaging in new experiences. In light of new information, people are required to compare it to prior knowledge and experiences and assess how it fits within their current understanding of the world. They can then either incorporate the new information into their existing knowledge base or dismiss it. This process requires active participation of the learner.

2.3 Learning Theories

Koohang et al. [16] present a model for designing an e-learning platform based on constructivism. The model contains two constructivist categories: the learning design elements and learning assessment elements. The learning design elements include fundamental design elements and collaborative design elements. The fundamental design elements support individual students in the learning process by encouraging them to relate the material to existing knowledge, place the material in its broader context and self-reflect. Meanwhile, the collaborative design elements allow students to support each other by offering feedback, discussing alternative perspectives and collaborating on tasks. The learning assessment elements provide guidance towards the learning objective and are divided into individual assessment, peer assessment and the facilitator's assessment. In our application, the AI agent acts as a peer and facilitator.

Deliberate practice is the main learning theory upon which our application is based [15]. Ericsson et al. define deliberate practice as regimented activities that are tailored to improving performance. These activities are designed to be educational and challenging, with little concern about whether they are enjoyable, and are met with immediate feedback. We will implement these principles by designing structured tasks befitting of the skill level of the student, while gently incentivizing them to advance their handwriting proficiencies.

Immediate feedback has an important part in guiding students towards the intended outcome of obtaining sufficient handwriting skills. Our design will offer feedback that is not only immediate, but also personalized. We prevent students from acquiring undesirable habits by identifying shortcomings and providing areas of improvement after completing a task. The feedback will be customized to the grade level of the student and patterns in their handwriting that the AI has uncovered over time. Personalized feedback provides the additional benefits of increasing motivation and instills a sense of academic self-reliance, increasing confidence in one's abilities [17]. Since our target audience is primary school-aged children, we are required to take enjoyment into account in order to create an age appropriate application that succeeds at maintaining engagement with the material [18]. The other elements are however represented in our design.

We aim to inspire and sustain engagement in the learning process by utilizing gamification. Gamification in education is a topic that has garnered a lot of interest in the academic world and has been shown to enhance motivation and engagement in students by incorporating elements common in games into the learning environment [9, 10]. Progression and achievement oriented affordances such as leaderboards, badges and progression levels are the most widely used patterns in gamification [10] and are featured within our design as well. Our design features a number of miscellaneous affordances as well, including in-game rewards and an AI assistant. Together, these components make handwriting improvement a captivating activity that is both useful and fun [9].

2.4 Related Work

The role of deliberate practice in achieving mastery has been explored in many different fields [19], yet handwriting is one that remains relatively neglected. Nevertheless, Dikken et al. [20] propose a framework for teaching handwriting skills by implementing the core principles of deliberate practice. The teaching loop consists of reciprocal interactions between the student and expert, who is either a human teacher or an automated evaluation system. The expert defines the task description and difficulty and provides an expert model that the student should adhere to in order to attain proficiency. The student in turn executes the task while following the instructions as closely as possible. Their performance is compared to the expert model in real time, allowing the student to get immediate feedback on areas that are not up to par. A task is repeated in this manner until the learning goals have been achieved, after which the student can shift their focus to a new objective.

Dikken et al. used this framework to develop *CaT* [20], a calligraphy tutoring application. *CaT* does not target the same audience of primary school children we do, nor does it utilize artificial intelligence techniques. The core teaching loop is however similar to our design, *Cat* thus serves as a guide in terms of implementing the deliberate practice framework, albeit one that we need to adapt for our use case.

Cat teaches calligraphy, a skill that generally assumes prior handwriting knowledge. Handwriting knowledge is usually acquired during the first years of primary school. Traditional methods involve writing in a notebook, but with the widespread adoption of technology in the classroom, handwriting instruction has evolved beyond pen and paper. A number of commercial applications have emerged that teach handwriting through digital means.

2.5 Current applications

2.5.1 Handwriting Without Tears. One of the applications that attempt to teach children handwriting is *Handwriting Without Tears* [21]. Handwriting Without Tears is a program geared towards primary school children that offers consistent guided practice to foster automaticity and fluency in handwriting. It centers a multimodal approach to learning, with the interactive digital teaching tool containing handwriting instructions with animations, music and videos. Instructions are age appropriate and broken down into smaller pieces to avoid confusion and frustration on the children's part. It is noteworthy that the actual writing on the tablet is limited to a single exercise, the remaining exercises must be performed on paper.

2.5.2 Intuiscript. An application that does leverage the possibilities offered by tablet styluses is *Intuiscript* [22]. *Intuiscript* was developed alongside pedagogical experts and offers six digital writing exercises to be performed in the classroom. Students are given handwriting exercises tailored to their skill level accompanied by real time feedback, enabling autonomous learning. To make the feedback easier for children to understand, it is presented using a colour scale ranging from green to red, with green indicating success while red indicates an area of improvement. Teachers have access to a dashboard containing detailed analyses of each student's performance and can assign custom exercises to address specific deficiencies. The handwriting analysis is based on three criteria: the shape of each letter, the order of strokes and the direction of each stroke. The letter recognition and handwriting analysis classifiers were trained with the HBF49 [23], a feature set consisting of hand-drawn symbols. *Intuiscript* shows promise but is only targeted towards children between 3 and 7 years old, which is quite a narrow demographic. This is reflected in the exercises, which revolve around letter and word formation but do not tackle sentences, despite their integral role in written communication.

2.5.3 Dynamilis. Another application that has arisen is *Dynamilis* [1], an application created for elementary school children between 5–12 years old in collaboration with teachers and therapists. The research this application is built upon includes many studies on children with dysgraphia [24], a neurodevelopmental condition making it harder for people to turn their thoughts into words, hence establishing an inclusive design.

On initial use, the application performs an analysis of the child's handwriting in order to recommend activities that target their deficiencies. The analysis is produced by an artificial intelligence evaluating a written paragraph based on 15 features important for handwriting. The type of artificial intelligence is not specified. *Dynamilis* features both digital and analog activities that consist of gamified exercises and actual games. The exercises are aimed at not only improving handwriting legibility, but also the fine motor skills involved in good handwriting.

However, the only form of immediate feedback is numerical game scores. While these offer an indication of performance, they lack the information necessary to apply targeted improvements. One could hypothetically use the analysis tool after every activity, but the team behind *Dynamilis* recommend a frequency of once a month. Additionally, the feedback procured by the analysis is not formulated in an age appropriate manner, using technical terms such as "azimuth angle". Although not explicitly stated, using such language does suggest that the application is meant to be primarily used under adult supervision, with this supervisor rather than the AI providing in-depth feedback to the child. This stands in contrast to our design, which offers immediate feedback to the child without requiring an intermediary to interpret the text in order to stimulate autonomy.

2.5.4 ITraceApp. Finally, an older application which teaches children handwriting is the *ITraceApp* [2]. This app allows children to learn to handwrite by tracing over words multiple times, attempting to simulate deliberate practice with gamification. Nevertheless, this approach does not allow a higher level of progress, leaving children that have mastered tracing bored and unchallenged. This lack of progression could lead to disinterest over time, hindering the app's effectiveness in maintaining children's interest in handwriting. Finally, the feedback it provides is shallow, as it only mentions whether the user has traced the word within the line or not. Without specific and constructive feedback, the children may not identify crucial mistakes in early development, leading to the forming of bad habits in handwriting.

As is evident, there are many approaches to teaching handwriting skills. We draw inspiration from these approaches, analyzing each for their strengths and weaknesses. Notably, most of the discussed applications lack gamification features. This observation underscores the potential for an innovative solution catering to primary school children, one that seamlessly integrates deliberate practice, gamification, and personalized AI feedback, thus addressing a notable void in the current market.

3 METHODOLOGY

This section will showcase how we applied the learning paradigms to create an application to teach handwriting. Furthermore, it discusses the merits of gamification, and how we utilized it in our system. Lastly, we discuss the affordances of our choice in technology, and address potential limitations.

3.1 System Design

The task of learning handwriting is rooted in both the learning paradigms of behaviourism and constructivism. Behaviourism emphasizes repeated practice as well as both positive and corrective feedback. Constructivism emphasizes hands-on experience and reflection.

Additionally, learning can be enhanced by having practice be deliberate [15]. This is achieved by having clear goals to work towards. By giving feedback on different sub-tasks, the user can more easily identify specific things to improve. This allows them to put deliberate effort into every sub-task, leading to more efficient learning.

With these concepts in mind, the main interaction loop was designed to teach handwriting while keeping users challenged and engaged. Users do short, simple exercises that are comprised

[1]https://dynamilis.com/

[2]https://itraceapp.com/en/

of writing letters or words. These exercises are divided over four difficulty levels based on the amount of assistance offered:

- **Tracing an expert**: Users will be presented with a video writing a word along with a traceable version of that word to draw over
- **Following an expert**: Users will only get a video showing the writing.
- **Copying an expert**: Users will see a completed version of the word, and have to copy it.
- **Writing without an example**: Users can challenge themselves by practising without a reference.

The first level has two assisting features. The traceable letters give the user immediate visual feedback, this helps them to quickly spot and avoid mistakes. A video of handwriting will allow users to get a grasp for the order of strokes for each letter, as well as an idea of how fast to move the pen for each part. The next levels slowly drop assistance, the third difficulty should force users to start developing their own pen movements. Lastly, the fourth difficulty level is like a basic handwriting final exam. If this consistently goes well, then that means the user has learned basic handwriting.

The second part of the interaction loop is the feedback. The users writing will be analyzed by a neural network as described by Bhoi et al. in [13]. This network is trained on images of expert handwriting. When given an image of handwriting, it will score the image on five metrics: legibility, spacing, size, form and alignment.

In addition to the 4 main exercise levels, we also include metric specific exercises to help users that struggle with specific metrics.

- **Spacing**: Offer visual aids such as fading guidelines and color-coded spaces between words and letters, which help users visually assess and adjust spacing in real-time.
- **Size**: Users will be tasked with writing the same word in small, medium and large size.
- **Form**: Users can practice specific elements of letters, such as loops in 'b', 'd', 'g', etc., and the ascenders and descenders. Furthermore, they will be asked to repeatedly write a specific form, letter, or word to help develop muscle memory.
- **Alignment**: The app shows a line of text above where the user should write. As they write, the alignment of each letter is compared in real-time to the example above, and the app provides instant visual feedback if the writing drifts from the alignment

Bonneton-Botté et al. gave several key principles for good handwriting instruction in [25].

(1) Repeated practice is important.
(2) Practice should be task specific, i.e. any practice outside of writing with the goal of improving motor skills etc., does not benefit handwriting legibility.
(3) Practicing handwriting should be the main objective.
(4) Both intrinsic and extrinsic feedback should be readily available in good quality.
(5) There should be variability in exercises, such as varying the letter sizes and fonts. This variance leads to greater memorization [26].
(6) Learning environments should provide motivation and support with options to self-regulate performance.

Points (2),(3) and (5) are all applicable to the set of exercises described before. Our exercises are always mainly about improving handwriting, and can also be on more specific goals to improve certain aspects of handwriting. Exercises are short and can thus also have great variance in both vocabulary/different letters and fonts/sizes, since this can be changed for every exercise. Of course, this variance is regulated by the difficulty level to keep the difficulty level as intended.

Points (4) and (6) give some guidelines as to how the feedback should be designed. Point 4 raises the importance of intrinsic and extrinsic feedback. Sadly, from the design perspective, intrinsic feedback, such as feeling the pen move and hearing the sound of writing, is largely outside our control. However, external feedback is a big advantage of our technology. After an exercise, immediate feedback can be given, this greatly enhances learning compared to typical classroom settings [27]. Still, the question remains how the feedback is given. Hattie et al. in [28] showed that if the feedback is given in a bad way, it could impact learners negatively. They described that feedback should not only say what is wrong but, importantly, also describe 'where to next?'. So along with the metric scores previously mentioned, the system will be able to explain the given score via the adapted LIME Image Explainer, proposed by Bhoi et al. [13]. This should help users quickly identify what can be improved. The feedback will also include exercise recommendations that help improve skills that the user is lacking in. Now, users can understand what they did wrong and know what to do to improve.

Point (6) has three topics to address, first support is given in the form of positive feedback alongside the corrective feedback. Highlighting good performance on certain metrics or in general, while also highlighting improvements compared to before. Gamification elements are used to motivate as well as support users, this will be described in a later section. Lastly, given that this is an app, users have a lot of opportunities to self-regulate their practice. They can choose how much and when they want to practice, and are given tools to reflect on their own performance.

3.2 Implementation of feedback

The neural network implementation has a typical convolutional architecture with default parameters, commonly used in classification tasks [29]. Because the network needs to score the input on several metrics, the dataset to train it needs both good and bad examples of all metrics, these can then also need to be labeled as such. Training on a sufficiently large dataset with these qualities, allows the network to learn the difference in structure between good and bad for each metric.

The visual feedback explainer, as proposed by Bhoi et al. [13], works by looking at the input and corresponding scores, and then comparing them to changes in the scores when changing pixels. This way, it can find the important pixels to add and/or remove. This can then be translated to a visual image showing where there should and should not be ink.

The exercises can be in different sizes and fonts, putting the user inputs strait into the network like that could potentially lead to problems. To address this we measure how large the prompted size is compared to the default and use a transformation on the input to translate it to the normal size. For specific fonts the dataset needs to be split into different fonts as well. The network can then be trained to recognize specific fonts. This way several networks can be trained and used whenever needed.

3.3 Gamification

Improving your handwriting takes a considerable amount of time and effort, and is generally considered to not be very exciting. In order to increase engagement, performance and motivation, we enhance our learning loop by incorporating gamification elements.

Gamification is defined by Deterding et al. as 'the use of game-design elements in a non-game contexts' [30]. They notably distinguish gamification with game-based learning, which is using actual games for learning. We chose to use the former over the latter, in order to be more aligned with the principles of deliberate practice. Gamification allows us to introduce motivational elements without deviating from the core practice activities. This alignment ensures that the primary focus remains on improving specific skills through repeated practice, without being overshadowed by game elements.

Gamification has been successfully applied in multiple sectors, including education [31], and is becoming more and more common in lessons [32]. Incorporating gamification has been found to yield various positive effects like, increased participation [33], motivation [34], and an overall performance in the skill learners are trying to acquire [35]. Nand et al. performed a study on the effects of gamification on primary school children [11]. They surveyed 120 children and report that the most appealing features are "challenge" (multiple levels), "feedback" (being able to see your score), and "graphics" (overall presentation". By incorporating these features, they note a significant increase in learning outcomes.

Our application will incorporate points, levels, achievements, and leaderboards. Points and levels are mentioned by Nand et al. as the most important features, which is supported by Mohammmed et al. who calls points and feedback "the most essential component of gamification [31]. Furthermore, we include achievements and leaderboards, as they are also commonly used, and shown to be effective [36]. Lastly, we will focus on creating a pleasant user experience by having high quality graphics, both audio and visual.

- **Points and feedback**: Users will be able to immediately see the score of their handwriting, graded by the system. This will allow them to strive to improve their score, and compare with their peers.
- **Achievement Badges**: Learners can earn badges for performing specific tasks. Achievements seem to be most effective when they are designed to be difficult and obtained with a low frequency [37]. Therefore, they will be given out, when learners perform something noteworthy, such as achieving a perfect score, unlocking a new difficult level, or increasing writing speed.
- **Progression Levels**: Our application has multiple difficulty levels. Users can unlock higher levels by taking a summative assessment, and scoring above a set threshold. The application will suggest a suitable difficulty level depending on the user's performance, but users will also be able to freely select the level they want.
- **Leaderboards**: Leaderboards enable learners to compare their rankings with peers, fostering a competitive environment. However, there's a risk that lower-ranking learners might feel demotivated [38]. To address this, Park et al. suggest several design strategies. Firstly, they recommend the use of both macro and micro leaderboards: macro leaderboards capture overall performance, while micro leaderboards focus on specific subsections. In our application, we incorporate this by displaying leaderboards for overall performance as well as for individual metrics. This approach increases the chances that learners will see themselves ranking higher in at least one category, thus boosting their motivation. Secondly, every measurable aspect should be included in the micro leaderboards. We adopt this principle by featuring leaderboards that track not only performance but also effort-based metrics such as cumulative daily logins, consecutive logins, and tasks completed. This variety helps sustain engagement across different levels of learners.
- **Visual Graphics**: High-quality visuals are crucial in maintaining learner interest and engagement. Our application is designed with vibrant colors and imagery, to complement the educational content without overwhelming the user.
- **Sound Design**: Sound effects and background music are integrated into the application to provide auditory feedback, which enhances the gamification experience. These sounds are designed to be rewarding and motivating, signaling achievement when milestones are reached or correct actions are taken. Additionally, soothing background music helps maintain a focused and engaging learning atmosphere, thereby reducing the monotony associated with practice.

3.4 Affordances

To realize our project vision, we will create an AI-based solution that uses the combination of a tablet and stylus. This choice of technology aligns with our goals and comes with numerous affordances. Firstly, the system is able to take objective measurements of static features like size, form and alignment. Hence, the application can provide feedback tailored to the user's specific handwriting style and pinpoint the individual's strengths and weaknesses. Thus, making it clear what aspect they need to focus on. Additionally, by tracking the data, we are able to show improvement over time. Secondly, the scalability of the system. Once the app has been developed, it can be mass-deployed, with the only barrier-to-entry being the cost of the hardware. Therefore, our application is a potential cost-effective solution. Lastly, the combination of accessibility and immediate feedback offers users the autonomy to practice and improve their handwriting whenever they want.

There have been multiple studies on the effectiveness of using a tablet in various educational settings. Couse et al. conducted a study on the viability of tablet usage in preschool education, and found that the preschool children were easily able to acclimate to the technology [39]. Another study by Van Deursen et al. explored the process and determinants of tablet adoption in primary education. They found that incorporating tablets brought several benefits, such as improved enthusiasm, increase in active participation in class, and enhanced focus on the task at hand due to less external distractions [40].

Moving on to specifically handwriting learning technology, the IntuiScript project serves as a noteworthy example [22]. The project designed a digital notebook that uses AI to analyze the user's writing and give them corresponding feedback. Bonneton-Botté et al. conducted a study using the application and found that the technology can support handwriting learning, with varying levels of impact depending on the initial level of graphomotor skills [41]. Additionally, Simonnet et al. reported a positive experience from children and teachers on the use of tablets for handwriting [42]. The in-class experiment showed that children quickly got accustomed to the technology and were motivated to improve their score.

3.5 Approach Limitations and Mitigations

Despite all the benefits of integrating tablets into the curriculum, they come with complexities that need to be addressed. Alamargot et al. found that writing on a tablet negatively affected student's legibility, when compared to writing on paper [43]. The smooth surface of the tablet, gives less propriokinesthetic feedback than the rough paper, resulting in a decrease in the legibility of the student's handwriting. The participants consisted of second-graders and ninth graders. The tablet caused the second-graders to have increased writing time due to more pauses. This effect was not found in the ninth-graders, instead they found increased exerted pressure and speed. Gerth et al. did a similar study, except with adults instead of children, and also found an increase in writing speed [44]. However, they noted that skilled writers were able to adapt to the smoother surface, a phenomenon that was not seen in the study of Alamorgot et al.

Another limitation is mentioned by Van Deursen et al. who reports instances of physical discomfort, in the form of back- and neck pain, and visual discomfort due to extended tablet usage [40]. Lastly, adopting tablets leads to many logistical complexities. Henderson et al. emphasize that schools need to carefully consider how they manage aspects like deploying, protecting, recharging, repairing, and replacing tablets [45].

To address these limitations, we will inform users in the app to give them clear advice. If a user wants to minimize the effect of the different surface feel, we will recommend them to use a paperlike-screen protector, a specialized stylus with graphite tip, or even specialized hardware like the reMarkable tablet [3]. We will combat potential discomfort by including a built-in reminder system. This system will send notifications to the user after extended use, prompting them to take short breaks. These reminders will encourage users to engage in stretches, change their posture, or take a moment to rest their eyes—adhering to the 20-20-20 rule for eye health.

4 STUDY DESIGN

In this section, we present the design of a year-long experimental study investigating the effectiveness of traditional handwriting instruction compared to an AI-based handwriting analysis application in improving children's handwriting skills.

[3]https://remarkable.com/

4.1 Introduction

The evaluation of our experiment aims to investigate the effectiveness of personalized feedback generated by AI-based handwriting analysis in enhancing children's learning outcomes for improving handwriting skills compared to traditional methods. We hypothesize that this personalized feedback will significantly enhance children's learning outcomes in improving handwriting skills compared to traditional methods. Personalized feedback tailored to each learner's specific areas of improvement is expected to provide targeted guidance, leading to more effective skill development. Through a comparison with traditional methods of handwriting instruction, we aim to assess the relative effectiveness and efficiency of our AI-based approach. Traditional methods typically involve static exercises and manual assessment by educators, whereas our system offers dynamic, personalized feedback based on neural network analysis.

4.2 Method

4.2.1 Participants. The participants for this study will consist of children aged 7 to 10 years old, recruited from local elementary schools. Participants will be randomly assigned to one of two groups: the *Traditional Method group* or the *AI Method group.* A sample size of at least 30 participants per group is often recommended for experimental studies to ensure sufficient statistical power and generalizability of findings. Therefore, a total of at least 60 participants (30 in the Traditional Method group and 30 in the AI Method group) would be appropriate for this study [46].

4.2.2 Procedure.

- **Pre-Assessment**: Before the intervention, all participants will undergo a pre-assessment to establish baseline handwriting skills. This assessment will include tasks to evaluate legibility, spacing, size, form, and alignment of handwritten text.
- **Group Assignment**: Participants will be randomly assigned to either the Traditional Method group or the AI Method group. Each group will consist of an equal number of participants with similar baseline handwriting proficiency levels.
- **Intervention**:
  - **Traditional Method Group**: Participants in this group will receive handwriting instruction from a qualified teacher using traditional methods. Instruction will include practice exercises focusing on letter formation, spacing, and alignment. Feedback will be provided by the teacher based on a manual assessment of written samples.
  - **AI Method Group**: Participants in this group will use the AI-based handwriting analysis application developed for this study. The app will provide personalized feedback on handwriting skills, including areas for improvement and suggested practice exercises. Participants will engage with the app during each session, following the prescribed exercises and incorporating feedback from the system.
- **Duration of Intervention**: The intervention will be structured to occur over the course of a year, with participants attending sessions every three months. A one-year study duration could provide valuable insights into the long-term

effectiveness of the interventions on children's handwriting skills. We decided against a longer longitudinal study in order to mitigate risk factors associated with a prolonged experiment period, such as participant retention and potential fatigue [47].

- **Post-Assessment**: Following the intervention period, all participants will undergo a post-assessment to evaluate changes in handwriting skills. Similar to the pre-assessment, this assessment will include tasks to assess legibility, spacing, size, form, and alignment of handwritten text.
- **Data Collection and Analysis**: Data collected during the pre-assessment and post-assessment phases will be analyzed to determine the effectiveness of the interventions. Specifically, comparisons will be made between the Traditional Method group and the AI Method group in terms of improvements in handwriting skills. Statistical analysis, such as t-test, will be conducted to identify significant differences between the two groups.

4.3 Ethical considerations

This study will be conducted in accordance with ethical guidelines for research involving human participants. Before we perform the study, we will ask for approval from the TU Delft Human Research Ethics Committee. Informed consent will be obtained from parents or legal guardians of all participating children. All data collected, including handwriting samples and personal information, will be securely stored and accessible only to authorized researchers involved in the study. Participant identities will be anonymized, and identifying information will be kept separate from research data to ensure confidentiality. Additionally, any identifiable information will be coded to further protect participant privacy. Participants will have the right to withdraw from the study at any time without consequence. Participants who choose to withdraw will have their data excluded from further analysis. The consent form defined for this evaluation can be found in Appendix A.

4.4 Tasks

- **Traditional Method Group**: Participants in this group will engage in handwriting practice sessions led by a qualified teacher. These sessions will include activities such as tracing letters, copying words and sentences, and free writing exercises, and will be conducted on a tablet, in order to ensure a common medium with the AI Method group. Participants will receive feedback and guidance from the teacher based on their performance during these sessions.
- **AI Method Group**: Participants in this group will interact with the AI-based handwriting analysis application. The app will provide personalized feedback on handwriting skills and suggest targeted practice exercises to address areas for improvement. Participants will engage with the app regularly, completing assigned exercises and incorporating feedback from the system.

Throughout the intervention period, participants' progress will be monitored and recorded. This will include tracking metrics such as the number of completed handwriting exercises, accuracy and consistency of handwriting, and improvements in specific areas identified for development. Progress data will be used to inform adjustments to the intervention strategies and assess individual learning trajectories.

Following the completion of the intervention period, all participants will undergo a post-intervention assessment to evaluate changes in handwriting proficiency. Similar to the baseline assessment, participants will be asked to complete tasks such as writing letters, words, and sentences, as well as copying text from a provided sample. Handwritten samples will be collected and compared to baseline measures to assess improvements in handwriting skills. In addition to the objective measurements obtained through assessments, participants' handwriting skills will be evaluated by teachers at the end of the study. Teachers will assess participants' handwriting proficiency based on the five objective measurements: legibility, spacing, size, form, and alignment. Multiple teachers may be involved in the evaluation process to minimize bias, with their assessments averaged to obtain a comprehensive measure of participants' handwriting proficiency [48].

4.5 Measures

The study utilized a combination of objective and subjective measures to assess the effectiveness of traditional handwriting instruction versus an AI-based handwriting analysis application in improving children's handwriting skills. The objective measures encompass legibility, spacing, size, form, and alignment [12]. Subjective measures include the teacher's evaluation, where the teachers use their professional judgment and expertise to assess aspects such as overall improvement, attention to detail, and adherence to instructional feedback.

Lastly, participants' post-intervention handwriting performance was compared to baseline measures obtained at the beginning of the study. This comparison enabled the assessment of improvement and growth in handwriting skills following the intervention period.

4.6 Data Analysis

The analysis involved both quantitative and qualitative techniques to comprehensively evaluate the outcomes of the interventions. Statistical analyses, such as t-tests, were conducted to compare objective measures of handwriting proficiency between the Traditional Method group and the AI Method group. These tests allow for the identification of significant differences in outcomes between the two intervention approaches. Longitudinal data collected at multiple time points throughout the study were analyzed to assess changes in handwriting skills over time within each group. Trends and patterns in handwriting performance were examined to identify growth trajectories and intervention effects. Lastly, correlation analyses will be performed to explore relationships between different aspects of handwriting proficiency, such as legibility, spacing, size, form, and alignment. This analysis aimed to uncover potential associations and dependencies among these variables.

Qualitative feedback obtained from teachers' evaluations will be analyzed thematically to identify common themes and patterns in participants' handwriting improvement. Teachers' subjective observations and insights provide valuable context to complement quantitative findings.

Additionally, by comparing the post-intervention assessment with the initial baseline, the change scores shall be analyzed to determine the magnitude and direction of improvement in handwriting skills following the interventions. Based on these, comparative analyses between the Traditional Method group and the AI Method group are conducted to assess differences in the magnitude of improvement and effectiveness of each intervention approach.

Lastly, in order to integrate the objective and subjective data, the objective measures of handwriting proficiency are combined with the subjective evaluations and teacher feedback to provide a comprehensive understanding of intervention outcomes. When the findings across quantitative and qualitative analyses match up, it strengthens the validity and reliability of the study results [49].

The findings of this evaluation hope to underscore the potential of technology-enhanced interventions in handwriting education and highlight the importance of integrating innovative approaches such as AI to support children's skill development in the digital age.

5 DISCUSSION

5.1 Limitations

Our current design comes with several limitations. Firstly, in order to realize our application, we require a dataset of considerable size. The data would need to be labeled on legibility, spacing, size, form, and alignment. Furthermore, in order to generate personalized improvements, the dataset must include a wide range of variations in style and font. Creating such a dataset is possible, but is costly and time-consuming.

An additional limitation is our lack of measuring ergonomic criteria like speed, pressure and pen angle [50]. These features are technically possible to measure, when using a tablet, and can be useful to improve handwriting. In our current design, we have left out these aspects as it would drastically complicate the system design, and classifier. However, these features should be considered in the future due to their utility and potential for improving learner's handwriting.

The final limitation is the lack of testing the system usability of our application design. We have devised an experiment to evaluate the effectiveness of an AI-based solution in comparison to traditional methods. However, there is no guarantee that our AI-based application will perform as expected, since we made multiple designs decision without consulting with an expert or testing it on the target audience.

5.2 Future Work

In this we paper, we have designed an AI-based handwriting system based on the principles of behaviorism, constructivism, and deliberate practice combined with gamification elements. The application is a scalable solution that gives the learner the autonomy to practice whenever they want by immediately giving them personalized feedback.

The next step is to fully implement the system, followed by a cycle of testing and optimization to fine-tune. Key to this process will be the creation of an extensive, well-labeled dataset that covers a wide range of handwriting characteristics. This dataset is crucial for enabling personalized improvements and enhancing the system's effectiveness. Additionally, future iterations should consider incorporating measurements of ergonomic factors, which can offer deeper insights into handwriting habits and further tailor the learning experience. Finally, once the product has been fully developed, we can carry out the experimental study we designed to evaluate the system's effectiveness against traditional methods

REFERENCES

[1] Daniëlla van 't Erve. Handwriting increasingly illegible. *De Algemene Onderwijsbond*, June 2023. Accessed: date-of-access.

[2] Syafrimen Syafril, Ria Susanti, Rifda El Fiah, Titik Rahayu, Agus Pahrudin, Nova Erlina Yaumas, and Noriah Mohd Ishak. Four ways of fine motor skills development in early childhood. 2018.

[3] Seth Polsley, Larry Powell, Hong-Hoe Kim, Xien Thomas, Jeffrey Liew, and Tracy Hammond. Detecting children's fine motor skill development using machine learning. *International Journal of Artificial Intelligence in Education*, pages 1–34, 2022.

[4] Peng Peng and Rogier A Kievit. The development of academic achievement and cognitive abilities: A bidirectional perspective. *Child Development Perspectives*, 14(1):15–20, 2020.

[5] Mona S Julius, Rivka Meir, Zivit Shechter-Nissim, and Esther Adi-Japha. Children's ability to learn a motor skill is related to handwriting and reading proficiency. *Learning and Individual Differences*, 51:265–272, 2016.

[6] Karin H James. The importance of handwriting experience on the development of the literate brain. *Current Directions in Psychological Science*, 26(6):502–508, 2017.

[7] Dynamilis. https://dynamilis.com.

[8] Itrace app. https://itraceapp.com/en/.

[9] Ilaria Caponetto, Jeffrey Earp, and Michela Ott. Gamification and education: A literature review. In *European Conference on Games Based Learning*, volume 1, page 50. Academic Conferences International Limited, 2014.

[10] Jenni Majuri, Jonna Koivisto, and Juho Hamari. Gamification of education and learning: A review of empirical literature. In *Proceedings of the 2nd international GamiFIN conference, GamiFIN 2018*. CEUR-WS, 2018.

[11] Kalpana Nand, Nilufar Baghaei, John Casey, Bashar Barmada, Farhad Mehdipour, and Hai-Ning Liang. Engaging children with educational content via gamification. *Smart Learning Environments*, 6:1–15, 2019.

[12] Judith Reisman. *Minnesota handwriting assessment*. Psychological Corporation, 1999.

[13] Suman Bhoi and Suman Sourav. Towards understanding and improving handwriting with ai. In *International Conference on Frontiers in Handwriting Recognition*, pages 331–344. Springer, 2022.

[14] Steve Olusegun Bada and Steve Olusegun. Constructivism learning theory: A paradigm for teaching and learning. *Journal of Research & Method in Education*, 5(6):66–70, 2015.

[15] K Anders Ericsson, Ralf Th Krampe, and Clemens Tesch-Römer. The role of deliberate practice in the acquisition of expert performance. *Psychological review*, 100(3):363, 1993.

[16] Alex Koohang, Liz Riley, Terry Smith, and Jeanne Schreurs. E-learning and constructivism: From theory to application. *Interdisciplinary Journal of E-Learning and Learning Objects*, 5(1):91–109, 2009.

[17] Uwe Maier and Christian Klotz. Personalized feedback in digital learning environments: Classification framework and literature review. *Computers and Education: Artificial Intelligence*, 3:100080, 2022.

[18] Christine Stephen, Peter Cope, Iddo Oberski, and Peter Shand. 'they should try to find out what the children like': Exploring engagement in learning. *Scottish Educational Review*, 40(2):17–28, 2008.

[19] Brooke N Macnamara, David Z Hambrick, and Frederick L Oswald. Deliberate practice and performance in music, games, sports, education, and professions: A meta-analysis. *Psychological science*, 25(8):1608–1618, 2014.

[20] Olivier Dikken, Bibeg Limbu, and Marcus Specht. Deliberate practice of handwriting: Supervision under the ghost of an expert. In *European Conference on Technology Enhanced Learning*, pages 434–440. Springer, 2022.

[21] Vanessa Brown, Schronda McKnight-Burns M. Ed. Assistant Director of Early Childhood Education, Lanor Payne, and Mary Toomey Assistant Superintendent. Learning without tears.

[22] Nathalie Girard, Damien Simonnet, and Eric Anquetil. Intuiscript a new digital notebook for learning writing in elementary schools: 1st observations. In *18th International Graphonomics Society Conference (IGS2017)*, pages 201–204, 2017.

[23] Adrien Delaye and Eric Anquetil. Hbf49 feature set: A first unified baseline for online symbol recognition. *Pattern Recognition*, 46(1):117–130, 2013.

[24] Roderick I Nicolson and Angela J Fawcett. Dyslexia, dysgraphia, procedural learning and the cerebellum. *Cortex*, 47(1):117–127, 2011.

[25] Nathalie Bonneton-Botté, Ludovic Miramand, Rodolphe Bailly, and Christelle Pons. Teaching and rehabilitation of handwriting for children in the digital age: Issues and challenges. *Children*, 10(7):1096, 2023.
[26] Julia X Li and Karin H James. Handwriting generates variable visual output to facilitate symbol learning. *Journal of Experimental Psychology: General*, 145(3):298, 2016.
[27] Raymond W Kulhavy. Feedback in written instruction. *Review of educational research*, 47(2):211–232, 1977.
[28] John Hattie and Helen Timperley. The power of feedback. *Review of Educational Research*, 77(1):81–112, 2007.
[29] Rahul Chauhan, Kamal Kumar Ghanshala, and RC Joshi. Convolutional neural network (cnn) for image detection and recognition. In *2018 first international conference on secure cyber computing and communication (ICSCCC)*, pages 278–282. IEEE, 2018.
[30] Sebastian Deterding, Dan Dixon, Rilla Khaled, and Lennart Nacke. From game design elements to gamefulness: defining" gamification". In *Proceedings of the 15th international academic MindTrek conference: Envisioning future media environments*, pages 9–15, 2011.
[31] Yakubu Bala Mohammed and Fezile Ozdamli. Motivational effects of gamification apps in education: a systematic literature review. *BRAIN. Broad research in artificial intelligence and neuroscience*, 12(2):122–138, 2021.
[32] Jonna Koivisto and Juho Hamari. The rise of motivational information systems: A review of gamification research. *International journal of information management*, 45:191–210, 2019.
[33] Olusegun Agboola Sogunro. Motivating factors for adult learners in higher education. *International Journal of Higher Education*, 4(1):22–37, 2015.
[34] Michael Sailer, Jan Ulrich Hense, Sarah Katharina Mayr, and Heinz Mandl. How gamification motivates: An experimental study of the effects of specific game design elements on psychological need satisfaction. *Computers in human behavior*, 69:371–380, 2017.
[35] Stuart Hallifax, Audrey Serna, Jean-Charles Marty, and Élise Lavoué. Adaptive gamification in education: A literature review of current trends and developments. In *Transforming Learning with Meaningful Technologies: 14th European Conference on Technology Enhanced Learning, EC-TEL 2019, Delft, The Netherlands, September 16–19, 2019, Proceedings 14*, pages 294–307. Springer, 2019.
[36] Juho Hamari, Jonna Koivisto, and Harri Sarsa. Does gamification work?–a literature review of empirical studies on gamification. In *2014 47th Hawaii international conference on system sciences*, pages 3025–3034. Ieee, 2014.
[37] Christopher Groening and Carmen Binnewies. "achievement unlocked!"-the impact of digital achievements as a gamification element on motivation and performance. *Computers in Human Behavior*, 97:151–166, 2019.
[38] Sungjin Park and Sangkyun Kim. Leaderboard design principles to enhance learning and motivation in a gamified educational environment: Development study. *JMIR serious games*, 9(2):e14746, 2021.
[39] Leslie J. Couse and Dora Chen. A tablet computer for young children? exploring its viability for early childhood education. *Journal of Research on Technology in Education*, 43:75 – 96, 2010.
[40] Alexander JAM van Deursen, Somaya Ben Allouch, and Laura P Ruijter. Tablet use in primary education: Adoption hurdles and attitude determinants. *Education and information technologies*, 21:971–990, 2016.
[41] Nathalie Bonneton-Botté, Sylvain Fleury, Nathalie Girard, Maëlys Le Magadou, Anthony Cherbonnier, Mickaël Renault, Eric Anquetil, and Eric Jamet. Can tablet apps support the learning of handwriting? an investigation of learning outcomes in kindergarten classroom. *Computers & Education*, 151:103831, 2020.
[42] Damien Simonnet, Eric Anquetil, and Manuel Bouillon. Multi-criteria handwriting quality analysis with online fuzzy models. *Pattern Recognition*, 69:310–324, 2017.
[43] Denis Alamargot and Marie-France Morin. Does handwriting on a tablet screen affect students' graphomotor execution? a comparison between grades two and nine. *Human movement science*, 44:32–41, 2015.
[44] Sabrina Gerth, Thomas Dolk, Annegret Klassert, Michael Fliesser, Martin H Fischer, Guido Nottbusch, and Julia Festman. Adapting to the surface: A comparison of handwriting measures when writing on a tablet computer and on paper. *Human Movement Science*, 48:62–73, 2016.
[45] Sarah Henderson and Jeff Yeow. ipad in education: A case study of ipad adoption and use in a primary school. In *2012 45th Hawaii International Conference on System Sciences*, pages 78–87. IEEE, 2012.
[46] Janice M Morse. Determining sample size, 2000.
[47] David P Farrington. Longitudinal research strategies: Advantages, problems, and prospects. *Journal of the American Academy of Child & Adolescent Psychiatry*, 30(3):369–374, 1991.
[48] Tom D Stanley, Hristos Doucouliagos, and John PA Ioannidis. Finding the power to reduce publication bias. *Statistics in medicine*, 36(10):1580–1598, 2017.
[49] Roberta Heale and Dorothy Forbes. Understanding triangulation in research. *Evidence-based nursing*, 16(4):98–98, 2013.
[50] Susan J Amundson. *Evaluation Tool of Children's Handwriting: ETCH examiner's manual.* OT KIDS, 1995.

A INFORMED CONSENT FORM

INFORMED CONSENT FORM

We invite you and your child to take part in a research study being conducted by Alexandra Neagu, Erwin Li, Tim Tian, Thomas Kuiper, and Vanessa Timmer from the TU Delft. The study, as well as your rights as a participant, are described below.

Description: The purpose of this study is to compare the effectiveness of a digital handwriting application with traditional teaching methods in improving handwriting skills among children aged 7 to 10 years.
If you agree to allow your child to participate in this study, they will be randomly assigned to either use the handwriting application or participate in a control group using traditional methods. Participants in the application group will exclusively use the handwriting application we developed to learn and improve their handwriting skills, while the traditional group will receive instruction from a teacher. The study will last for 1 year with participants attending sessions every three months to measure progress.

Potential Risks and Discomforts: This study is designed to be as safe as possible. Your child may experience minimal discomfort from using a digital device for extended periods, similar to regular classroom activities. Appropriate breaks and ergonomic adjustments will be provided to minimize discomfort.

Confidentiality: Your child's identity will remain confidential in any report about this study. Data will be stored securely and only researchers directly involved in the study will have access to the information.

Participation and Withdrawal: Your child's participation in this study is entirely voluntary. You can withdraw your child from the study at any time.

Questions? Please feel free to ask the investigator any questions before signing the consent form or at any time during or after the study.

Informed Consent Statement

I, ____________, give permission for my child, _________ to participate in the research project entitled, “Testing the Effectiveness of an AI-based Handwriting Application vs Traditional Methods”. The study has been explained to me and my questions answered to my satisfaction. I understand that my child’s right to withdraw from participating or refuse to participate will be respected and that his/her responses and identity will be kept confidential. I give this consent voluntarily.

Parent/Guardian Signature:

_____________________________ _____________________

Signature *Date*

Investigator Signature:

_____________________________ _____________________

Signature *Date*