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The idea: **Handwriting exercise tool**

Competitors review:

We reviewed three applications that are currently available, each designed to simplify the handwriting exercise process in its unique way.

The first app we reviewed is “**Dynamilis Handwriting Practice”** which offers fun and personalized activities for kids to improve their handwriting skills, using AI to create a profile for the child, showing his weaknesses and strengths.

The next app we have researched is “**Writing Wizard - Learn Letters”** which takes on a much simpler approach, guiding the child to write the various characters by tracing with guided animations, with feedback provided based on correct or wrong tracing.

Finally, we reviewed “**Kaligo”,** an app primarily designed for classroom use. Similarly to the last app, the child is provided with word tracing for him to fill, and a more open option to write the words on his own, receiving feedback for each character in it. Giving teachers the option to build lessons and track each student's progression.

App / Criteria	Dynamilis Handwriting Practice	Writing Wizard - Learn Letters	Kaligo	Our application
Variety	High - various types of games provided.	Low.	Medium - teachers can upload lessons - that include words to exercise .	Medium - will generate appropriate words, or a word from a domain to help with the planning step of the writing process.
Languages supportability	English, French, German, Italian, Spanish.	English, French, German, Italian, Japanese, Spanish, Swedish.	English, French, German.	Will have a simple UI to support any language the model recognizes.
Learning path customization	Personalized activities based on AI assessments.	Adjustable difficulty with tracing, guides, and custom letter or shape practice.	Adults can adjust the student's learning path.	Personalized activities based on AI assessments.
Progression tracking	Detailed - including graphs of the child's on each writing aspect, by week.	Non.	Highly detailed including replayable videos of the student writing and the scores given.	Will provide a personalized progression tracking.
Direct feedback	Provides a color-coded feedback system - green/yellow/red according to writing quality.	Provides immediate feedback for correct or incorrect tracing.	Correct or incorrect tracing, in free writing - AI feedback per character.	feedback based on the model's analysis, identifying similar letters that got misrecognized (like i and l)
Requirements	iPad + stylus.	any mobile platforms.	iPad + stylus.	mobile platforms or a computer + camera.
Popularity	approx. 10,000 users.	5M+ downloads.	100,000+ users according to their site.	Currently there are no users.
Cost	Monthly: parents:10$ therapists:2$ schools: 150$ (for classroom).	Free app, contains in-app purchases, and a school version for $10.	Quotation basis (depended on the user).	free to use.

Literature Review:

Handwriting skills are a critical part of a child's learning path and are often taught between ages 6-8 while it's finally automated in ages 10-14[1]. According to one of the most accepted cognitive models, the writing process has 3 separate steps, which often occur simultaneously:

- Planning - goal setting, idea generation
- Translating – production of handwritten text for the generated ideas
- Reviewing – the writer evaluates and revisits his written text.[4]

To enhance and improve this process, studies have recognized key principles:

- Practice – handwriting should be practiced at least 2 times a week for 10 weeks, and be repetitive (like writing the same letter a lot of times)
- Handwriting instruction should be explicit.
- Intrinsic and extrinsic feedback of sufficient quantity and quality should be available. Feedback is a crucial parameter in the learning process.
- Variability should be introduced during handwriting learning (Varying the letter font and size)
- Learning environments should be motivating, supportive, and include self-regulation of performance

The time dedicated to practicing handwriting skills has decreased over the last 30 years (varies from country and teacher), as well as growing challenges such as a large portion of teachers who don't consider themselves to be properly trained to teach handwriting, and the growing amount of students in each class that makes it difficult to implement individualized instruction, to provide physical guidance for each pupil.

These challenges may be the cause of the growing number of students struggling with writing, which ranges from 6% to 30%. These students face challenges such as poor legibility, slow writing speeds, spelling errors, and excessive pen pressure[1]. These challenges may be caused by struggles with the planning phase of the writing process, which may be due to immature working memory[4].

The main options to evaluate handwriting today are tests - that often assess aspects like letter formation (difficult to quantify), writing speed, and ergonomic features. However, these evaluations face limitations, including subjectivity and difficulty identifying underlying causes of handwriting issues[1].

Students who are identified with poor handwriting can attend writer's workshops to improve their skills. In such workshops they are given important feedback on their handwriting, revisiting their written text, and showing it in front of their classmates who provide feedback themselves[4]. Another option to improve those skills is rehabilitation which often involves occupational therapy and is personalized based on the child's challenges and environment[1].

Feedback on handwriting plays a crucial role in the student learning process, providing guidance, academic interaction, and accepting it could lead to increased writing success. Unfortunately, due to the difficult process of accepting feedback, not all students consider it helpful, and that can lead to a variety of emotions, both positive and negative, the latter could invoke negative responses and decrease motivation. Knowing the student's openness

beforehand could improve the feedback given, and it has been shown to be connected to the student's confidence in their writing skills[4].

Article [4] describes a study: 867 students in grades 3-5 across four elementary schools took an online survey in which they were asked: a closed question (yes or no) “Do you like to receive feedback about your writing?”, and an open question in which they explained their first answer. To the closed question, 765 students answered "Yes"(88%) and 102 "No"(12%).

The reasons that were most provided for liking feedback were separated into these groups:

- Mastery – to become a better writer.
- Positive aspects – when the feedback highlights positive aspects of their work.
- Helps with recognizing areas of mistakes in their writing and what to avoid.
- Others could offer good ideas for their future writings – appreciation for others opinions
- Invokes positive effects, emotions (such as pride), and experiences.
- Gives motivation to keep improving their writing skills.

The reasons students have given for disliking writing feedback:

- Avoidance – students don't care about the feedback, it doesn't matter.
- Negative feedback – expectation for negative feedback, without providing what is good, only good feedback was appreciated by them - which might be turned into positive experiences that may open their minds to accept negative feedback in the future and improve their beliefs of their own handwriting.
- Embracing (the teachers may be mean or disappointed)
- Negative affect – may cause negative emotions or experiences.

One way to encourage the feedback process is to have conversations about it with the students, about its use and purpose[4].

AI could help build tools that will take these findings into account and automate such feedback for evaluating and improving handwriting, and offer personalized practice. Such AI could be implemented as a part of a digital learning technology, which is used by people to overcome the social and infrastructural barriers of learning, and often used as tutors, teaching aids. There are already some tools designed for handwriting exercising that aim to support the acquisition of handwriting for all children, including those with special needs.

However, implementing these AI solutions would require overcoming challenges like ensuring accessibility, maintaining data privacy, and integrating cultural and linguistic variations in handwriting styles, as well as overcoming the lack of acceptance of new technologies by educational professionals that may prevent their mass use[1].

The accessibility challenge may prevent children from feeling comfortable with using such tools. This requires a clean, intuitive, and easily understandable user interface.

Article [3] dives into possible solutions to this issue. It outlines best practices for creating AI interfaces that prioritize safety, engagement, and trust. Key recommendations include:

- Simplified design**-** the interface should be easy to navigate with clear buttons, simple visuals, and age-appropriate language.
- Interactive features**-** animations, games, and interactive elements to engage children and enhance motivation should be included.
- Customization**-** personalization options like avatars and themes.

- Safety measures**-** implement content filtering, privacy policies, and parental controls to ensure safe interactions.
- Fairness and diversity**-** all children should be treated equally, avoiding content biases.

In addition, the AI itself should have these attributes:

- Accuracy - provide reliable information to prevent confusion.
- Consistency - ensure stable, predictable AI behavior.
- Robustness - adapt to various inputs and scenarios.[3]

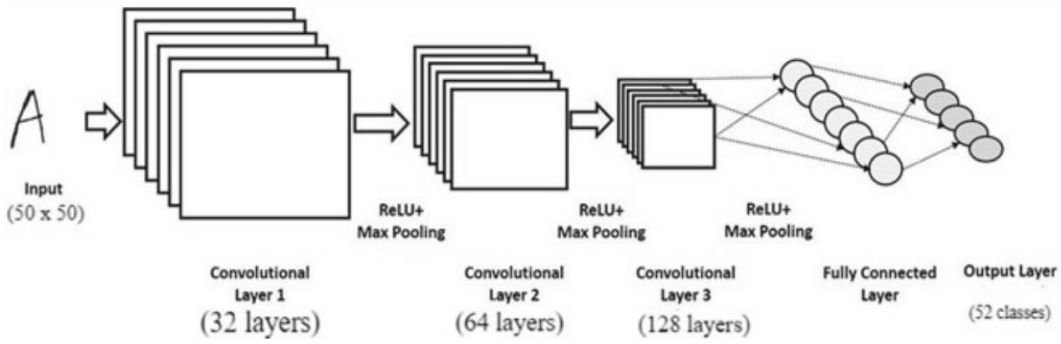
With these attributes in mind, an OCR model can be designed to detect, analyze, and evaluate handwritten text.

OCR stands for optical character recognition, and there are two approaches for such models:

- The “online” approach involves real-time user input (rather than scanning or using pre-captured images).
- The “offline” approach refers to the process of recognizing text from an image or scanned document that has already been captured and stored on a device.[2]

Article [2] and [5] each describe possible models to evaluate handwritten text, of these different approaches.

One of the proposed models, using the “online” OCR approach, is a CNN(convolutional neural network) based model. This model architecture includes three CNN layers, one flattened layer, and two dense layers, each followed by a ReLU activation function and max pooling operation. The model demonstrates strong performance, classifying all 52 english character classes with 96% accuracy on both test and validation sets. It was trained using Adam optimizer which is known for its efficiency on optimizing deep learning models. The training process consisted of 80 epochs. The handwritten input has been captured in real time through an HTML canvas.[2]



A recent study, conducted in 2024, presents a comparative analysis and integration of 4 'offline' OCR engines - Tesseract OCR, Keras OCR, Paddle OCR, and Microsoft Azure Computer Vision.

The study evaluated the performance of these engines across different image preprocessing techniques, such as Edge Detection, Image Thresholding, and diverse datasets like the IAM and the FUNSD dataset. It aimed to investigate the strengths and weaknesses of each

engine in various scenarios, including recognizing different handwriting styles and extracting key information from complex layout forms, even under challenging conditions like poor image resolution.

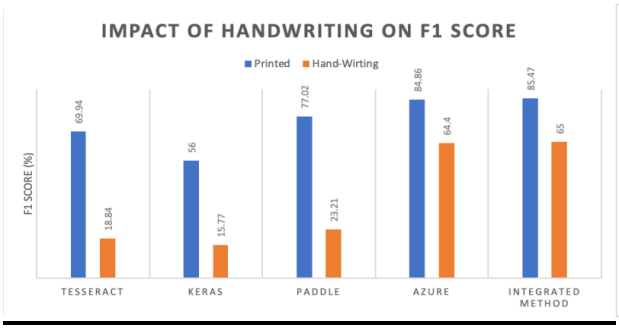
The evaluation metrics used in the study were - accuracy, precision, recall, F1 score, Character Error Rate (CER), Word Error Rate (WER), and running time per image(RT). These metrics offer insights into inclusivity, detail sensitivity, and the trade-offs between speed and accuracy in practical scenarios.

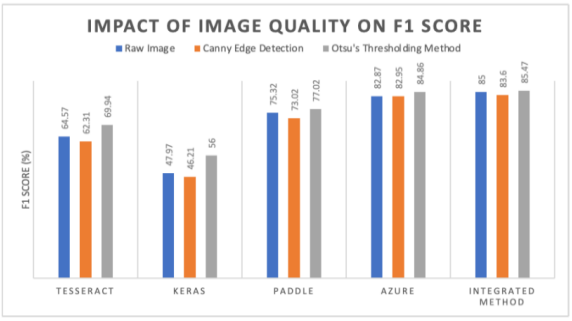
The study proposed an integrated OCR scoring system (which is similar to ensemble method in ML). The idea is to process a text image simultaneously by the four OCR engines, and then each one of them will produce outputs of detected words and their according confidence scores. If an OCR engine consistently performs well on certain types of texts, more weight is given to its output in the scoring process. The final output is a string of words that have been selected based on the highest score from the aggregated results, aiming to form the most accurate rendition of the text from the image.

The main findings of that study are:

- All OCR engines tend to perform a lot less effectively on handwritten text compared to printed text, as it has a significantly lower f1 score and longer running time per image. This disparity is primarily because OCR works by pattern recognition which is easier for printed text recognition. However, human handwriting typically lacks consistent patterns. Moreover, handwriting is usually more diverse and often features variations in character shapes, sizes, and spacings, which challenges the pattern recognition capabilities of general OCR technologies.
- Azure OCR stands out in handwriting recognition compared to other OCR models. It might be due to advanced machine-learning algorithms trained on a wide range of both handwriting and printed samples, and use of Intelligent Character Recognition (ICR) techniques.
- Otsu's thresholding image processing method positively impacts performance metrics across all OCR engines.

However, that result of comparative analysis may not completely reveal or indicate the superiority of one OCR engine to another. Due to the limitation of the project scope, no fine-tuning of weights or any customizations were done to the OCR engines selected. It has been proven that certain OCRs, especially open-source engines, benefit a lot from task-specific learning and fine-tuning by adopting a pre-trained weight while training and evaluating on a prepared dataset[5].





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[1] Bonneton-Botté, Nathalie, et al. "Teaching and rehabilitation of handwriting for children in the digital age: Issues and challenges." *Children* 10.7 (2023): 1096.

[2] Kumar, Ashutosh, J. B. Simha, and Shinu Abhi. "A Deep Learning Approach for Evaluating Children's Handwriting." International Conference on Smart Computing and Communication. Singapore: Springer Nature Singapore, 2024.

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[4] Marrs, Sarah, et al. "Exploring Elementary Student Perceptions of Writing Feedback." Journal on Educational Psychology 10.1 (2016): 16-28.

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