



Research article

Using Android Tablets to develop handwriting skills: A case study

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ARTICLE INFO

Keywords:

Education
 Improving classroom teaching
 Interactive learning environments
 Evaluation methodologies
 Architectures for educational technology systems
 Elementary education

ABSTRACT

A system to support the teaching and learning of handwriting skills is proposed. It is composed of two components: the hardware component (e.g., Android Tablet); and the software component. The software component as two modules: the server and the client. A teacher chooses what exercises/games a child should do directly in the Android table or using the server, from the existing ones in the system. A child does the exercises/games by logging into the system in the Android Tablet. Automatic feedback about the correctness of the answers is provided by the system. Data (number of tries, time spent, etc.) are automatically grabbed and processed to be presented to the teachers and parents. Registered parents can see the results and follow their children's "academic life", by logging into the server side of the system. We found a significant improvement in the development of handwriting skills in the children throughout the academic year, and improvements were also more present when comparing children who had contact with the system with children who did not have this contact. Educators, children, School Boards, City Town Hall and the Educational Community are unanimous in stating that the implementation of this system was a real success.

1. Introduction and aims

The teaching and researching communities agree that it is through the use of exercises and games that learning becomes effective. Proponents of sociocultural theory claim that learning is primarily a social process mediated through interactions using tools (Vygotsky, 1978; Wertsch, 1992). According to Vygotsky, mediation occurs through the use of 'semiotic' and 'material' tools. The semiotic tools include symbols, signs, and spoken languages. Material tools include such items as pens, spoons, and particularly networked computers. These tools do not simply facilitate the set of activities that might take place, but they fundamentally shape and define the type of activities that might be developed (Wertsch, 1992; Berge et al., 2019). Seymour Papert proposed the use of tools, particularly the computer—"a mighty education tool", in helping in the process of construction of knowledge (given rise to the "constructionist" theory), adapting the beginnings of the cognitive constructivism of Jean Piaget in order to a better use of technology (Papert, 1980).

In order to become more accurate in their work, both in reading problems and in working out solutions, kindergarten and primary students need more practice to reinforce what they are learning, a process which traditionally takes place on paper, and is distributed in textbooks

or tutoring books. Unfortunately, these materials are usually designed for average learners, and it is often difficult to find the best-fitting content for students with differing abilities and skills. "Literate" students may need a higher-level tutoring, and "illiterate" may need a lower-level tutoring. Therefore, the depth and flexibility of ability gained from these textbooks are restricted. Some programs based on e-learning technology may provide personalized contents for learners by collecting the learning process. But kindergarten and primary students will certainly become restless and unfocused when staying in front of computers for long periods of time. As putted by Warschauer (2007), "New technologies do not replace the need for strong human mentorship, but, indeed, amplify the role of such mentorship". Obviously students must become into contact with the new teaching/studying tools progressively, in order for they to become a part of the learning environment as smoothly as possible. Resnick (1998) and Sylla et al. (2018) discuss how computationally enhanced manipulative materials, called "digital manipulatives", may be designed to radically change the traditional progression, i.e., from direct manipulation of physical objects, such as Cuisenaire Rods and Pattern Blocks, to more abstract formal methods. These new manipulatives, such as programmable building bricks and communicating beads, "aim to enable children to continue to learn with a kindergarten approach even as they grow older, and also to enable

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young children to learn concepts (in particular, systems concepts such as feedback and emergence) that were previously considered too advanced for them”.

In this context, at least in Portugal, the typical educational computer applications are being developed to be used in desktop computer systems or laptop computers. Consequently, the interaction of the child with the application is typically made using the keyboard, mouse (or other pointing system), leading to an additional barrier. More recently, the market is assisting to the growing of solutions for mobile devices, commonly known as “Tablets” and/or “iPads”, especially in the English language. The utilization of this type of devices to teach/learn can be classified in the field of Mobile-Learning (m-Learning). One of the greatest advantages that can be pointed out is the possibility to use it anytime and anywhere. Additionally, the kind of interaction is more “natural”, because the traditional “mouse like” (or keyboard) interaction can be replaced by the direct screen touch.

Here we present a system to teach and learn pre-writing skills (graphisms). This system is composed by two components: the hardware component, the Android Tablet; and the software component, forming the exercises/games that the child must solve/complete. The software component as two modules: the server and the client. As suggested by the name, the server component runs at the server side, and is responsible to send to the client (i.e., the Android Tablet) the exercises/games that a child should do. Besides this, the server module also includes all the management functions, which will be explained later. The client module, runs on the Android Tablet, and has an engine that executes the exercises/games; it also has a communications module, responsible to communicate to the server all the data (child name, number, class, exercise number, execution time, number of tries, etc.).

We believe that a presentation of some of the concepts and materials will help in better understanding the system and the choices we have taken. Section 2 is devoted to the presentation of the literature review and related software applications. The system is presented in section 3. Section 4 is used to present and discuss the results achieved so far. The paper ends with the conclusions and future work section.

2. Related work

2.1. Handwriting and the use of IT

There are several factors determining the difficulty of handwriting for children (Feder and Majnemer, 2007; Berninger and Rutberg, 1992; Hammerschmidt and Sudsawad, 2004). These factors can be categorized into external and internal factors. Examples of external factors include instructional procedures and materials used during writing. Internal factors are abilities found within the child: visuomotor skills; visual perception; motor planning, that is, the ability to plan new motor behavior; in-hand manipulation; and kinesthetic awareness.

For example, Conroy (2004) notes that children need to perfect coordination in order to learn writing skills, because “through repetition and practice of specific movements, the brain and muscles learn to work together as a team”. In line with this idea, Striker (2001) points out, among other, the following tips for beginning writers:

- Realize children learn best through modeling (use drawings on a board to illustrate characters or objects in a story).
- Don't rush into writing (allow youngsters time to experiment with shapes and alphabets by “scribbling”).
- Plan for fun opportunities.

According to Levine (1987) all children, including those with handicaps, must go through the following stages of pre-writing:

- Scribble or pretend to write;
- Gain the awareness that letters can be arranged to form words;
- Begin to organize letters and shapes in a line;

- Begin to print letters and numbers;
- Become adept at printing letters;
- Become preoccupied with visual appearance of writing;
- Use invented spelling of words liberally.

Additionally, there are several research studies reporting the potential, advantages and disadvantages, and risks of using Information Technologies—IT (which some authors define as Information and Communication Technologies—ICT) in the teaching and learning, and in particular of pre-writing skills; see, for example, Rogers and Graham (2008) and Castilla et al. (2016). The review presented by Wollscheid et al. (2016) aims at assessing the emerging literature on digital writing tools, such as Computers and Tablets, compared to traditional writing tools like pen (or pencil) and paper, on early writing outcomes among first writers.

In particular, Tablets, iPads and other mobile devices are being used in many different fields with many objectives. For example, Foley and Masingila (2015) used these devices as assistive technologies in resource-limited environments for learners with visual impairments in Kenya. Kremer and Cingel (2014) have researched parent-child joint reading in traditional and electronic formats. Matthews and Seow (2007) have tried to understand children's representations through their interactions with digital paint. The use of these mobile devices to learn aural skills have been researched by Chen (2015). Additionally, the ever growing interest of schools in engaging students with mobile learning, from preschoolers through high school-age students, during and beyond the school day, and in “bring your own device” (BYOD) models is reported by Grunwald Associates LLC (2013).

Wollscheid et al. (2016), in their research review, concluded that the benefits of replacing handwriting by typing in early writing instruction lack consistent evidence. As stated by these authors, “studies with a cognitive psychological and those with neuroscience and learning perspective point in favor of handwriting, studies with a socio-cultural perspective rather point in favor of digital writing. The studies that used a cognitive psychology and neuroscience and learning approach applied quasi-experimental or cohort designs, while studies based on a socio-cultural perspective mainly were qualitative”.

Genlott and Grönlund (2013) used their “Integrated Write to Learn” method to improve literacy skills. Children in the 1st grade “use computers and other ICT tools to write texts and subsequently discuss and refine them together with class mates and teachers”. Only at the 2nd grade students do handwriting. They claim that “the biggest improvement concerned writing skills”, but reading skills were also improved considerably. They also found that “students in the test group wrote longer texts with better structure, clearer content, and a more elaborate language”.

Sulzenbruck et al. (2011) showed that the skill to produce precisely controlled arm-hand movements is related to the usage of computer keyboards in producing written text in everyday life. As stated by the authors, “this result supports the notion that specific cultural skills such as handwriting and typing shape more general perceptual and motor skills. More generally, changing technologies are associated with generalized changes of the profile of basic human skills”.

van Mier and Hulstijn (1993) investigated the initiation time required in handwriting. They used letters, figures and patterns, both familiar figures and novel nonsense (unfamiliar) patterns. They found that initiation time increases linearly with the number of strokes, but the “effect was much larger for figures and patterns than for letters, and rapidly decreased with practice (successive presentations)”. In a second experiment, they used the same stimuli, but the number of strokes had to be doubled by requiring the subject to draw each line twice. For the figures and patterns, the initiation time increased significantly with the increasing number of strokes, but the increase was irrespective of the number of strokes for letters. As the authors state “these results suggest that the planning of a movement sequence involves several levels and

that the amount of preprogramming is highly influenced by the amount of motor practice”.

Several researchers have addressed the study of handwriting characteristics (differences) among children with disability problems and children with no problems (proficient vs non-proficient). For example, Barnett et al. (2018) have proposed a “Handwriting Legibility Scale (HLS)”. This non-language dependent scale aims at being a “quick and practical tool to assess legibility” in children facing handwriting difficulties. From the analysis of the results obtained, the authors concluded that this scale “may be a useful tool to identify poor handwriting legibility, with application across different languages and writing scripts”. As stated by Prunty et al. (2014), “There is substantial evidence to support the relationship between transcription skills (handwriting and spelling) and compositional quality”. In this study, the authors tested a free-writing task, with children with developmental coordination disorder. The results indicate that “children with developmental coordination disorder performed significantly below their typically developing peers on five of the six Wechsler objective language dimensions items”, and that they also have a higher percentage of misspelled words. They concluded that the handwriting difficulties typically reported in children with developmental coordination disorder “have wider repercussions for the quality of written composition”.

Also included in this research field, Rosenblum et al. (2003) used computerized temporal measures to examine and compare the writing process of proficient and non-proficient third grade handwriters. They compared temporal handwriting measures of two groups of 8 and 9 year old children, and the teachers of the classroom used a questionnaire to identify 50 students who were non-proficient handwriters and 50 students who were proficient handwriters. They recorded the “total time”, “on paper time”, “in air time”, “speed” and “number of characters per minute”, as the participants performed graded writing tasks. The results showed that “non-proficient handwriters required significantly more time to perform handwriting tasks”, and that their “in air time” was especially longer, when compared to the proficient handwriters. Additionally, their handwriting “speed” is slower, and they write fewer characters per minute. They concluded that “the use of a computerized handwriting system provides objective temporal measures of handwriting performance, and may lead to the development of additional tools for the evaluation and treatment of handwriting difficulties”. Another example is presented by Rosenblum et al. (2016), where unique handwriting performance characteristics of children with High-Functioning Autism Spectrum Disorder (HFASD) were studied. They compared the handwriting process and product characteristics of children with HFASD to those of typically developing children, with the aim to determine the best means of differentiation between the groups. The children have performed three graded writing tasks on electronic Tablets, and their paragraph copying product was then evaluated using the Hebrew Handwriting Evaluation (HHE). They found significantly inferior handwriting performance among children with HFASD, in both the handwriting process and in the product measures. Finally, the behavior organization of children with Developmental Coordination Disorders (DCD), in varied tasks requiring generating and monitoring mental representations related to space and time requirements, was studied by Rosenblum (2015). She evaluated 42 children (aged 7–10) using handwriting tasks on Tablets. In addition, teachers from the classroom completed a questionnaire for assessing students’ organizational abilities—teachers (QASOA-T), to assess the children’s daily organizational ability. She found significant group differences (DCD versus controls), for all handwriting kinematic measures and for the children’s organizational abilities. Berninger et al. (2009) tested the writing by pen and by keyboard with children with and without learning disabilities in transcription (handwriting and spelling). The two groups did not differ significantly in verbal IQ but did in handwriting, spelling, and composing achievement. Although the groups did not differ in total time for producing letters by pen or keyboard, both groups took longer to compose sentences and essays by keyboard than by pen, wrote longer

essays with faster word production rate by pen than by keyboard, and wrote more complete sentences when writing by pen than by keyboard.

2.2. Software review

As far as our knowledge, there is no system (or Application—“App”) available, using the same approach and ideas as those used in the one presented and discussed here. However, there are some tools available for helping in the teaching and learning of pre-writing skills that share some of the ideas that we have used for the development of our system. Some of these tools include websites and Android applications (apps). Almost all of the sites, and their contents, are presented as being part of “therapeutic activities”. For example, the site “Therapy Street for Kids” (<http://therapiststreetforkids.com/PreWritingSkills.html>) is “your short cut to finding therapeutic activities to enhance your child’s school occupational therapy program”. There we can find a list of “skill areas”, such as fine motor, crossing midline, handwriting, self-help and so forth, and related activities. Many activities address more than one skill, and typically are easy to do at home and with common materials we probably already have. The major therapeutic associations in the world have their sites available with useful activities and links; see, for example, the “Canadian Association of Occupational Therapists” site <http://www.caot.ca>.

The list of available Android Apps to teach/learn pre-writing skills, is huge. A review of them all is beyond the objectives of this work, but we believe that the highlighting of some of their main characteristics will help clarify some of the options we have taken during the development of the system presented here. Table 1 presents a list of the ones we elected as the most representative. All these applications include some sort of animations and sounds, including associating a letter to a word (e.g., name of an animal) and its sound when pronounced. As we can see, the majority of these Apps were developed in English, and let children “print” upper and lowercase letters and numbers. Some of them include sets of shapes (‘arrow’, ‘circle’, ‘crescent moon’, ‘cross’, ‘diamond’, ‘ellipse’, ‘heart’, ‘heptagon’, ‘hexagon’, ‘octagon’, ‘parallelogram’, ‘pentagon’, ‘polygon’, ‘rectangle’, ‘square’, ‘star’, and ‘triangle’) for the children to color, fill or follow the contour. The possibility to adjust the color, shape and width of the “pencil” is also present in some of them. The writing of the letters or the contour shapes can be fully guided (i.e., the child must follow the path of the letter and start at the beginning point—initial point—and end at the ending point), partially guided (i.e., as long as the child paints the path of the letter it will be considered correct/well succeeded, no matter the order and color of the strokes), or loose (although children do have a “reference model” to follow they can “print” the letters, numbers or shapes anywhere in the screen, i.e., it is not mandatory for the child to follow the “path” of the letter, number or shape). Finally, the difficulty level (easy, medium, and hard) can also be adjusted in some of these Apps.

Most of the characteristics present in the system proposed here are also present in these Apps, in particular in the “Patchimals — First lines”, by “Patchimals”, and “Writing Wizard”, by “L’Escapadou”, Apps. As will be explained in detail in section 3, our Android App (i.e., the game engine) is integrated in the learning/teaching system proposed here, and data will be gathered during the execution of the exercises/games and presented to the teacher, so that he/she can analyze the results and adapt the next exercises to the needs of the children. Also, the execution of these exercises/games by the children is fully guided (if a child tries to print a point elsewhere in the screen it will not be printed; only those points at the pre-established path and obeying the pre-established order will be printed). For example, if a child begins by “pressing” the screen at the ending point of the sequence it will not be printed; this is not the case with “Patchimals — First lines” App. The system we present here is not intended for the writing of letters; it uses only pre-writing shapes and the number of shapes available is very big (at least when compared with the majority of the Apps listed in Table 1).

Table 1

Main characteristics of available Android Apps to teach/learn pre-writing skills (EN—English, SP—Spanish, IT—Italian, FR—French, GR—German, Y—Yes, N—No, P—Partially).

	Languages	Uppercase letters	Lowercase letters	Numbers	Shapes	Colors	Sounds	Guided	Difficulty level
123s & ABCs Print Letters for Kids (TeachersParadise Studios)	EN	Y	Y	Y	Y	Y	N	N	N
Handwriting, ABC Learning (First Step)	EN	Y	Y	Y	N	Y	Y	Y	N
Write letters: Tracing ABC (Trigonom)	EN	Y	Y	Y	N	Y	N	P	N
Escribir alfabeto (AprenderJugando)	SP	Y	Y	Y	N	Y	N	Y	N
Kids letters tracing (Dareman)	EN IT SP FR GR	Y	Y	Y	N	N	N	P	Y
Kids Learn Alphabet & Numbers (Mufimob)	EN	Y	N	Y	N	N	Y	N	N
Pre Scrittura PARLANTE! (MicioVille)	IT	Y	N	Y	N	Y	Y	N	N
ABC Preschool Free (Sound House LLC)	EN	Y	N	Y	N	Y	Y	N	N
Apprendre à écrire 1: Graphisme (Upbraining)	FR	Y	Y	Y	Y	Y	N	Y	N
LetterSchool Free (Sanoma Media)	EN	Y	Y	Y	Y	Y	N	Y	N
Patchimals—First lines (Patchimals)	EN SP	N	N	N	Y	Y	N	Y	Y
Writing Wizard (L'Escapadou)	EN IT SP FR GR	Y	Y	Y	Y	Y	N	Y	Y

As can be seen, there is a lot of research in the field of handwriting and computer-based (keyboard) writing, discussing the benefits of each over the other. However, the number of works testing the use of devices that enable the “direct” use of handwriting (like Tablets) is very low. Here, we propose a system that uses Android Tablet digital devices to develop handwriting skills, trying to take advantage of the fact of being a flashy appealing media for the children, and, at the same time, being closer to the “traditional” way of handwriting learning, and thus developing the competences associated to that way of learning.

3. The system

Agudo et al. (2015) have showed that the design of hyper-media tasks can be optimally implemented when following previous phases of data collection on preferred items. The results showed the need to steer the learning path towards an effective adaptation to the children’s cognitive abilities. These facts deeply influenced the way we developed the system presented here. Additionally, to the development of the system presented here, whenever applicable, we have had in mind the recommendations presented and discussed by Sim et al. (2006), Rubens et al. (2005) and Squires and Preece (1996).

The user of this system must be registered, and in order to get full access to the features of the system s/he must pass through the authentication (login and password) process. Only the data of registered users will be sent and inserted in the database. A non-registered user has access to general information and may download a demo version of the Android app.

Fig. 1 presents a block diagram with the relations involved and information flow in a typical working session. As explained below, first,

the teacher creates the set of exercises/games that the student/child should solve. The child should solve the exercises/games recommended by the teacher, but can also randomly solve exercises/games from the list of existing ones. Statistical data will be only gathered for the exercises proposed by the teacher. These data will be available for the teacher, student/child and parent.

As stated in the introduction section, this system is composed of two components: the hardware component, the Android Tablet; and the software component, forming the exercises/games that the child must solve/complete. The software component as two modules: the server and the client. The server component runs at the server side, and is responsible to send to the client (i.e., the Android Tablet) the exercises/games that a child should do. The server module also includes all the management functions. The client module, runs on the Android Tablet, and has an engine that executes (“runs”) the exercises/games.

3.1. Server module

To develop the server module, we have used PHP, HTML 5, JavaScript, and MySQL. This module works like a typical web-portal, implementing some of the functionalities available on typical Learning Management Systems (like, Moodle, Sakai, etc.). Fig. 2 shows a block diagram of the server module.

The server module has a management component that includes everything related to the management of the daily life in the kindergarten/school. This includes the traditional operations of creating, changing, deleting and reporting (listing and plotting) users, kindergartens/schools, classes, exercises, among other. Also included in the management component is the statistics module, which grabs and

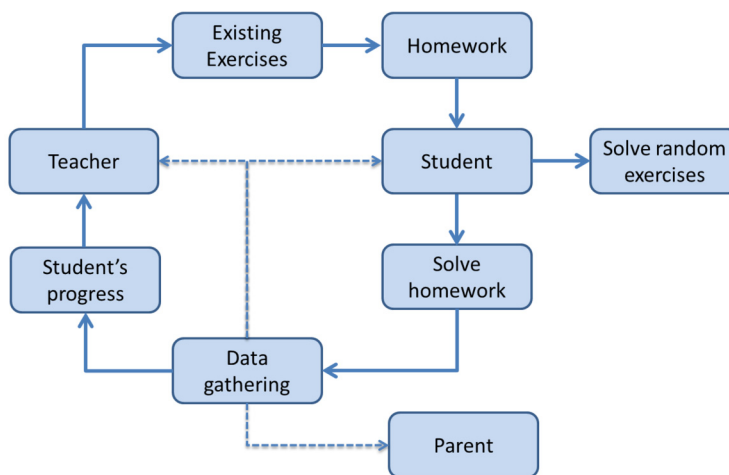


Fig. 1. Block diagram showing the relations and information flow of a typical work session.

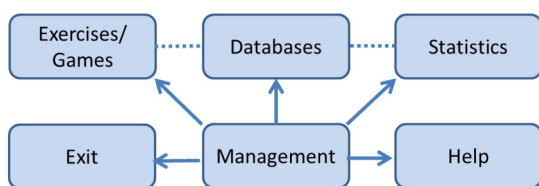


Fig. 2. Block diagram of the server module.

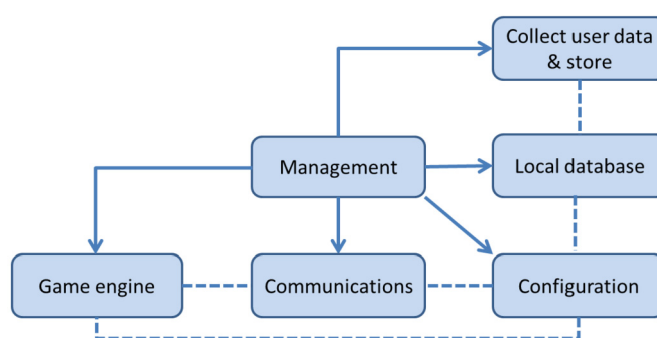


Fig. 3. Block diagram of the client module.

processes all the data, and modules responsible for the downloading of exercises to the Android Tablet, help, and exiting the system. The databases module is able to manage distinct databases, including the databases for the exercises, images used to produce the exercises/games, as well as all the information related to the registered kindergarten/school, classes, users, storing of statistics, among other.

Once logged into the system, a teacher may propose new sets of exercises/games for the children to solve, access the statistics module, and all other functionalities provided by the server module. The teacher may query information from a child (individually), a group of children or the entire class. This information includes grades/marks, time spent per exercise, number of tries, among other.

There are several researchers proposing and using different systems to automatically provide the students with the exercises they must solve during their working sessions. Examples of such system are the ones proposed by Chrysafiadi et al. (2018) and Troussas et al. (2019). However, here we have intentionally leave this responsibility to the teachers; as such, in the current version of the system proposed here, there are no exercises automatically provided by the system. The statistical data gathered by the system can be used by the teacher, but it is solely the responsibility of the teacher to provide the students/children with the next exercises to solve. To produce a set of exercises/games (i.e., prepare a typical work session), the teacher simply chooses the exercises/games from the existing ones, and then the group of children who should apply. A teacher can have the groups of children s/he wants by just creating emailing lists (e.g., for different classes, and groups in a class). Statistical data is “attached” to a particular set. The teacher may also concatenate statistical data from several groups of students and sets. This may be very helpful if the class needs to be divided into several groups (e.g., due to its heterogeneity). The data can be either presented as lists/tables or plots.

Note that a teacher may individual- and directly set in each Android Tablet the exercises/games a child should do.

3.2. Client module

The client module was fully implemented in Android. It has four main components: the management module, the game/exercise engine, the configurations module, and the communications module. Fig. 3 shows a block diagram of the client module.

The management module does all the management of the client side (Android) application: it maintains the user/child information, the exercises/games to be executed, configuration profiles, and controls all the operations flow of the application. Exemplifying, if there should be two or more children sharing the same Android Tablet, then the data concerning the user/child executing the exercises/games must be changed every time the user/child changes. Then, the management module calls the module to collect the user data and stores it in the local Android Tablet database. Every time an exercise/game should be completed, the management module calls the game engine module and passes it to the exercise/game. When the exercise/game finishes the results are passed to the communications module, to transmit it to the server (if an Internet connection exists, or saves the data in a local database for later transmission).

The exercises/games engine gets the exercise/game to be executed from the management module and runs it. After completion of the exercise/game, it returns control to the management module. The engine must receive a background image, that serves as the context of the game, and a sequence of coordinates, that actually constitute the pre-writing path (and hence the exercise). In other words, the child must press the screen at the coordinates of the path in order to correctly “travel the path” and fulfill the exercise/game objective. This set of points (coordinates) mark out the child’s writing. Fig. 4 helps to clarify this idea. The gray dots show the correct path that a child must travel in order to complete the exercise, and hence practice his/her pre-writing

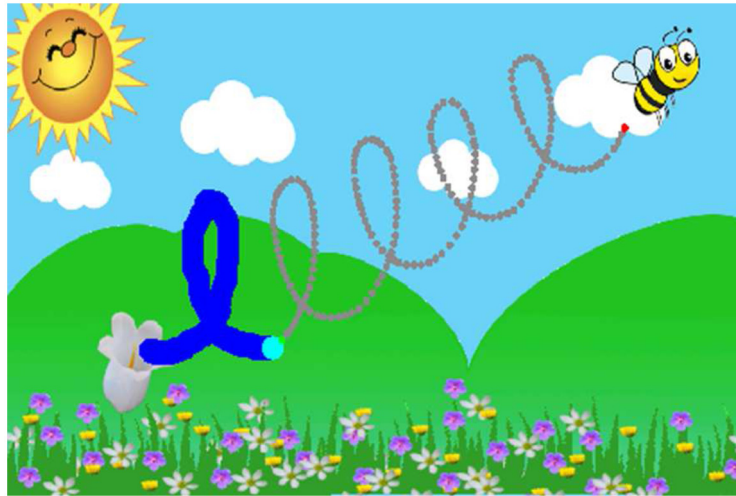


Fig. 4. A sample exercise/game.

skills. In this example, the bee is collecting pollen to make honey, and is flying from one flower to another. The background image gives the context (the bee, flowers, sun, etc.), and the dots provide the path to be filled by the child. Note that only the gray dots will be highlighted, if they are touched in the correct order and within the limits of the maximum error allowed (brush/pencil width).

The configurations module keeps track of the current configurations of the Android application. These data include the user's login, kindergarten/school, class, teacher, etc., but also the exercises/games running options, which include four options: width of the brush, help on/off, multiple strokes on/off, and sound on/off. In its current version, the width of the brush is directly related to the degree of difficulty, because the thinner the brush the harder the completion of the exercise/game. In other words, if the same exercise/game is accomplished with a thicker brush the "error" that a child can make is greater, also meaning that the strokes of the brush are wider and hence the precision of the path can be much lower. Linked to this "difficulty level" is the option "multiple strokes" on or off. If this option is on, this means that a child may raise the painting brush (his/her finger or pointer) as many times as needed (the number of strokes/tries will be saved). If this option is off, the child must accomplish the exercise in a single try (which is very hard to do). When the "help" option is on, the next point in the stroke will be highlighted; this works like a "guiding green dot" which the child should follow to complete the exercise/game. If the "sound" option is on, for every correct dot/stroke of the brush a 'click' sound will be heard, and at the end of the exercise/game an "applause" will also be heard.

The communications module is responsible to send and receive every data to and from the server. This includes receiving the exercises/games to be played, comprising the background image and the set of coordinates of the path, and sending the results of the exercises/games to the server for storage and processing. These results include the total difference to the "ideal path" (the gray dots presented as "guiding lines"), number of strokes/tries, the total time, and total effective time of the exercise/game. As noted before, if no Internet connection is detected these data will be locally saved and will be sent to the server as soon as an Internet connection is available. The communications processes are implemented using web-services.

The difference to the ideal path is computed in the following way: the lengths (norm of the vectors) representing the ideal and the painted paths are computed and then the final difference will be equal to the absolute value of the difference between them, i.e., $||\text{ideal path}|| - ||\text{painted path}||$, where $|| \cdot ||$ denotes the norm of the vector and $| \cdot |$ the absolute value. The number of tries/strokes corresponds to the number of times the child raises her/his hand/finger from the Android Tablet to complete the exercise/game. The total time is the elapsed time since

the child produces the first screen touch, until s/he completes the exercise/game. This includes all pauses. When an exercise/game is about to start a "ready to start" message is presented. The "total time" clock starts counting right after the child touches the screen (anywhere), even if the child will take a bit longer to find the starting point of the path. On the other side, the "effective time" clock will start counting only after the child hits the beginning of the path and will not include eventual pausing times. This will be used by the teacher, for example, to see if a child has any difficulties identifying the start of the sequence, which seems to be the case if the child has some kind of cognitive problem.

4. Results

The system proposed here was developed having in mind the teaching and learning of pre-writing skills, i.e., kindergarten and first year of primary school.

The system was tested in two Kindergartens in the city of Vila Real, Portugal. More specifically, pre-writing skills sessions were developed with the children attending the Kindergarten of the Basic School of "Árvores", below designated by Room 1, belonging to the Grouping of Schools of "Diogo Cão", and the Kindergarten of "Mateus", below designated by Room 2, belonging to the Grouping of Schools of "Morgado de Mateus". Informed consent was obtained from all the parents of the children involved in this study.

Room 1 consisted of 23 children, 10 boys and 13 girls: 2 with 6 years old, 11 with 5 years old, 5 with 4 years old and 5 with 3 years old. Room 2 comprised 21 children, 11 boys and 10 girls: 9 with 5 years old, 6 with 4 years old and 6 with 3 years old. In Room 2 there were 2 students of Romanian origin, who rarely attended the room, and 3 students of gypsy ethnicity. Although all the children in these rooms (both in room 1 and room 2) had contact and used the Tablets, we only present and discuss the results achieved by children with 5 and 6 years old, both for experiment 1 and experiment 2 (presented in the next subsections).

Four Android Tablets were available for each of the rooms, implying that students had to share these devices. Thus, the teacher responsible for each of the rooms was asked to update the "user data" whenever there was a change in the student using the Tablet.

We started by using a two-week trial period where the children could interact with the Tablets and experience the different games/exercises in a more or less free and flexible way. After this initial period, several work sessions were held; the data presented below corresponds to the period of time from the beginning of November 2016 to the end of March 2017.

Statistical analyzes were performed using the SPSS Statistics software package (v.24, IBM SPSS, Chicago, IL), with $\alpha = 0.05$.

We have conducted two different experiments, reported in the following subsections.

4.1. Experiment 1

The first unexpected fact relates to the existence of a considerable number of records in the database, all associated with Room 1, with “userID” equal to -1 , meaning that the user is not registered in the database. In a first analysis to the data contained in the databases we were unable to identify the reason for such situation. However, after the manual copy of the data from Room 2, which, contrary to what was expected at the beginning of this study, did not have an Internet connection, we were able to identify the “source of the problem”. We had foreseen that if the Internet connection was not available (for example, due to network loss, accidental disconnection of the network from the Tablet by the children, etc.), data for all work sessions would be recorded locally in a database. When we manually imported this database into the global database, we found the names of students without accents, with lowercase letters, with extra spaces between the first and last names, among others. Although this was not the Room where the problem had been detected, it undoubtedly helped us to solve it. Of course, in this situation, the user data were corrected manually, resulting in a much higher data available for Room 2, and as a consequence we only have used the data of Room 2 in Experiment 1.

Data recorded in the database and used in this test were as follows:

- student identification;
- number (identification) of the exercise;
- date and time;
- degree of difficulty, this being determined by the combination of the following options:
 - the width of the stroke/brush, which can be thin (harder), medium (medium difficulty), and thick (easier);
 - the sound: on—easier (there is sound aid), or off—harder (no sound aid);
 - the stroke: single—the exercise must be completed in a single attempt (harder), or multiple strokes—several attempts may be made (easier);
 - the help, which may be on, indicating the “next point” in the exercise (easier), or off—not indicating the “next point” (more difficult);
- number of attempts used to finish the exercise;
- the difference between the graph made and the one considered ideal;
- the total time to complete the exercise;
- effective time;
- the percentage of completion of the exercise (divided from 0 to 25%, from 25 to 50%, from 50 to 75% and from 75 to 100%).

Although in total there were 5194 records of exercises performed by the children of the two Rooms, from November 2016 to March 2017 (547 relating to Room 1, and the remaining ones relating to Room 2), and for the reasons of incoherence presented above, the data presented below were collected from 7 5-year-old children from Room 2, using exercises where the degree of difficulty was minimal (large stroke/thick brush, multiple strokes/more than one attempt, sound on and help on) and totally (100%) completed by these children, in the following terms:

- the earliest date (in the study period) of each exercise for each child was chosen as moment M1 (November 2016);
- the most recent date (in the study period) of each exercise for each child was chosen as moment M2 (March 2017);
- for each day of study, the “lowest differential” was chosen for each exercise and child: that is, for each of the moments (M1 and M2),

the best-performing exercise for each of the children involved was chosen, so that no difference was artificially introduced;

- there were only two moments (two results) per child and exercise; a database (for treatment and analysis) was created with the values of these two moments, corresponding to a total of 129 cases.

The tables below present the results of the statistical tests applied, where:

- “attempts” — represents the number of attempts used to complete the exercise;
- “difference” — represents the difference between the executed exercise and the one considered ideal;
- “dif. time” — represents the difference between the total time for the completion of the exercise and the effective time.

These parameters were chosen based on the literature review presented above. They can also be used to measure the children’s accuracy in solving the exercises/games, but also to indicate how motivate the children feel during the execution of the exercises/games, and how challenging they feel the exercises/games are (Oudeyer et al., 2007; Schiefele, 1991; Ames, 1992).

To measure the type of statistical test to be applied to the two moments on the various paired samples (number of attempts, difference, difference between the total time and the effective time, etc.)—if parametric using the T-student test for paired samples, if non-parametric using the Wilcoxon test— it was necessary to verify the assumptions of the parametric statistical tests, namely through the application of the Kolmogorov-Smirnov test with Lilliefors correction, to analyze the normality of the distribution, and the Levene test for the homogeneity of the variance. Applying the Kolmogorov-Smirnov test, it was verified that all the indexes follow a non-normal distribution (with $p < 0.001$), so non-parametric tests have to be used.

To determine if whether or not there was a decrease in the “difference”, a decrease in the number of “attempts”, a decrease in the “effective time”, a decrease in the “total time”, and a decrease in the “difference between total time and effective time” from moment 1 (November) to moment 2 (March), the Wilcoxon non-parametric test was used, and the means were calculated using the parametric t-student test for paired samples; see Tables 2, 3, 4 and 5.

As can be concluded from the reading of these tables, a significant reduction was observed in all these variables, from moment 1 to moment 2, with a mean decrease of 23.125 in the difference, a mean reduction of 8.829 in the number of attempts, an average reduction of 5.397 seconds in the effective time, an average reduction of 7.185 seconds in the total time and an average reduction of 1.788 seconds in the difference between the total time and the effective time (Table 5). We can therefore conclude that there has been an improvement in all parameters. It should be noted that the decreasing in the difference between the total time and the effective time in about 2 seconds demonstrates that the children learned what was needed to be done in each of the exercises, significantly reducing the “interpretation” time in each of the exercises.

4.2. Experiment 2

The second experiment consisted in the application of a set of 6 paper-and-pencil based exercises (of the same type as those implemented in the Android Tablets) to two groups of children in the Kindergarten of the Basic School of “Árvores” (Room 1): a group of 9 children of 5 and 6 year-old who had contact with the Tablets, and another control group with 10 children (also 5 and 6 years old) who did not have access to the Tablets (a copy of the 6 paper-and-pencil based exercises can be downloaded from <http://www.mcabral.utad.pt/pre-writing.pdf>, in Portuguese). It should be noted that the choice for the two groups of students both belonging to the same school (Room 1), and not to

Table 2
Ranks

		N	Mean Rank
difference M2 – difference M1	Negative Ranks	80 ^a	67,56
	Positive Ranks	49 ^b	60,82
	Ties	0 ^c	
	Total	129	
attempts M2 – attempts M1	Negative Ranks	100 ^d	63,99
	Positive Ranks	24 ^e	56,29
	Ties	5 ^f	
	Total	129	
effective time M2 – effective time M1	Negative Ranks	99 ^g	66,13
	Positive Ranks	30 ^h	61,27
	Ties	0 ⁱ	
	Total	129	
total time M2 – total time M1	Negative Ranks	104 ^j	64,87
	Positive Ranks	25 ^k	65,56
	Ties	0 ^l	
	Total	129	
dif. time M2 – dif. time M1	Negative Ranks	98 ^m	72,81
	Positive Ranks	31 ⁿ	40,32
	Ties	0 ^o	
	Total	129	

- ^a difference M2 < difference M1.
- ^b difference M2 > dif. M1.
- ^c difference M2 = dif. M1.
- ^d attempts M2 < attempts M1.
- ^e attempts M2 > attempts M1.
- ^f attempts M2 = attempts M1.
- ^g effective time M2 < effective time M1.
- ^h effective time M2 > effective time M1.
- ⁱ effective time M2 = effective time M1.
- ^j effective time M2 < effective time M1.
- ^k total time M2 > total time M1.
- ^l total time M2 = total time M1.
- ^m dif. time M2 < dif. time M1.
- ⁿ dif. time M2 > dif. time M1.
- ^o dif. time M2 = dif. time M1.

Table 3
Wilcoxon signed ranks test (based on positive ranks).

	Exact sig. / p (2-tailed)
difference M2 – difference M1	0.004
attempts M2 – attempts M1	<0.001
effective time M2 – effective time M1	<0.001
total time M2 – total time M1	<0.001
dif. time M2 – dif. time M1	<0.001

Table 4
Paired samples statistics.

	Mean	Std. deviation
Pair 1	difference M1	148.711
	difference M2	125.586
Pair 2	attempts M1	17.82
	attempts M2	8.99
Pair 3	effective time M1	25.336
	effective time M2	19.940
Pair 4	total time M1	28.239
	total time M2	21.054
Pair 5	dif. time M1	2.903
	dif. time M2	1.115

Table 5
Paired samples test.

		Paired differences	
		Mean	Std. deviation
Pair 1	difference M1 – difference M2	23.125	103.226
Pair 2	attempts M1 – attempts M2	8.829	15.280
Pair 3	effective time M1 – effective time M2	5.397	32.587
Pair 4	total time M1 – total time M2	7.185	33.256
Pair 5	dif. time M1 – dif. time M2	1.788	3.682

different schools, was made with the main objective of isolating other variables that may influence the results, among which we highlight the socioeconomic and cultural level and daily experiences of the children. As such, these two groups of children (because they belong to the same school) lived more or less the same experiences throughout the year and had more or less the same opportunities. Note also that both groups have low prior experience of performing graphic activities in “pencil-and-paper” versions, similar to those performed here.

At the end, we asked a panel of 5 experts to assess these exercises, this evaluation being “blind” (i.e., these experts did not know “which children” performed “which exercises”). The results are presented and discussed next.

Given the reduced size of the sample, 9 students belonging to the “Testing” group and 10 students to the “Control” group, and because this is a case study, we chose to use non-parametric tests. However, the performed tests of normality proved this need. Table 6 presents the results of non-parametric tests. As can be seen, the results are better for the “Testing” group than for the “Control” group, i.e., the ranks of the “Testing” group are better than the ones for the “Control” group.

As mentioned above, although the reduced number of samples and the results of normality tests indicate the need to use non-parametric tests, T-test results are shown in Table 7. Although its validity is questionable, the values presented in this table confirm the best results of the students included in the “Testing” group when compared to the “Control” group. As can be seen, not only the average score assigned by the experts is better (higher), but also the standard deviation is lower (the difference between the scores obtained is lower).

5. Discussion

The system presented and tested here was developed with the aim to help the teaching and learning of pre-writing skills by kindergarten and first year of primary school, and having in mind the orientations, principles and rules presented above, in particular the ones presented in section 3. The system grabs a set of data, in accordance with the systems presented in the literature review section.

As stated above, from the analysis of the results of experiment 1, we have observed a significant improvement in the children’s handwriting performance. We have register a mean decrease of 23.1 in the difference between the ideal path of the graphism and the one produced by the children, a mean reduction of 8.8 in the number of attempts, an average reduction of 5.4 seconds in the effective time, an average reduction of 7.2 seconds in the total time and an average reduction of 1.8 seconds in the difference between the total time and the effective time spent by the children.

We have to stress out that the decreasing in the difference between the total time and the effective time in about 2 seconds demonstrates that the children learned what was needed to be done in each of the exercises, significantly reducing the “interpretation” time in each of the exercises.

Concerning experiment 2, and as mentioned above, although the reduced number of samples, the values obtained confirm the best results of the students included in the “Testing” group (the ones that have had access to the Tablets) when compared to the “Control” group (not only the average score/mark assigned by the experts is better (higher), but also the standard deviation is lower).

Table 6

Results of the non-parametric tests performed. E1 to E6 represent the exercise number. The “Total” represents the (total) sum of the ratings assigned by the 5 experts and “Avg” their average.

	N		Mean rank		Sum of ranks		Statistic		
	Group		Group		Group		Mann-Whitney	Wilcoxon	Sig. (2-tailed)
	Testing	Control	Testing	Control	Testing	Control			
E1	9	10	13.28	7.05	119.50	70.50	15.500	70.500	0.007
E2	9	10	14.33	6.10	129.00	61.00	6.000	61.000	0.001
E3	9	10	14.89	5.60	134.00	56.00	1.000	56.000	<0.001
E4	9	10	13.39	6.95	120.50	69.50	14.500	69.500	0.007
E5	9	10	13.94	6.45	125.50	64.50	9.500	64.500	0.002
E6	9	10	14.89	5.60	134.00	56.00	1.000	56.000	<0.001
Total	9	10	15.00	5.50	135.00	55.00	<0.001	55.000	<0.001
Avg	9	10	15.00	5.50	135.00	55.00	<0.001	55.000	<0.001

Table 7

Results of the T-test performed. E1 to E6 represent the exercise number. The “Total” represents the (total) sum of the ratings assigned by the 5 experts and “Avg” their average.

	N		Mean		Standard deviation	
	Group		Group		Group	
	Testing	Control	Testing	Control	Testing	Control
E1	9	10	28.67	26.80	1.000	2.044
E2	9	10	28.00	25.10	1.22	1.287
E3	9	10	28.56	24.40	0.882	1.897
E4	9	10	26.89	25.00	1.269	1.333
E5	9	10	27.67	24.10	1.803	2.079
E6	9	10	28.22	22.70	0.833	2.791
Total	9	10	168.00	148.10	3.571	6.244
Avg	9	10	28.00	24.68	0.595	1.041

Most of the experiments presented in the literature review section used keyboards to measure the children’s proficiency (e.g., Berninger et al. (2009), and Wollscheid et al. (2016)). Here, we have tested the handwriting of children directly in the Tablets’ screen. Also, most of that experiments were conducted with children with disabilities (e.g., Prunty et al. (2014), Rosenblum et al. (2016) and Berninger et al. (2009)), but here have conducted these experiments with children “typically developing”.

Some of the results presented here are in line with the ones presented in the literature review section, and in particular the ones achieved by Genlott and Grönlund (2013). Contrarily to the idea presented by Berninger et al. (2009), although they have tested the differences in writing with pen and using the keyboard and we have tested the handwriting directly in the Tablets’ screen, we have found differences both in total time and in the effective time children spend in the solution of the different exercises.

In line with the findings of van Mier and Hulstijn (1993), we have found that the “initiation time” in handwriting increases with the “complexity”. However, in our case, we have also observed a reduction of this initiation time, in experiment 1, from moment one to moment two.

Parallel to these findings, it is also worth to highlight the statements made by teachers, children, Direction Boards of the School Groups, the Town Council and the educational community in general, in the different interviews carried out with the various media (newspapers, radio and television, both at regional and national level). For example, in the newspaper “Jornal de Notícias”, March 2, 2017, p. 24, it can be read that “Maria Isabel” says that “it is more fun than the dolls”, “Inês” says that the application “is fun”, the teacher Regina Nunes highlights the “good reaction of the children” and the teacher Maria Adélia Matos found that “the elders, when they achieve the goals, have a party. The smaller ones still have some difficulties and there are those who are making contact with this reality for the first time, but it is going very well”.

The teachers are unanimous to affirm that this system has potentialities that will allow them to make better profitability of their time. The feedback given by some parents is also very encouraging and motivating.

We also believe that children with special education needs may greatly benefited from the use of this system, in line with what was succeeded elsewhere (Reis et al., 2010; Candeias et al., 2015).

6. Conclusions and future work

We have proposed a system to support the teaching and learning of handwriting skills. This system is composed of two components: the hardware component, the Android Tablet; and the software component, i.e., the exercises/games that the child must solve/complete. The software component as two modules: the server and the client. The server component runs at the server side, and it is responsible to send to the client the exercises/games that a child should do. The server module also includes all the management functions. The client module, runs on the Android Tablet, and has an engine that executes the exercises/games, which also includes a communications module, responsible to communicate to the server all the data (child name, number, class, exercise number, execution time, number of tries, etc.).

A teacher chooses what exercises/games a child should do directly in the Android Tablet or using the server (from the existing ones in the system).

A child does the exercises/games by logging into the system in the Android Tablet. Automatic feedback about the correctness of the answers is provided by the system. The system grabs all the data (number of tries, time spent, etc.) and processes it to present the data to the teachers and parents. Registered parents can see the results and follow their children’s “academic life” by logging into the server side of the system.

This system has proved its usefulness, as the results presented above show. In line with the literature review presented in section 2 and discussed in the section 5, we found a significant improvement in the development of handwriting skills in the children throughout the academic year (“Experiment 1”), with a decrease in the difference between the ideal path of the graphism and the one produced by the children, a reduction in the number of attempts, a reduction in the effective time, a reduction in the total time and a reduction in the difference between the total time and the effective time spent by the children doing the exercises. A decreasing in the difference between the total time and the effective time in about 2 seconds demonstrates that the children learned what was needed to be done in each of the exercises, significantly reducing the “interpretation” time in each of the exercises. As explained in the discussion section, although the reduced number of samples, the values obtained for “Experiment 2” confirm the better results achieved by the students that have had access to the Tablets, when compared to the results achieved by the students that did not have contact with the Tablets.

Most of the experiments presented in the literature review section used keyboards to measure the children’s proficiency. Here, we have tested the handwriting of children directly in the Tablets’ screen. Also, most of that experiments presented in the literature review section

were conducted with children with disabilities, but here have conducted these experiments with children “typically developing”.

Educators, children, directions of the School Groups, City Town Hall and the educational community are unanimous in stating that the implementation of this system was a real success.

In the near future we want to implement a forum area, intended to promote the interaction between teachers and parents. Also, we want to add to the system the possibility for the teacher to add new exercises. We believe that this will be possible, because, as described above, the teacher will have to provide a background contextualizing image and the path (“strokes”) that a child must pursue to achieve the final goal. Based on this path the system will automatically generate the coordinates for the Android game engine.

We also want to include other classes of exercises/games: paint, count, imitate, copy, identify colors, shapes, spatial relationships, position in space, among other.

Declarations

Author contribution statement

Miguel Candeias: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Maria G. A. D. Reis: Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Joaquim Escola: Performed the experiments; Contributed reagents, materials, analysis tools or data.

Manuel J. C. S. Reis: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Competing interest statement

The authors declare no conflict of interest.

Funding statement

This research was partially funded by National Funds through the FCT - Foundation for Science and Technology, in the context of the project UID/CEC/00127/2019, and by the Town Hall of Vila Real (NIPC: PT5067359670, with no explicit grant number).

Additional information

No additional information is available for this paper.

Acknowledgements

We are very grateful to the Town Hall of Vila Real, Portugal, the Schools of “Morgado de Mateus” and “Árvores” and their Directors and Educators for helping and supporting this research. We are also very grateful to Eng. Jorge Godinho in helping us with the statistical tests.

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