Digital Pen Technology's Suitability to Support Handwriting Learning

Emerging Technology Research Strand

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ABSTRACT
While digital technology is entering today's classrooms and learning environments, handwriting is still primarily taught using regular pencil and paper. In our research we explore the potential of digital writing tools to augment the handwriting process while preserving its cognitive benefits. In particular, we are interested in (1) how the characteristics of digital writing tools influence children's handwriting experience and quality, compared to regular pencil and paper and (2) what kind of feedback may be beneficial to digitally augment the handwriting process and how this can be integrated into handwriting technology. In this paper we describe early findings of a study we conducted at a primary school to investigate how existing digital pens (iPad and stylus, WACOM tablet, and Livescribe pen) affect children's handwriting quality and the handwriting experience. As part of this we discuss our methodology on evaluating handwriting quality, an inherently subjective activity. Furthermore, we outline the potential design space that digital writing tools open up when it comes to augmenting the handwriting process to facilitate learning.

Author Keywords
Digital pens; children; handwriting process; evaluation

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

1. PROBLEM STATEMENT AND CONTEXT

Learning how to write is considered an essential skill that forms the foundation of education. The early years of education are therefore dominated by learning how to hold a pencil and how to form letters and words. As technology has developed, so too have expectations toward the skill sets children need to acquire over the years. For example, mastering technology such as PCs and, more recently, direct-touch tablets, has gained importance. However, the introduction of digital technology into the classroom means that there is now a divide in both time and opinion between traditional teaching practises, such as handwriting, and modern approaches that exploit digital technology such as touch-typing. Research has shown that there are educational benefits of learning how to write using traditional methods [2, 12, 14]. Likewise, technology can be used to facilitate classroom activities [4, 30] and, potentially, the process of learning to hand-write. As we move towards a classroom and teaching activities that involve digital tools, it is not unlikely that, in the near future, young children will learn how to write using digital pen and paper, or tablet devices.

Our writing tools, analog or digital, greatly influence our writing experience and handwriting quality and, potentially, the context where we make use of them. If we think of digital handwriting technology in the classroom and how it should be designed, it is necessary to carefully consider (1) how this kind of technology will affect children's handwriting experience and (2) how it can potentially enhance the handwriting (learning) process. In this paper we focus in particular on the first question. We conducted an in-situ study where we assess three existing digital handwriting tools (a WACOM tablet, an iPad, and a Livescribe pen) and how these affected children's writing experience and handwriting quality.

In the following sections we provide the context for our research including a description of our research questions. This is followed by an outline of our study including the methods used to assess handwriting quality and to evaluate different writing devices, whilst tackling the challenges of working with children as study participants. We present an overview of our study findings and discuss their implications with regards to future work in the area of augmenting the handwriting process using digital pen technology.

Research Context

Our research draws from previous work in education and psychology on the cognitive benefits of handwriting. In the field of HCI, research has introduced various approaches to pen technology to support handwriting processes in general as well as in classroom scenarios.

Educational & Cognitive Benefits of Handwriting

Some argue that teaching practices need to adapt to reflect the prevalent technological advances that today's children are exposed to [3]. Yet, studies have shown that tools such as

keyboards, cannot replicate the inherent cognitive and educational benefits that handwriting provides [2, 12, 14].

The most effective teaching methods, when introducing young children to the alphabet and letter sounds, incorporate both visual and haptic cues [2, 15]. The haptic feedback from keyboard typing does not differ from letter to letter. In contrast, moving a pencil to form letter shapes leaves unique imprints in motor memory, which is why learning how to write by hand is more effective [11, 10]. On a higher level, the skill of handwriting has shown to benefit literacy skills, specifically letter recognition [10], phonological associations and orthographic rules (grammar and spelling) [9, 14], as well as compositional skills and expression [19].

This positive influence of handwriting on cognitive and educational development, alongside the popularity of low-cost pen and paper, has motivated research into the development of digital writing tools. Such writing tools aim to complement these benefits with the additional functionalities that we so value in our digital writing tools.

Digital Handwriting Tools

Research into pen and paper computing aims at combining the conventions of handwriting with the benefits of digital technology: such as the editing, sharing and processing of written information [29]. Successful applications of digital handwriting technology can be found in the context of design [27, 28], ideation [8], or education [4]. In classroom situations, the use of automatic handwriting recognition can translate handwritten information into typed text [21, 22, 23].

Digital pen technology can augment the handwriting process in different ways. Pens have been augmented to provide haptic feedback, resulting in improved letter recognition and phonological awareness in children [1, 17] and better handwriting fluency in adults when learning Japanese [6]. Beyond the pen itself, we see the integration of calculus functionality through digitally augmented pen and paper [30]. Other advances use pens to apply annotations on paper and also to navigate and control projected digital information [27, 28]. Similarly, digital projection on paper has been introduced to the classroom to better understand and support learning processes when teaching geometry [4].

Previous studies that have explored the differences of interacting with digital materials vs. pen and paper have shown that people still prefer paper [16, 18]. Previous studies have explored the potential of digital writing tools and handwriting recognition software as possible text entry devices in classroom scenarios [22, 20, 24]. However, we still lack studies of how today's digital pens (both display-based and paper-based) impact children's handwriting experience and quality.

We aim to close this gap by studying how existing digital pen technology compares to regular pencil and paper when it comes to handwriting experience and quality. Our findings can be used inform the design of future digital writing tools in general and in order to support the handwriting learning process for both children and adults.

Research Questions

The goal of our research is to explore the potential of digital pens as writing tools in classrooms, and to derive a list of design considerations that will guide the process of designing and developing such digital writing devices. This implies the following two research questions:

Q1. How do Digital Pens Affect the Writing Experience?

The tool used for handwriting has a huge affect on our general handwriting experience and, as such, the context in which we will consider using it. Writing with chalk on a blackboard feels different from writing with a pencil on paper. Writing with a fountain pen feels different to writing with a ballpoint pen. All these tools also effect the character and quality of our handwriting. In order for digital handwriting tools to become considered for classroom or other learning environments, it is important to explore how their characteristics, which differ from analog writing devices, will influence the handwriting experience. As a first step in our research, we therefore explored how using digital pens affects children's writing experience and handwriting qualities

As part of this, we recorded how the characteristics of the digital technology (e.g., size, weight, and thickness of the pens, feel of the pen on the digital surface) affect the handwriting process (e.g., handwriting result, body and hand posture during the writing process).

Conducting studies with children as participants can be a challenge in itself. Children express and explain experiences in unique ways that require further careful probing and interpretation. For instance, they may express their immediate reaction to a writing tool but often find it challenging to explain what factors influence this experience. Furthermore, the unfamiliarity of the study situation coupled with interaction with the experimenter (a stranger) may influence how they express their opinion during interviews.

As assessment of handwriting can be subjective we combined different approaches of eliciting feedback on handwriting quality from both the children themselves and two independent teachers. We also applied this process to characterize features that influence handwriting quality.

Q2. How can Pen Technology Support the Writing Process?

Accomplished writers can use a pen or pencil as an extension of their mind to write words and sentences with a level of automaticity that requires little thought as to the physi-

Figure 1. Video cameras captured children's writing and posture.

cal process involved. For young children, learning this skill takes time and involves training that can be arduous. Consider the analogy of a young child as they begin to write. They pick up their classroom pencil, having decided what they want to write, they adjust their sitting position and pencil grip and then start to form letters and words on the paper. During this process children are concentrating on what they want to say whilst also considering spelling, letter formation, spacing, sizing, location on the page and overall appearance. Traditionally it is the role of teachers to help children learn and progress to proficient writers by offering guidance, feedback and encouragement to their pupils. However, most classrooms have one teacher to many pupils so perhaps a digital pen could provide a level of support to each child in the absence of a teacher. The introduction of digital writing tools provides obvious additional functionalities, such as digital record keeping and analysis, which may be beneficial to writers. Beyond this, digital pen technology can potentially support the handwriting process itself. For instance, digital pens can provide direct feedback and instructions to the writer to help improve their handwriting style and skills. As part of our research, we consider if future digital writing devices can be more like teachers: providing guidance, feedback and encouragement, in order to assist children as they learn to write.

2. METHOD EMPLOYED

To address our first research question (Q1) we conducted a study with school children at a local Primary school over the course of one week. The goal of this study was to assess the potential of existing digital pen technology to be used for writing exercises in the classroom. We were interested in (1) how existing digital writing tools are experienced by children and (2) how the different characteristics of these tools influence children's handwriting quality. During the study we asked children to complete short writing exercises using four different (digital) pen technologies and to describe, rate and compare their experiences and handwriting quality. We used a mixed method approach combining both quantitative and qualitative methods to gain in-depth insights into the handwriting experience with the different tools from different perspectives. In the following we briefly describe the technologies explored, the study setup, and our data analysis.

Study Setup

We recruited 13 children from the same class (aged 9-10, 5 boys and 8 girls). Over the course of 4 days, each child completed 4 writing exercises (each with a different writing device). Each exercise was followed by a brief interview where we asked children to describe their experience with the writing tool. During the final interview we asked children to compare their experience with all 4 writing devices.

Digital Writing Tools Studied

We asked the children to write using an iPad2[1] and stylus, Wacom Cintiq[2] and Livescribe Digital Pen[3], as well as a common school pencil (see Figure 2). Each of the digital pens used in the study was carefully chosen to cover a range of characteristics that digital pen technology can offer: the iPad is becoming increasingly common in school environments [26, 13], and, in combination with a stylus, may become a legitimate writing surface in the future. In our study we used an iPad 2 and a popular stylus (Adonit Jot Pro[4]). The writing application of our choice was SVG notes [5], which can replicate the line spacing common in notepads used in classrooms.

The WACOM Cintiq tablet is a high-end graphics tablet, specifically developed and commonly used by artists and designers for complex drawings and detailed pen work and, as such, should be suitable for handwriting tasks. The tablet features a built-in display (like a monitor). The Livescribe Digital Pen is a high-street adaptation of Anoto technology[6]. This digital pen resembles a normal ballpoint pen, but it is capable of "reading" ink from special patterned sheets of paper. Our final condition, using a common pencil and paper, formed the baseline of our study.

To eliminate ordering effects we counterbalanced the order in which children used each writing tool. Each day children close-copied a different brief paragraph, which was carefully chosen considering the age and expertise of children, using the different writing tools.

Data Collection

We collected each of the handwriting samples that children created during the study for comparison and analysis (see Figure 3). In addition, each child was video- and audio recorded during the writing exercise and the interviews.

During the interviews we encouraged children to describe their experiences with the writing tools in an open-ended way. In addition, we asked them to rate their handwriting samples (on a scale of 1 to 5), and to provide up to three words that would characterize their writing experience with each writing condition best. Children also indicated their preference of (a) each device versus a standard pencil (after every study session) and (b) which of the conditions they most preferred or disliked overall (at the very end of the study). Asking the children to report their opinions using various approaches allowed us to record meaningful experiences from each child.

Data Analysis

For our data analysis we transcribed all interviews with children. Based on these transcripts we iteratively coded and categorized children's statements according to themes such as physical characteristics of the writing devices, overall experience with the device, as well as positive and negative aspects of the devices that children brought up.

We also analyzed the ratings that children provided for each writing device and how they compared for each child individually and across all participants. In addition, we got two independent teachers from different schools to assess and

[1] http://store.apple.com/us/buy-ipad/ipad2

[2] http://www.wacom.eu/_bib_user/dealer/bro_c12_en.pdf

[3] http://www.livescribe.com/en-us/smartpen/echo/

[4] http://adonit.net/jot/pro/

[5] https://itunes.apple.com/us/app/svg-notes/id569602013?mt=8

[6] http://www.anoto.com/lng/en/pageTag/page:home/

Figure 2. Digital Pen Technologies used in Study.

rate children's handwriting samples. These assessments were conducted blind to condition.

The recordings of the two video cameras provided insights into children's overall writing posture, writing grip and arm posture. Additionally, these recordings were analysed to deduce total writing time of each participant during the study (see Figure 1).

We provide a high-level overview of the results in the following section; we are in the process of conducting a more detailed analysis of our study.

3. RESULTS AND EVALUATION

Our results provide rich insights into the suitability of currently available digital writing devices for children. Our final interviews with children where we asked them to compare the different writing devices they had tried across the week, indicated that, overall, the Livescribe pen was the most popular among the writing devices. Eight out of 13 children chose it as their favourite device (two children selected it as a joint favourite with the WACOM). In comparison the WACOM received 5 votes for favourite (again, two children selected it as a joint favourite with the Livescribe pen). The iPad received only one nomination as overall best device.

Additionally, day to day comparisons of the digital writing devices directly with a regular pencil indicated that the Livescribe was preferred over a pencil by nine of the 13 children. Likewise, nine children also preferred the WACOM to the pencil; only five children stated that they would prefer to use an iPad rather than a classroom pencil. A close analysis of the interviews with children and of the handwriting samples that were produced sheds light into the reasons for these preferences.

Children's Writing Experience

During the interviews, children were asked to express their thoughts about each writing device regarding their writing experiences, special characteristics, or benefits and drawbacks that the tools introduce. These comments capture children's differing opinions and writing experiences for each of the digital writing tools.

When talking about the regular pencil children remarked "*it was easy and accurate*" [p1]. Whereas for the iPad condition children often commented that it was "*hard*", "*difficult*" or "*tricky*" to write with. Paradoxically, some still thought it made for a "good" writing experience. Children had a positive writing experience with the WACOM but felt that the WACOM surface felt "smooth" and "*slippy*" which caused difficulties when controlling the pen on it. In contrast, most children praised the Livescribe as "*easy to control*"; this is not surprising considering that it closely resembles regular pen and paper.

When we collated all of the words children provided to characterize their writing experience, some interesting themes emerged. For the baseline condition of pencil and paper, children most often used the terms *normal* (five children), then *comfortable*(4) and also *easy* (3) to describe their writing experience. For the iPad condition, children used words such as *cool* (4), *fun* (4) and *different* (4). Similarly, the WACOM was described first as *cool*(four children), *easy* (4) and also *fun* (3) to write with. Finally, the Livescribe pen was described as *easy* (seven children) followed by *fun* (3) and then *big* (2).

These descriptive words reflect children's attitude and perception of technology. For example, all digital writing tools were frequently described as '*fun*' or '*cool*'. Interestingly, whilst the Livescribe pen was described as "*cool*" by some children, the most prevalent adjectives comment on its usability and physicality. Our analysis of all the descriptive words shows that children often commented on the physicality of the writing device (using words such as "*slippy*", "*light*", "*smooth*", or "*circular*"). Of all the pens in the study, the Livescribe pen was the biggest and heaviest (see Figure 2, right). This may account for children's focus on its physical features.

Changes in Handwriting Quality

For the analysis of handwriting quality, we not only took into account children's self-assessment across all study days, we also collated the ratings of two independent teachers that came from two different schools. Both teachers have particular focus and expertise on handwriting education for primary school children. In the following, we describe how children's handwriting quality differed across devices from both the children's and teachers' viewpoints.

Children's Assessment of Handwriting Quality

All children's writing samples (see Figure 3 for an example) were rated by the children themselves on a Likert scale from 1 to 5 (where 1 is the worst and 5 is the best handwriting) immediately after they completed them. We analyzed whether children believed their handwriting quality improved with certain devices, decreased or stayed the same in comparison to the

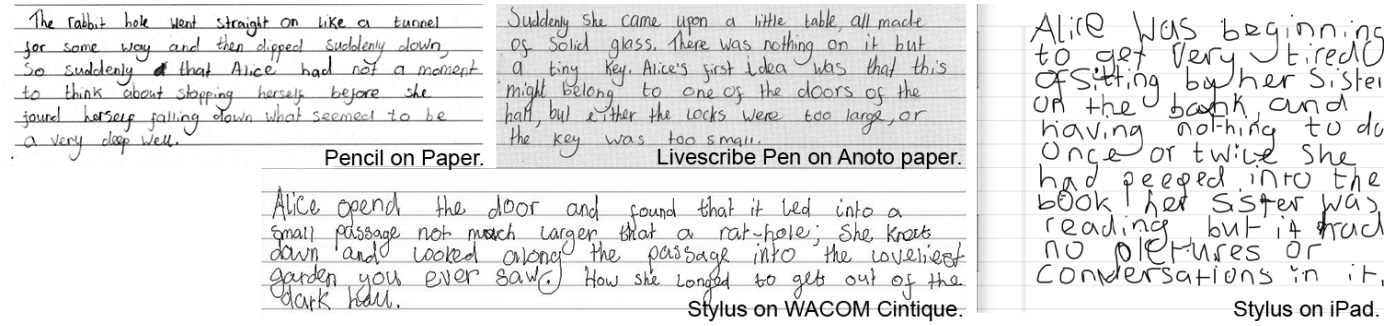

Figure 3. Handwriting samples from Participant 7.

baseline condition (Pencil & Paper) and to the handwriting they normally produce in the classroom.

For the pencil condition seven children identified their handwriting quality as the same as their normal level, but five children felt that their handwriting was of a lesser quality. This perhaps is a pointer to how the study situation impacted on either children's self-confidence or their ability to write to their full potential. When we look at the results when writing with the iPad, all children except one felt that their handwriting quality decreased. In the Wacom condition, five children felt the quality matched their normal performance, but six children felt it had a negative impact on their handwriting. When using the Livescribe pen responses ranged from "no change" in handwriting quality (4 children), improved handwriting (5), and decreased quality (4). Based on this, the Livescribe pen fairs well as a writing tool, since it does not seem to impact handwriting quality as negatively as the other digital tools.

Interestingly, these results show that there is a similarity between handwriting quality ratings and the overall device preference described earlier. However, there is not a direct correlation between each child's overall preference and changes to handwriting quality. This suggests that handwriting quality is likely to be a contributory factor, but not the only consideration when children decide what they find desirable in a writing tool.

Teacher's Assessment of Handwriting Quality

We passed copies of the children's handwriting samples to two teachers and asked them to provide a score for overall handwriting quality. In addition we asked teachers to rate different contributory aspects to handwriting standards that we extracted from previous literature [5, 7, 25] (see Figure 4). We compared teacher's handwriting quality ratings of children's handwriting samples created with pencil and paper, with those created with the digital pen tools. Teacher 1 indicated that the iPad decreased the quality of the handwriting in all cases, while Teacher 2 indicated a decrease in 10 participants. Both teachers indicated that handwriting quality was decreased when children wrote with the WACOM (Teacher 1: 10 children and Teacher 2: 12 children).

Similar to the children's ratings, Teacher 1 found a range of changes to handwriting ratings using the Livescribe (5 improved scores, 4 decreased scores and 4 scores with no change). However, Teacher 2 was more negative, rating the handwriting in 9 samples the same score as with a pencil and the remaining 4 as of less quality than the pencil samples.

This preliminary analysis of teacher's scores largely supports the children's scores and opinions. We are currently conducting a more in-depth analysis looking at the differences in teachers' and children's scores.

Important Handwriting Features

Figure 4 shows the categories of handwriting features and their importance as rated by both teachers. It becomes clear that that both teachers agree that writing on the line, correct letter formation and character sizing are the most important aesthetic aspects of children's handwriting. In contrast, teachers' opinions slightly differ on the remaining factors: word and character spacing and joined up writing. This emphasizes the highly subjective nature of handwriting assessment.

Physical contributory factors such as writer's posture and grip were both rated as highly important. While teachers' rating on the importance of writing speed differed, both scored this factor as of low importance compared to their other scores.

The information gathered from the teachers regarding important handwriting features will prove useful when considering the future steps of our work which includes an exploration of how to utilize digital pen technology to provide feedback on the handwriting process.

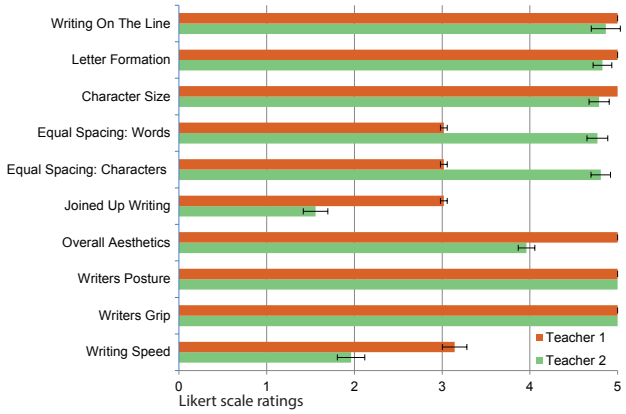

Figure 4. Rated importance of handwriting features by teachers.

Effect of Devices on Physical Aspects of Writing
We analyzed the video data regarding children's writing posture and writing speed. Our initial observations indicate that children's posture changes when using a writing tool that includes a screen, i.e. the WACOM and iPad. When using a pencil, children used their non-dominant hand to support their writing process with this hand leaning on the paper, holding it in place. However, in the conditions including a digital screen, they constrained their non-dominant hand to not touch the display. Furthermore, children modified the posture of their dominant (writing) hand, keeping it above the display to avoid direct touch. It is likely that children avoided bringing their hands close to the display to avoid interference with the writing: the iPad screen reacts to all touches which, at times, caused some interruptions of the writing exercise. Although this is not an issue with the WACOM tablet, children may have transferred their experience with the iPad. Another factor that may have contributed to this behaviour is some children's concern with mishandling the display, which may have influenced them to modify their posture. We can assume that the change of posture is a contributory factor in the decreased handwriting quality with the WACOM and especially the iPad (as visible in the samples shown in Figure 3).

These results show that the different characteristics of the digital writing tools we evaluated, indeed, have an influence on children's handwriting experience and quality. The Livescribe pen seems to influence handwriting quality the least negatively and children found it easy to use because it reminded them of writing with a regular pencil on paper. We will therefore include it into our future research steps regarding how to augment the handwriting process. While the WACOM tablet led to slightly more negative results when it comes to handwriting quality, we will also include it in our further research, because its display offers a wide range of providing visual feedback. We outline our future research directions in the following section.

4. FUTURE WORK

The discussion of our future work focuses on the question of how digital pen technology can support the handwriting process (Q2, see Section 2). This involves design considerations concerning (1) what features to provide feedback on as outlined in the previous section, (2) when to provide the feedback, and (3) what kind of feedback to provide.

What Features to Provide Feedback On

When teachers look at a child's writing, they can holistically assess the sample and identify where a student needs to improve. For digital pens to mimic this process, they need to be able to identify specific features of handwriting (as listed in Figure 4). It may be that some features of handwriting will benefit from feedback more than others: for example, a writer being reminded how to form the letter "b" correctly, may prevent further "b" and "d" transpositions. However, pushing writers to increase their writing speed may result in a degradation of overall quality and legibility (though an increase in speed is desirable once a level of handwriting proficiency is achieved).

Similarly, some features of handwriting are easier to master than others [1]. For example, the ability to "write on the line" is easier to achieve than consistent character size and style. This has to do with children's physical development; over time, they develop more fine-grained defined motor control—building a motor memory of how to form letters makes handwriting a consistent and near-automatic, easy process that hardly requires cognitive effort.

Our next research steps therefore will explore which handwriting features would benefit the most from intervention through digital pen technology.

Guidance, Feedback or Encouragement

Teachers can provide guidance, feedback and encouragement in the handwriting process in different ways and at different stages. They can stand above a child as they write a paragraph, providing guidance in-situ. They can also provide feedback when writing is completed, when the pupil brings over a completed exercise to their desk. Even more removed from the situation, they can provide feedback on the pupil's handwriting when grading schoolwork at home.

In each of these examples the temporal aspect plays an important role for both the teacher's and the child's experience. In order to translate this role to the scope of a digital writing device, it needs to be considered *when* a child would receive guidance, feedback or encouragement about their handwriting. As in the example above, we propose that there are different options that can be considered here: during (termed as guidance), shortly after, or long time after writing (both termed as feedback). The timing and nature of assessment may prove instrumental in its level of efficiency.

Additionally, the potential scope for the nature of encouragement means that feedback may be at its most effective in different forms: it can be positive or negative, brief or detailed.

Direct Feedback In-Situ.
In-situ feedback is provided during the writing process. For instance, it may be helpful to remind children to hold the pencil in a certain way or to sit correctly while they are in the process of writing, because the child can adjust immediately. Similarly, it is difficult for a teacher to comment on a child's posture when assessing a piece of written work. Furthermore, guidance provided immediately before a child writes may inspire a child to do well i.e. providing outlines for children to trace or emphasising the line on which the child should write. This would contrast greatly from instantaneous feedback that may highlight when the child should have or did write on the line, just as they complete a word, sentence or paragraph.

Reminders & Comments.
Some advice on the handwriting process and quality may be more appropriate after the child has finished a paragraph or the entire exercise. Reminders and comments provided less immediately during the writing process but still in-situ focus on aspects such as character formation or size. Here, an overview of the produced handwritten text where, certain features are highlighted could be provided: "*Look at this page . . . can you see that the 'a' look like 'u'? Try to write the 'a'*

correctly by closing the circle". This kind of feedback may be more detailed and encourage the child to focus on particular aspects in the next writing exercise.

When considering the temporal aspect to guidance and feedback, it may be that a layered approach is effective i.e. providing the same feedback at different points in time, or providing feedback only when it is most likely to be effective. We will conduct studies to explore this further. Another important consideration is the nature of the guidance and feedback provided, which we discuss next.

Nature of Encouragement: Positive or Negative.
There are different approaches to providing encouragement: positive or negative, and both may prove to be effective. For instance, children may benefit from encouragement that highlights only the positive features of their work, which will make them feel good about their work: we shall term this as positive encouragement. However, negative encouragement, where attention is drawn to aspects of their handwriting that requires improvement, forces the child to reflect on mistakes and try to improve. Teachers in class may use a mixture of negative or positive approaches to encourage their pupils. However, children may not feel engaged with a digital pen and will not respond to the pen's guidance in the same way they would a teacher. If that is the case, then further studies should seek to evaluate whether positive, negative or a mix of both would be most the most suitable approach for encouragement in a digital handwriting aid.

Feedback Type.
Another important aspect to consider is how to provide feedback. Consider the role of our teacher in the analogy described earlier, feedback could be provided verbally (such as "*well-done, try to . . .* ") or visually (through textual/ pictorial annotations). Furthermore, past handwriting samples can be kept in order to compare a child's progress over time. Digital pen technology could provide similar feedback using different approaches.

Audio Feedback.
Audio feedback, including phrases or sounds, can easily be provided with the addition of (external or integrated) speakers (as is the case with the mainstream LeapFrog LeapReader [7]). An advantage of audio feedback is that it does not interfere visually with handwriting, however, use in the classroom may be impractical and distracting to other children.

Visual Feedback.
Digital pen technology that includes a display (e.g., the WACOM Cintiq) makes it easy to provide visual guidance and feedback alongside or integrated into the handwriting in textual or abstract form (shapes or colours). With other digital pen technology, such as the Livescribe pen, that utilises paper instead of a digital display, it is possible to use projection to augment the writing surface. Visual feedback can be provided directly in-situ or later on as part of a broader analysis. Access to a writer's past writing samples, will allow for comparison and monitoring of progress —as a teacher might. Furthermore, this kind of technology may be of interest for teachers as well as an additional tool to assess the handwriting skills of children and to provide better guidance for particular areas for improvement.

Haptic Feedback.
Another way that digital pen technology can provide feedback on the handwriting process is through haptic cues. As discussed earlier, haptic feedback can be beneficial when learning to write [7, 6, 17]. Introducing haptic feedback to students in order to improve their handwriting, therefore, shows promise.

Intensity of Feedback: Subtle or Disruptive Cues.
A further consideration is the degree subtlety of feedback provided. For example, the feedback could be so subtle it can easily be ignored or obvious, creating an urge to react upon it immediately. Some types of feedback may be more disruptive by nature (e.g., audio feedback), while others allow for larger ranges of subtlety. The intensity of feedback provided may change with timing and type of feedback.

Additionally, we have to consider that certain types of feedback may be detrimental to the writing process because they may add too much complexity to the activity, especially considering that children are our target group. It is therefore necessary to consider a spectrum of the level of feedback that is provided to the user. This may mean that some feedback is so subtle it is barely perceptible by the writer, though they modify their writing in response to it. The level of perceptibility can continue up a scale to where it is disruptive to the a person's work. In an extreme case, for instance, the ink will vanish if the child does not form a letter correctly, forcing them to write and rewrite the letter until they can produce it perfectly.

Evaluation
If a digital pen can provide meaningful feedback, guidance and encouragement to the user, then it stands to reason that potentially, digital pens can make the process of learning to write easier. However, considering the delivery of feedback in terms of form and intensity leaves a large scope for exploration. We are currently planning a series of future design explorations and studies where we will design prototypes and evaluate them in classroom environments. The challenge will be to assess when a certain design can be considered successful, since handwriting learning is a long process. One metric we will therefore apply is if the digital pen technology is detrimental compared to current writing technologies. However, we feel that this area would benefit from further research.

CONCLUSION
In our work we explore the potential of existing digital pen technology for handwriting with children. We conducted a study, where we asked children to complete short writing exercises using different digital pen technologies. Our findings show that the different characteristics of different digital pen technologies influence handwriting quality and children's writing experience. We also show that children are willing to adopt digital pen technology and that it may be suitable for

[7] http://www.leapfrog.com/en_gb/landingpages/leapreader.html

use to support the handwriting learning process. Based on these initial findings, we discuss the design space that digital pen technology opens up regarding augmenting the handwriting process in the classroom. In particular, we consider what, when, and how digital pen technology can integrate feedback on the handwriting process.

ACKNOWLEDGEMENTS

We thank all our study participants and the teachers who helped us analyze our study data. We would also like to thank the primary school involved in our study for their generous support of our study. Last but not least we thank our colleagues of the SACHI group for their invaluable support and feedback on this work. This work is funded by EPSRC.

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