The Usability of Digital Ink Technologies for Children and Teenagers

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This paper describes an empirical study that considered the usability of digital pens, Tablet PCs, and laptop PCs for handwritten text input by young users. The study was carried out in two parts, firstly with young children aged 7 and 8, and then with older children aged 12 and 13. The study found that digital pens were particularly well suited to older children and that the both sets of children were able to use the Tablet PC without too many errors. Digital ink technologies are often evaluated by the calculation of recognition rates and this paper exposes some of the flaws in the process of estimating recognition rates from activities involving the copying of text. With particular reference to the personalization of text, possibilities for the use of digital ink for the task of writing are explored and a new interaction, digital doodling, is presented.

Keywords: teenagers, children, usability, empirical study, digital pens, Tablet PC, handwriting recognition, digital doodles, evaluation.

1 Introduction

In the book Human–Computer Interaction in the New Millennium, John Carroll describes HCI as:

> The study and practice of usability. It is about understanding and creating software and other technology that people will want to use, will be able to use and will find effective when used. [Carroll 2002]

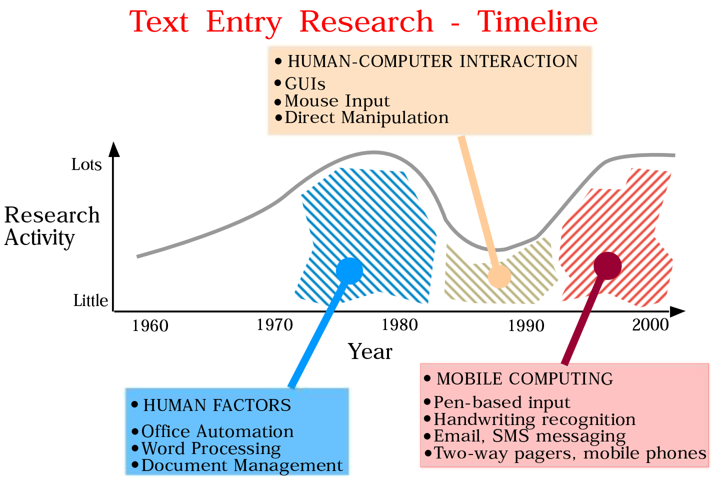

Figure 1: Text entry timeline [MacKenzie & Soukoreff 2002b].

This aligns closely with the three requirements for product success that are proposed by Dix et al. [2003], these being for products to be used (attractive, engaging, fun), usable (easy to use), and useful (accomplish what is required).

These 'permanent' definitions of HCI effectively dictate the landscape upon which HCI is painted. The detail within the HCI community changes over time with different aspects of interaction gaining favour and momentum at the expense of others. Pattern languages, web interaction, task analysis, and mobile technology are all examples of issues that have drifted in and out of favour over the years.

The study of the usability of text input methods and specifically the effectiveness of different text entry methods is one area of research that has moved in and out of fashion. The timeline in Figure 1 shows how changes in interest in this area have primarily resulted from the arrival of new technologies [MacKenzie & Soukoreff 2002b].

The growth in sales of pen-based systems and the improved functionality of handwriting recognition are both important developments with respect to text entry research. When text is captured using a stylus on a Tablet PC or by the use of a digital pen, a new method for interaction is available. The handwritten text can be manipulated and stored without recognition or can be converted into ASCII text using handwriting recognition software.

The people that interact with technology have also changed over time. Over the last 20 years, the user population has expanded to include a wide range of people including children, older people and people with sensory and motor disabilities. Children are an interesting user group, they represent the only user group that is ageing in a positive way, their acquisition of skills and knowledge is rapid and their motivation for using computers is very different from the work place adult user.

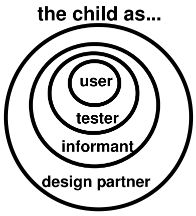

Figure 2: Roles of children in interactive product development [Druin 2002].

The investigation of children and their impact at different stages of product development as shown in Figure 2 has resulted in the emergence of a new discipline, Child Computer Interaction (CCI) [Read 2005]. This discipline takes its roots from a few early pioneers Frye & Soloway [1987], Solomon [1978], and Kafai [1990] and owes much of its current impetus to the design work by Druin [1999] and the vision of Bekker et al. [2002] in instigating a dedicated conference series.

1.1 Motivation for the Research

Twenty years ago it was highly unusual for a child to be doing text input at a machine but nowadays children spend a considerable time at the computer, inputting short and lengthier text via a range of different applications ranging from the search bar in Google, through the chat interface of MSN to the familiar Microsoft Word word processing package. It is common for children to be expected to word-process schoolwork, often creating the first draft using pen and paper and then typing up the final version for assessment or display.

For adult users, prolonged keyboard use is known to cause muscle ailments, stress injuries, and eyestrain [Thelen 1996]. Children are using the same technologies as adults with little regard for any long-term effects of computer text input by children, whether that is at a keyboard, on a mobile phone keypad, or by some other method. The effect of prolonged computer use on the eyesight and posture of children was known in the early nineties with Palmer [1993] reporting vision problems and Weikart [1995] detailing muscle disorders. More subtle affects, such as the impact of computer text creation on the language and understanding of children have been less well explored. The creation of text using digital pen and ink technologies may reduce some of these problems.

1.2 The Research Study

The work described in this paper is an exploration of the usability of three pen based digital ink text input methods for children. It begins with an overview of text entry and then goes on to explore some alternative text entry technologies including descriptions of handwriting with a stylus on a Tablet PC, handwriting with a graphics tablet and pen on a standard PC, and handwriting with a digital pen on digital paper. The paper then provides an overview of the methods that are commonly used for the evaluation of text input technologies.

An empirical study is then presented that explores the usability of the three digital ink technologies with two distinct user groups; one was a group of seven and eight year old children, the other a group of twelve and thirteen year old children.

The paper concludes with a discussion of the results, and a discussion of some emerging issues.

2 Computer Text Input for Children

There are good reasons for encouraging children to engage in computer text input. Writing text in emails, for instance is known to help children understand the notion of writing for an audience [Garvey 2002] and is also seen to be liberating as emails can be *'written in any style'* and *'allow children to explore their inner voice'* [Turrell 1999]. Written work produced at a computer can be made to look good, thus motivating poor writers [Day 1994], and computers allow the representation of ideas in dynamic forms, provide improved feedback to pupils, and allow information to be easily altered [Moseley et al. 1999].

Traditionally, text is input to a computer using an alphabetic keyboard. These keyboards can be arranged in different ways with the most common presentation being the QWERTY keyboard that lays the characters out in the same way as the early typewriters. The action of using a keyboard for text entry is occasionally referred to as keyboarding, but as the term keyboarding also refers to the mastery and use of electronic organs, in this paper, the action of entering text, is described as typing.

The process of typing can be broken into five phases, these are, character recognition, storage, motor activity, keystroke and feedback [Cooper 1983]. Character recognition is when the typist recognizes the letter on the keyboard, storage is the process by which the typist is able to be reading ahead (possibly four to eight characters at a time for experienced adults), the motor activity is the movement of the fingers to the keys, the keystroke is the pressure needed to press the key and the feedback is essential for error detection and correction (this could be omitted or could be made to happen later, for example with blind users who may have the text read back to them at a later time).

It is possible to become quite skilled at the alphabetic keyboard; but many people, and particularly children, find typing difficult [Norman & Fisher 1982]. The layout of the keyboard makes high demands on short-term memory and poor motor control can also limit keyboard efficiency as children may 'miss' the appropriate key, hold it down for too long, or fail to press it sufficiently.

2.1 Alternatives to the Keyboard

The most commonly found alternatives to the alphabetic keyboard are the reduced keyboards (as seen on mobile phones) and the recognition technologies of speech and handwriting. Text entry at a mobile phone is a specialist area of research and is not explored here in any detail; readers are directed to the work by MacKenzie & Soukoreff [2002b] for a full treatment of this area.

The two recognition technologies are essentially quite similar; the user communicates by speaking or writing and this is captured by the hardware and then digitized. The digitized speech or writing is then converted into ASCII (or similar) representation by the application of recognition algorithms, sound, word or character matching, and in some instances, the application of language models. These recognition processes are error prone both at the point of capture and at the point of recognition [Plamondon & Srihari 2000]. Speech recognition is problematic for children as their speech is immature and young children are often unable to read the training text that is needed to individualize (train) the recognition algorithms. Work by the author has established that speech recognition without training is highly error prone with children [Read et al. 2001].

Handwriting recognition software is reasonably robust and can be used without individualization; earlier work by the authors has established that there is scope for its use with child users [Read et al. 2004]. To use handwriting recognition for text input there is a need for technology that can support the capture of the written text and software to carry out the recognition.

2.2 The Usability of Digital Ink Technologies

The effectiveness or usefulness of handwriting recognition interfaces is generally measured by determining the accuracy of the recognition process. This is only relevant if the handwritten text is to be converted into ASCII text before use. If no conversion is intended, the accuracy of the recognition algorithms is irrelevant. Research studies tend to report recognition error rates that are generally derived from information about what the user wrote and what the recognizer subsequently output. There is very little research that takes a holistic view of recognition-based systems. The value of the system to the user, and the effort saved by the user is seldom reported [Hartley et al. 2003; Huckvale 1994].

The accuracy of the recognition process for text entry is typically measured by apportioning a percentage score to text after it has been through the recognition process. Metrics that are used for this have been derived from those used for the accuracy of keyboard input, and accuracy (or error rate) scores are generated by comparing a string of presented text (input) (PT) with a string of transcribed text (output) (TT) [Frankish et al. 1995; MacKenzie & Chang 1999; Tappert et al. 1990]. The two strings are compared and the 'errors' in the transcribed text are classified as insertions (I), deletions (D) or substitutions (S). These are then totalled and used to calculate the Character Error Rate (CER):

$$CER = (S + I + D)/N$$

where N is the total number of characters in the presented text.

To calculate the errors, the two phrases are aligned by the use of a minimum string distance (MSD) algorithm that generates a set of optimal alignments (those which result in the least error rate) between the two text strings [MacKenzie & Soukoreff 2002a]. An example is shown here:

PT = `The cat jumped over the moon`
TT = `Then cat jumpd over he moon`

The MSD in this case is 3 and there is one optimal alignment which is:

PT = `The- cat jumped over the moon`
TT = `Then cat jump-d over -he moon`

Once the optimal alignments are generated, it is possible to identify the individual errors by inspecting the two text strings. In this example there is an insertion after `The` (shown by a dash in the PT), a deletion after `jump` (shown by a dash in the TT and a deletion after `over` (also seen in the TT) resulting in an error rate of 3/23 or 13%. As these alignments, and the resulting error rates, can be generated automatically the character error rate metric is an attractive choice for researchers [MacKenzie & Soukoreff 2002a].

Reported error rates for pen-based input devices vary according to the type of writing that is supported; a study by MacKenzie & Chang [1999] tested error rates with 32 subjects copying words of discrete characters onto a tablet, using a constrained grid and reported error rates of between 7% and 13%. Frankish et al. [1995] reported error rates for free form text (natural text) that averaged 13%, and fell to 9% when only lower case letters were used.

The efficiency of text input is normally measured in characters per second or words per minute, and user opinions are obtained by asking the users for their views or by observing them as they use the technology.

3 Empirical Study

The study that is described here compared three methods for text input using digital ink technologies. The three methods were handwriting with a stylus on a Tablet PC, handwriting with a graphics tablet and pen on a standard PC, and handwriting with a digital pen on digital paper.

The focus in the study was on the usefulness of the technologies with the assumption that the writing created on them would be required later in some ASCII form; therefore, recognition rates were important. It was hoped that the study would identify whether or not the technologies were useful, whether or not children of both ages could use the technologies and also to find out how recognition rates improved between the Tablet PC and the Wacom tablet and laptop presentation.

The study was carried out over two sessions. The first session involved 15 children aged seven and eight; the second session was for a group of 25 twelve and thirteen year old children. The organization of both sessions was identical; the description that follows applies therefore to both groups of participants.

3.1 Apparatus

The apparatus that was used varied for the two sessions. In the session with the younger children, the children used either a Tablet PC (as shown in Figure 3) or a Digital Pen (as shown in Figure 4), hereafter referred to as the primary technologies. In the session with the older children, the children were also directed to one of these two technologies but were subsequently given the opportunity to use a Laptop PC with graphics tablet (referred to later as the secondary technology). This option was not offered to the younger age group as the author had used this extensively with that age group and was aware of the usability and the expected recognition rates for this product. The decision to not offer it to the younger children was also taken with the intention of improving the efficiency of the experiment given that children took quite a long time doing the experimental tasks.

Figure 3: Child using the Tablet PC.

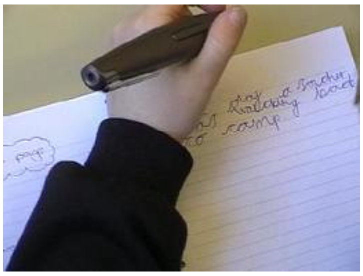

Figure 4: Child using the digital pen.

The Tablet PC that was used was a Toshiba Portege and this was used with Calligrapher handwriting recognition.

The digital pen that was used was a Logitech USB pen and this was used with the digital paper notebook that was supplied with the pen. The writing appeared on the notebook, just as if it had been written with a biro.

The writing from the digital pen was uploaded to a laptop once it was written and it was recognized by the software that was supplied with the MyScript software that supported the pen application.

The standard PC was a Hi Grade Notino laptop with a Wacom graphics tablet attached at the USB port. The children wrote on the graphics tablet and their writing was displayed on the laptop screen. The writing was not visible on the graphics tablet. The recognition software that was used was the Calligrapher software, which was the same as that used in the tablet application.

3.2 Procedure

The experiments took place on a single day in a laboratory setting at the University. The younger children carried out the work in the morning, the older children in the afternoon. The children that took part in the experiments came from two local schools and were convenience samples in as much as they were from classes that the schools had chosen to bring to the experiment following a request from the researcher.

Figure 5: Smileyometer used to rate the Applications.

The children entered the room in small groups and were brought to a table where the researcher allocated them to one of the two primary technologies. Before the children used the technologies, they were given an explanation of how they worked and were also told what the purpose of the study was.

As the children completed each application, they rated their experience using a Smileyometer [Read et al. 2002] — see Figure 5.

3.3 Design

This was an exploratory study, designed to establish how usable the technologies were, whether or not the children would use them (given a choice) and what recognition rates could be expected for these technologies.

3.3.1 Design of the Text Phrases

The children were presented with a single A4 sheet of text phrases for copying into the technology. These phrases had been taken from the text phrases published by MacKenzie & Soukoreff [2003], and were selected on the basis of their word familiarity for the younger children and for easy spellings. Both groups saw the same phrases. The phrases were displayed in a size 16 comic sans serif font with five phrases on each side of the paper. The phrases that were presented on the first side of the paper were:

My watch fell in the water
Time to go shopping
You must be getting old
The world is a stage
Do not say anything

The phrases that were on the rear of the paper were:

Are you talking to me
You are very smart
All work and no play
Did you have a good time
Play it again Sam

The order of the presentation of the first five phrases and of the second five phrases was different for each event; this meant that although the phrases followed one another in sequence, the first phrase that was written differed across the technologies and across the children. For instance, My watch fell in the water appeared either 1st, 2nd, 3rd, 4th or 5th. The researcher ensured that the presentation

	Young Children	Older Children
Number	8	11
Average	0.181	0.072
SD	0.125	0.082

Table 1: The error rates for the digital pens.

of these phrase sets was arranged to minimize the effect of learning on the recorded recognition rates and to provide a reliable set of results.

3.3.2 Design of the Interfaces

The three technologies were presented in different ways. The digital pens were placed on a table and the children wrote with them into the digital paper notebooks that had been provided with the pens. These were A4 size, spiral bound and presented in a portrait layout.

The Tablet PC was used with an experimental interface that was identical to the one on the laptop PC. This interface gave the children a space to write and when they were ready it displayed the results of the recognition process to them. They then cleared the interface and wrote their next phrases.

At the end of the session, the digital ink from the pens was uploaded to the computer and recognized by the Logitech notes software. The writing on the Tablet PC and the laptop was recognized using calligrapher software. Both types of recognition software utilized a standard dictionary.

3.3.3 Design of the Evaluation Sheet

An evaluation sheet was presented to the children after they had used the technologies. This required the children to give a rating for each of the technologies that they used.

3.4 Analysis

There were two analysis processes. The text that was generated from the recognition activities was aligned to the text that was copied by using an MSD algorithm, and a character error rate was derived as explained in Section 2.2.

The ratings from the children with respect to the technologies were given numerical scores from 1 (awful) to 5 (brilliant).

3.5 Results

Not all the children wrote all write all ten phrases at each technology, but all completed the first five phrases. Because of this, the numerical results that are presented here only represent the error rates from these first five phrases. Optimally, these represent 88 characters; some children wrote less than 88 characters as they missed out letters or words, and some added letters or words to end up with more than 88 characters. The error rates were all measured against 88 characters; the implication of this is discussed later in the paper. Table 1 shows the error rate statistics for first five phrases written on the digital pens.

	Tablet PC		Wacom and Laptop
	Young Children	Older Children	Older Children
Number	7	12	10
Average	0.170	0.156	0.193
SD	0.118	0.113	0.139

Table 2: Error rates for the Tablet PC and the Wacom Tablet.

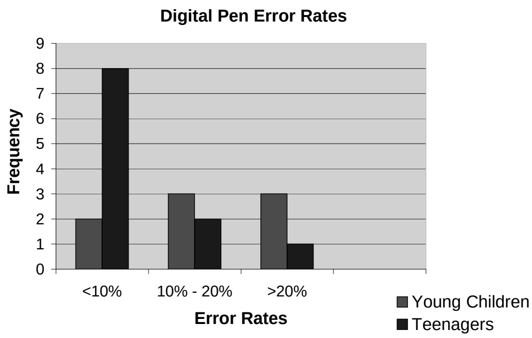

Figure 6: Error rate distribution for digital pens.

The error rates for the first five phrases on the Tablet PCs (used by both sets of children) and the first five phrases on the Wacom and laptop (used only by the older children) are presented in Table 2 — Error Rates for the Tablet PC and the Wacom Tablet.

There is a significant difference ($t_{17} = 2.41$, $p < 0.05$, two-tailed) between the results for the younger children and the older children in the error rates for the digital pens. Summary data from their writing is shown in Figure 6 where it can be seen that for many of the older children, error rates were very low; in fact, three children produced work that resulted in no recognition errors.

There was not a significant difference for the error rates between the two user groups when the Tablet PC was being used (distribution shown in Figure 7), but for the older children, the results between the Tablet PC and the Digital Pens were significantly different, $t_{21} = 2.17$, $p < 0.05$, two tailed).

The average preference scores for each technology are shown in Table 3.

The results for the digital pens are particularly interesting as there is a significant difference ($p < 0.05$) between the recognition rates for the younger and the older children. As shown in Figure 6, very few of the younger children had well recognized writing. For one of the younger children, a portion of writing was not captured even though it was clearly seen in the notebook. The reason for this was not discovered but it may be that the way the child held the pen interfered with its operation.

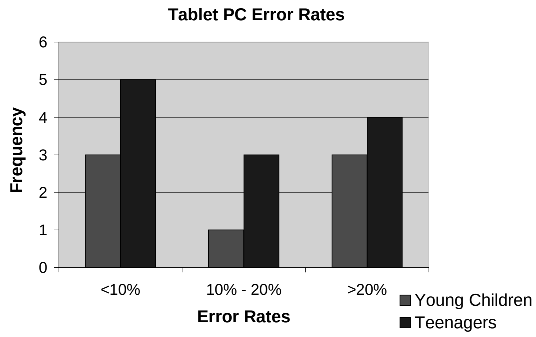

Figure 7: Error rate distribution for Tablet PC.

	Digital Pen	Tablet PC	Laptop PC
Young Children	4.182	4.429	N/A
Older Children	3.733	4.273	3.417

Table 3: Average preference scores for each technology.

It is interesting to note that there is not a significant difference between the writing at the tablet for the younger and older children, neither was there any significant difference between the tablet and the Wacom for the older children. The Tablet PC was generally preferred by the children, but the digital pen also gained a high score for user choice, especially from the younger children (who had had relative success with that technology).

4 Findings from the Work

The findings from the work are considered in three sections; the first looks at the usefulness of the technologies, the second at how usable the technologies were and the third explores whether or not the children would use them.

4.1 How Useful was the Technology? Recognition Rates Revisited

The major determinant of usefulness in this study was the recognition accuracy of the process. The accuracy rates seemed quite high in some instances (older children using the digital pens for example) and even with the tablet technologies the recognition rates are reasonable when compared to other similar studies [Read et al. 2003]. It may be that with real use (i.e. composed text), these recognition rates would be higher; in the studies reported here, the children copied phrases rather than composed their own words and in Read et al. [2004] it was shown that copied text resulted in more errors than composed text.

The reason for there being a difference between copied and composed text is partially explained as follows. Figure 8 shows the four text strings, IT, WT, PT and TT, that are present in a recognition process.

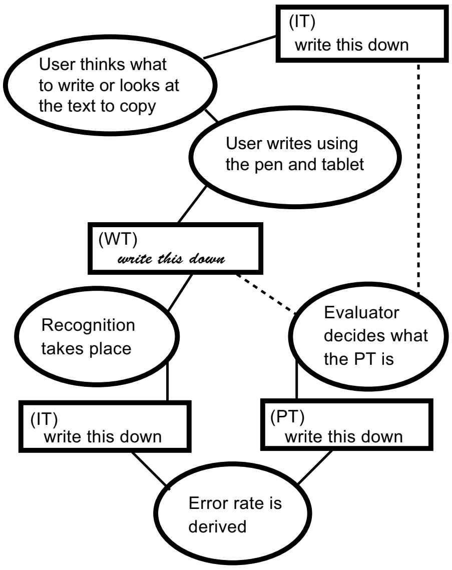

Figure 8: The text strings in a system.

Type of error	Number of instances
Wrote in text speak	3
Spellings incorrect	5
Missed words	2
Substituted words	1

Table 4: Reasons for variance in intended and written text.

The first string (IT) is the 'intended text' and this may have been presented to the users for subsequent copying or may be thought text that exists only in the users head. This text is then written by the user to create a second text string that is the written text (WT).

When the user is composing text (rather than copying), this written text is inspected and interpreted for use as the presented text (PT). When text has been copied, the intended text is generally, but not always, used as the presented text (PT). In the example shown in Figure 8, it can be seen that the user intended to write `write this down` but in fact did not write the `e` in `write` and so using the intended text as the presented text (as was done in this experiment reported here) will result in a worse recognition rate (1 substitution, 1 deletion) being recorded than perhaps should have been (1 substitution).

To determine the size of the effect of using the intended text as the presented text, the writing that the children did using the digital pens was investigated for those cases when the intended and the written text varied. This investigation included a

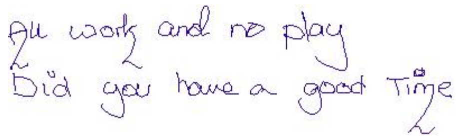

Figure 9: Writing displaying personalization.

look at the second five phrases (not included in the summary data in the results). The reasons for the intended and written text being different are summarized in Figure 4.

The child that wrote in text speak used `r u talking 2 me` instead of `are you talking to me` (this resulted in three instances of text speak and one spelling, which it could be argued was also a text speak!). This would result in an almost 33% error rate even before a single character was recognized. Incorrect spellings and substituted words can have varying effects on recognition rates depending on the distance from the intended text. Missed words are generally small words and their impact is often small; in this study words that were missed were both unimportant words, an `a` and an `is`.

4.2 How Usable was the Technology? Errors Examined

All the children were able to quickly use the technologies presented to them and the technologies were all suitable for the task. There were a couple of instances where the child needed some assistance, three of the younger children needed to be shown how to write on the Tablet PC and four of the older children needed help with the Wacom tablet but this they provided for each other as a number of these children had used Wacom tablets and pens in their artwork at school.

With the digital pens, aside from the problem with the pen not capturing the digital ink, the most common error was with children starting too near the top of the page. This caused poor (or absent) recognition of the first phrase and happened with three of the children (all in the younger group). One boy wrote all his phrases with the book upside down and these were subsequently not recognized at all by the software — his results were not included in the summary in Table 1.

All three technologies supported the children's individuality as they allowed for different writing styles, but in some instances, this reduced recognition. Figure 9 shows an example from one girls writing that clearly shows how she embellished her writing with irregular descenders and circles in place of dots. Remarkably, this writing was recognized quite well, probably due to the fact that the embellishments were added as she wrote; children that added embellishments after they had written created more problems for the recognition process.

It is clear when looking at the writing in this form (as shown in Figure 9) that children, (and in this small experiment, this was notably the older girls) see their writing as both individual and as an artistic product, seven of the girls in the study wrote with embellishments. The conversion of this writing into ASCII text seems to be almost an act of vandalism and so the possibilities for manipulation of digital ink, especially for this user group, are worth further exploration.

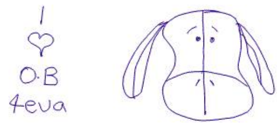

Figure 10: Digital doodling.

4.3 *Would the Technology be Used? Digital Doodles*

The high ratings that the children gave to the technologies suggest that were they available to children in schools these digital ink tools might be used. For users with high levels of discretion (and children are such a user group) technology is only adopted if it makes things easier, faster, or more fun than the present alternative. One particular aspect that was seen in the work of this study was the interplay between art and writing, especially with the older children, and this cannot be easily enabled in a QWERTY writing environment.

Pen and paper provides a very creative medium that children explore from an early age. When they are very young, they use drawings to express ideas and convey meaning but as age, they draw less and write more [Kress 1997]. During the teenage years it is common for children to add art forms to their writing and to their writing artefacts (books etc.) in the form of doodles. In a small investigation of the prevalence of doodles among older children, the researcher found that over 85% of children of this age added doodles to over 50% of their standard pen outputs. These doodle behaviours are enabled by digital ink; an example from the work of this study can be seen in Figure 10 which shows how one child added her own symbols to her writing.

It is perhaps unsurprising that digital doodling might happen with pen technologies, as the nature of the pen is very different from the nature of the keyboard. Pens are used for both art and writing whereas the keyboard is simply a text creation tool. Microsoft have recently acknowledge this by providing a pen writing space to their recent MSN chat application.

The older children saw the potential in the technology; one child remarked that she could write letters in secret using the digital pen, destroying the paper version, but keeping the digital version safe in the technology, another suggested that the pen could double as a mobile phone and be used to store everything! One challenge for digital ink recognition technology is to be able to discriminate between doodles and writing so that only the writing is recognized. In the study described here, the recognition software that was supplied with the digital pens coped well with doodles but the software on the Tablet PC tried to recognize the drawings (and failed!).

5 Further Work

These results indicate that children can use both the novel technologies of digital pens and tablet PCs. The results show that when children copy text into these technologies, recognition rates of around 80% can be expected for most children, but these may be higher for composed rather than copied text. The results for the younger children using Tablet PCs (average error rate 17%) compare favourably with the results reported for children using Wacom tablets and PCs (average error rate 34%) [Read et al. 2004] and suggest that there is a measurable improvement when the problem of separation between writing surface and screen is removed.

The children using the technologies in this study were all enthusiastic and the older children were keen to offer suggestions for the possibilities for the technology use in the classroom. The involvement of older children in the envisioning and testing of future technologies is an area that is worth further investigation. Observing the author writing this paper using a QWERTY keyboard, one teenager remarked *'just think, in about ten years time someone will invent ink and say ' Hey that's a good idea you can use it with paper and stuff"*.

The author intends to carry out further work with digital text and digital doodling for older children. This work will focus on personalization of text, both presented as digital ink and as ASCII representations.

Other work will determine the recognition rates that might be possible for composed text and a longitudinal study of the usability of digital pens.

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