Usability of tablet computers to facilitate instant written feedback

Authors and affiliations:	Dr Martyn Prigmore, University of Huddersfield Dr Duke Gledhill, University of Huddersfield

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Corresponding author:	Dr Martyn Prigmore School of Computing and Engineering University of Huddersfield Queensgate Huddersfield HD1 3DH Tel: 01484 472083 Email: m.prigmore@hud.ac.uk

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Abstract

We undertake a usability evaluation of tablet computers and handwriting capture and recognition software for use in the classroom. The aim is to assess whether the current crop of tablets and available software offer a viable platform for the immediate capture and dissemination of formative or summative written feedback. If so, then these devices could offer an effective and efficient approach to sharing feedback with our students.

We examine a range of tablet devices, covering the major operating systems and touchscreen technologies. For each device, we consider a selection of handwriting capture and recognition apps, in each case choosing the best available for a detailed usability analysis. We develop usability criteria based on Nielsen's Heuristics, refining them for the task at hand. The set of usability criteria developed should prove useful as a basis for future usability analyses of mobile technologies

Our findings indicate that there are combinations of tablet computer and handwriting capture, or recognition, software available now that are suitable for use in the classroom. The better quality combinations can be used for capturing and disseminating both formative and summative feedback. Handwriting recognition does require a tablet with an active digitizer and good quality commercial

software. Tablets with a good capacitive screen and high quality handwriting capture apps are an acceptable alternative if recognition is not required.

Introduction

Providing immediate written feedback to students on in-class presentations presents tutors with a practical problem: producing one copy for the student and one for the tutor. For group presentations the problem is multiplied, since several copies of the written feedback are required. For students and staff, ensuring prompt feedback is important; for staff, minimising the time spent copying the feedback, and having it easily available for moderation, is also important. This study investigates the feasibility of using tablet computers to capture immediate hand-written feedback in the classroom, and to disseminate this to students without delay.

Over the years the authors have tried a number of strategies to achieve these goals. Keeping the original feedback to photocopy or scan after class and giving the original to students the following week is reasonably efficient in terms of staff time, but students chafe at having to wait a whole week for feedback they know is already written. Transcribing the handwritten feedback and emailing this to students is simply too time consuming, even with voice recognition software. Scanning the feedback immediately (if the room has a scanner) and giving the original straight to the student, or nipping down to the Department office to photocopy the feedback while the student waits, achieves immediacy but is intrusive when there are several presentations in succession. In addition, scanning and photocopying are much more efficient when done in bulk.

With the move from paper-based to digital module evidence any paper-based feedback must eventually be digitised for storage in the University's document management system, so easy digitization became a further goal. In terms of digitized content plain scanned or photocopied images are less useful than text documents since the former cannot be searched and require careful indexing and use of meta-data to tie the feedback to the student, tutor and module concerned. A proper text document can easily incorporate such details into its content.

In 2008, attempting to address some of these problems, one author purchased a specialist hand-writing capture device, the ACECAD DigiMemo A402. "The DigiMemo is a stand-alone device with storage capacity that digitally captures and stores everything you write or draw with ink on ordinary paper" (ACECAD, 2006). The DigiMemo consists of a clipboard to which you can attach standard A4 paper, and a pen; both require batteries. When turned on, anything written with the pen on paper attached to the clipboard is captured by the DigiMemo and can be downloaded to a PC. The file format is proprietary but can be exported to PDF. Capturing the written feedback on the DigiMemo for staff and giving the written page straight to the student ensured that feedback was prompt and readily available in a digital form. Several years' experience with the DigiMemo demonstrated that it offers a viable solution to the problem of providing prompt feedback with easy copying and digitization.

However it does have some drawbacks. The major drawback is that the DigiMemo has no way of knowing when you move to a new paper page. The user must press a button on the device to tell it to start capturing handwriting on to a new digital page. If the user forgets then handwriting from two separate paper pages is captured on a single digital page: the paper feedback is fine, but the digital copy is indecipherable. A further drawback is that the digital pages can only be viewed by connecting the DigiMemo to a computer with specialist software installed. There was always a risk that the handwriting had not been captured and this would only be discovered after the only paper copy had been given to the student. Such a situation is unacceptable when the feedback is summative.

Handwriting capture and recognition are only one possible solution to the problem of providing immediate feedback on in-class presentations. Writing on paper and then photographing this original for immediate digital distribution via email or shared cloud storage is a simple alternative. This approach is similar to the scanning and photocopying approaches mentioned above, and suffers similar problems. Using tablet computers to type feedback is the most obvious alternative, and will be the obvious route for many teachers. However, surprisingly many people still write faster than they can type, cannot type while watching a presentation (i.e. cannot touch type, but need to watch the keyboard) or suffer joint pain after typing.

Similarly tablet computers are not the only devices that can capture handwriting. There are a number of digital note taking pens on the market. However, while these capture feedback; you must return to a computer to download the captured feedback for dissemination. Tablets wrap up both functions in an easily portable solution.

This paper reports part of a project to explore the capabilities of tablet computers to capture handwritten feedback and share this feedback with students. The work reported here used an expert usability analysis to compare a range of tablets and handwriting capture and recognition software. As the work was carried out at an English University it focuses on the capture and recognition of handwritten English. It is important to note that we expected rapid changes in the tablet market during the research and expect significant developments since we tested our last purchased tablet, the Microsoft Surface. The Methodology explains how we sought to deal with these changes. In particular we do not recommend any particular tablet, since such recommendations are best dealt with by technology journalists. Instead we focus our analysis on issues of usability in the classroom, and offer advice on features to pay attention to when choosing a tablet.

Literature review

Mobile device proliferation

In 2011 the top five smartphone manufacturers sold 491 million devices, a 61% increase on the 304 million sold in 2010 (IDC 2012c). Tablets also saw a significant rise in sales, 19 million in 2010, up to 68 million in 2011 (IDC 2012b). At Apples Q32012 earnings conference call CFO Peter Oppenheimer revealed that Apple had sold twice as many iPads as Macs to education (Apple 2012). This data suggests a large percentage of students, and their educators, are moving further towards mobile device adoption in the educational context.

Current state of the art in mobile device technology can be split into two main categories, smartphone and tablet. The general characteristics of a smartphone are small screen (<5”) and always on internet connection which doesn’t rely on Wi-Fi, e.g. 3G/4G. The general characteristics of a tablet would be large screen (>7”) and a dependence on Wi-Fi for internet connectivity. General specifications such as CPU, RAM and storage are otherwise similar. There are cross over devices which are sometimes categorised as “Phablets” which generally have a larger screen (5-6”) but with always on connectivity through 3G or similar. The most popular single tablet device is the iPad from

Apple. General characteristics are an 8.9” high resolution display, excellent battery life and a considerable software library. Android as an operating system has higher sales (IDC 2012a). The most popular include those from Samsung and Asus. Their current state of the art don’t generally have the high resolution displays of the iPad, but have more hardware specification options available to suit varying budgets. The most popular single smartphone is the iPhone from Apple, although Samsung as a company, who use Android, sold the largest number of devices. The smartphone market is similar to the tablet market where iOS devices are fewer in choice but with a large software library, and Android caters to a wider budget audience. There are also alternative device manufactures and operating system options, but these have a significantly lower market penetration (IDC 2012a).

The importance of feedback

In his book, Ramsden (2002) states that it is impossible to overstate the role of effective comments on students’ progress in any discussion of effective teaching and assessment.

It is worth defining the word feedback at this point as suggested by Ramaprasad (1983) as information about the gap between the actual level and the reference level which is then used to alter the gap in some way. Further, Sadler (1989) adds that this information about the gap can only be considered feedback if it can be used to alter the gap. Walker (2009) concludes that feedback should be usable by students and that a high proportion of comments made on assignments are unlikely to be usable. However, the paper also concludes that students use comments to alter gaps in two different ways; retrospectively for a submitted assignment, or to avoid similar gaps in future submissions. It can be surmised then that the time taken to provide feedback on the gaps can be useful in both reflection, when viewed retrospectively, and guidance, when looking forward. Reducing the time-to-feedback might also help with problems such as those suggested by Chanock (2012) in students understanding of what tutors write . A rapid feedback system would provide sufficient time for students to query any difficult to understand comments before the next submission point. Weaver (2006) suggests several ways to improve the value of feedback including ensuring it is timely . Falchikov (1995) comments that although it is important to provide timely and useful feedback, there is pressure to reduce the amount of feedback due to increasing student numbers. A system must therefore be developed which provides timely, usable, concise feedback to the students, but at the same time reduces the workload for the tutor.

Hand writing capture and recognition

Capture of handwriting is being adopted across many devices now that tablet computers are more accessible. The main touchscreen technologies in current use are capacitive and active digitizer. Some very low end devices use resistive technology.

For consumer devices, such as the iPad, capacitive touch screens allowing the use of fingers as input have replaced resistive touch screens. Resistive screens required pressure to activate (using a stylus or finger nail), whereas capacitive uses electrodes to sense the conductive properties of objects, such as a finger, making for a “softer” experience. These screens are generally not designed for accuracy so make accurate handwriting capture difficult. The more business oriented devices tend toward accurate input technologies, such as using an active digitiser from Wacom or N-trig. Although they support capacitive finger input, they also use electronic pens to capture detailed accurate handwriting. The different technologies used will be evaluated in this paper.

Automatic reading systems have evolved over the last 50 years to be very accurate at reading machine printed text, but due to the substantial variation in appearance of hand written text there are still many issues with handwriting recognition (Plötz and Fink 2009). There are several software solutions that attempt to accurately recognise handwriting which will be evaluated in this paper.

Tablets facilitate instant written feedback

In the current technological climate there is often encouragement to engage students through alternative mediums when it comes to feedback, for example using podcasts or video. Anecdotally, detailed written feedback has also been replaced in many instances with a Rubric and some general comments. Brodie (Brodie and Loch 2009) shows though that detailed written feedback is seen to be more personalised and specific.

Hence, the focus of this study is to address the question does the longer battery life and lower weight of current tablet technology mean they are now at the stage of being usable for capturing and disseminating instant written feedback in the classroom?

Methodology

Heuristics for usability testing in general

There are ten standard usability heuristics, proposed by Nielsen (HEC 2009) (Nielsen, 1994), used when designing user interfaces. These ten heuristics are a guide to designing ideal user interfaces, and can be applied to both hardware and software. While heuristic evaluation is a well-established research method in usability studies, Po et al (2004) note that the context of use has a significant effect on the heuristic evaluation of mobile technologies; they call this the "realism gap". They recommend the use of scenarios to guide expert usability analysts, arguing that scenarios may help by "sensitizing the evaluator to goal related activity" (Po et al, 2004, p.57) and so bridging the realism gap. This is a useful approach when the evaluators lack practical experience of the context, but in this study the evaluator was an experienced classroom teacher; the realism gap would not be a problem.

In this research we use Nielsen's ten heuristics as a starting point for developing our testing methodology. Although there are many proposed approaches to usability testing for mobile devices (Schusteritsch et al. 2007; Duh et al. 2006; Bertini et al. 2006; Po et al. 2004; Kjeldskov and Stage 2004; Waterson et al. 2002) the research discussed in this paper focusses on a less regulated approach. The devices are tested over a period of time, using the guidelines presented in this paper, by the academic staff member, adopting an "expert review" approach to each device. Although guided by derived usability heuristics the result is more reflective. This approach is taken because of real world constraints such as location, time and necessity of tutoring during the testing.

The research fell naturally into three stages:

Stage 1: Tablet selection

Stage 2: App selection

Stage 3: Heuristic evaluation of viable tablet / app combinations

We outline the approach taken at each stage in the following subsections.

Stage 1: Tablet selection

The market for tablet computers during the lifetime of the project was expected to be extremely volatile, and was. Early in the project Hewlett Packard released its TouchPad tablet computer running Web OS. The tablet received favourable reviews (Arthur, 2011) but within a month was being heavily discounted (Beavis, 2011) and has now been discontinued (Which?, 2011), although Web OS continues as an open source project (Open webOS, no date). Further evidence of the recent volatility in the Tablet market comes from the low end Andy Pad and Andy Pad Pro (Andy Pad, no date). These Android tablets came to market shortly after the TouchPad targeting the low end tablet market (McFerran, 2011). Although not officially discontinued the website has been reporting both tablets as out of stock for some months. Similarly the Samsung 700T is no longer available from the Samsung web site (Samsung, no date). Even product lines which continue to be marketed, such as the iPad and Samsung Galaxy Note, have released new versions during the project lifetime.

To manage this volatility it was decided early on to seek to purchase a representative range of tablets in terms of operating system, screen size, touch technology, and price. Some older tablets, already owned by the research team, were also included in the evaluation. The project budget was not released in time to acquire a HP Touchpad, but tablets running four different operating systems were purchased. The preponderance of Android tablets reflects the market at the time of purchase.

Once purchased we chose to treat the tablets like living devices: the operating systems were upgraded when possible, and all aps kept up to date. As the expert usability analysis was conducted towards the end of the project this meant that although the hardware was already dated the software was not. Table 1 lists the tablets, and the version of their operating system, used in the expert usability review. Note that the Samsung 700T was first evaluated using Windows 7 SP1, and then upgraded to Windows 8 Pro and re-evaluated.

Stage 2: App selection

Handwriting apps for tablet devices come in two forms. Input method apps both capture and recognise handwriting and insert the recognised text into other applications; e.g. the address bar of a browser, a calendar item text box, etc. Note taking apps capture the handwriting itself, and some perform handwriting recognition. All input method apps implement a “write-now-convert-now” model, where written words are recognised in real time. Note taking apps that implement handwriting recognition typically support a “write-now-convert-later” model, with some supporting the write-now-convert-now method.

Apple and Blackberry have dedicated app stores for installing apps on their tablet devices, an approach adopted by Microsoft for Windows 8 devices in tablet mode. Windows 7 has a handwriting recognition input method built into the operating system (Microsoft, 2009) and note taking applications available to be installed; this is also true of Windows 8 in its desktop mode.

Windows 8 also has handwriting capture and recognition apps available from the app store for use in tablet mode. One curious result of the split between the desktop and tablet modes in Windows 8 is that the tablet mode OneNote app only does handwriting capture, but handwriting captured using the tablet mode OneNote app can be recognised in OneNote 2013 on the desktop.

For Apple iOS devices there a number of handwriting capture and recognition apps, though no input method apps for handwritten English were found. Note that Notes Plus uses the MyScript handwriting recognition engine, though WritePad from PhatWare has its own recognition engine. For Blackberry there was only really one choice for handwriting capture and no handwriting recognition or input method apps. Table 2 list the handwriting apps considered on the iPad, Blackberry Playbook, and the Windows tablets (with the developer in parentheses).

For Android devices there are different app stores available, some tied to particular manufacturers. During the course of the research the Lenovo app store was closed down and the Android Market re-branded as the Google Play store in 2012. GetJar is the best known independent app store for Android, and the source of apps for the low-end AndyPad tablets; Getjar does not name the publisher of the app. Both the Samsung Galaxy Note phablet and Lenovo Thinkpad Android tablet came with note taking apps pre-installed: SNote from Samsung, and Myscript Notes Mobile from Vision Objects respectively. These apps are not always available on other devices. Table 3 lists the handwriting apps considered on Android tablets, including pre-installed, device specific apps.

Having downloaded a reasonable range of apps (and Windows desktop applications) for each tablet the next stage was to whittle down the list to a selection of tablet and app combinations that could be used in a classroom situation for capturing handwritten feedback. It became immediately apparent that the input method apps were unsuitable for extended note taking. Although suitable for entering search criteria or filling out web forms there was often too little space to enter extended notes. The write-now-convert-now approach of input method apps also led to problems when the conversion was incorrect, since it was too difficult to monitor the word conversions while trying to listen to, or converse with, a student.

There were also problems with the note taking apps. For example WritePad on iOS was designed as a note taking app for phones and did not scale to tablet resolutions, while on Android it was an input method app. To be worth testing as an app suitable for use in the classroom we needed to feel confident that the app would, at the very least, not interfere with student-teacher interactions. After trialling each app and comparing it to the others available for each device the best of the note taking apps were identified for heuristic evaluation. Table 4 lists the apps chosen for each tablet.

Stage 3: Heurisitic evaluation

We chose heuristic evaluation as our main research method, based on the original heuristics for assessing the usability of user interfaces developed by Jakob Nielsen (Nielsen, 1994). For each of Nielsen's heuristics key aspects of digital inking technology, such as inking mode (capture only, recognition only, or both) and the quality of the captured glyphs, were identified as significant factors in the evaluation of tablet and app combinations. A rationale was given for each of these aspects, together with an indication of whether it was an aspect of the hardware or of the handwriting capture software. The final list is shown in Table 5.

Having identified the key aspects for investigation the next task was to develop a scoring system. For each aspect a score of 0 would mean that it was absent or completely ineffective; a score of 3 would mean that it was as good as could be expected with current technology. The caveat "with current technology" is necessary since, for example, it is likely that the average weight of tablets will continue to decrease over the next few years. Table 6 shows these scores.

With the criteria for evaluation agreed the evaluator began to use the tablets to capture formative feedback in a classroom situation. This experience fed into the more formal out-of-classroom usability testing, where any failings found in the classroom could be examined more closely. For example, in the initial classroom testing of the iPad with MyScript Notes Mobile the evaluator had struggled to scroll the page as the scrollbars were hidden by default and the evaluator was unfamiliar with the two-finger-scroll mechanism in iOS. This apparent weakness was resolved during out-of-classroom testing, allowing for a more accurate evaluation of the technology.

Results and analysis

Table 7 summarizes the results of the heuristic usability evaluation. The number in the first column maps to Table 4 The selected combinations of tablet and handwriting app, with the actual tablet name included for ease of reference; only the Samsung 700T was used twice, with different operating systems. The "Score" column is the sum of the scores (see Table 6) for each tablet and "Missing" is the number of usability criteria (see Table 5) for which a score of zero was recorded. Results are ordered by score. Note that the maximum possible score was 78 (twenty-six criteria with a maximum score of 3).

The first significant divide is between tablet and app combinations that supported handwriting recognition, occupying the top eight places, and those that did not, occupying the bottom six places. The best of the capture-only combinations was the Microsoft Surface RT with the OneNote Windows Store app.

Only five criteria addressed handwriting recognition directly: 1.3, 2.6, 2.7, 5.2 and 9.1 – see Table 5 and Table 6 for details. The capture-only apps mostly scored zeroes on these criteria, though there were two exceptions: Handrite and the OneNote Windows Store app. Handrite has a PDF export, from which handwriting recognition is fairly straightforward, and the OneNote app can use cloud based OneNote notebooks making handwriting recognition easy; capturing on one device and recognising on another was a strength of OneNote. So, on 2.6 the Asus Transformer, Samsung Galaxy Tab and Microsoft Surface scored 1. On 2.7 the Surface with OneNote app scored 3, but the recognition accuracy of the Handrite PDF exports was so poor it got a zero.

However, the lack of recognition was not the only reason for the poorer performance of lower ranked tablet and app combinations. Table 8 summarizes the results when the five criteria directly addressing handwriting recognition are excluded from the data (note that the maximum score in Table 8 is 63).

The only major difference between the rank order in Table 7 and Table 8 is that the Samsung Galaxy Note with SNote and the Lenovo Thinkpad with MyScript Notes Mobile have swapped places. Heuristic 7, Flexibility and efficiency of use, was a significant factor, with SNote outscoring Myscript Notes Mobile on all three criteria. However, the consistency in the rankings clearly shows the strength of the top ranked tablet and app combinations in both handwriting capture and handwriting recognition tasks. A significant problem for the lower ranked apps is that they had no or poor documentation (10.1) and none could print notes directly (7.2). The ability to share notebooks across devices (4.1) was also generally poor (OneNote excepted) typically requiring export in another format, making it impossible to continue to edit notes on the other device.

A second significant divide evident from Table 7 is between devices with an active digitizer and those without. The top five all have active digitizers. Unsurprisingly palm rejection (5.1) was excellent on all devices with an active digitizer, although the older HP Slate 500 had some problems. On the other devices, Microsoft Surface had no palm rejection and, surprisingly, there was no way to mask a portion of the screen in the OneNote app. AntiPaper Notes and Sketchblock also lack masking capability. In these cases writing on the device with a finger worked fine, but using a stylus required a brush-hold rather than a pen-hold. This will be a familiar way of writing in some cultures, but isn't in England.

In sixth place in Table 7 are the two iPads, without an active digitizer, followed in seventh by the Samsung Galaxy Note, with active digitizer. The help documentation (10.1) in SNote was poor, reading more like marketing copy. The MyScript Notes Mobile help is not great (it scored 1) but at least aims to help rather than enthuse, so decent help documentation for SNote would have lifted the Galaxy Note above the two iPads. A more serious problem in SNote was that word recognition was final making correction tricky (9.1); MyScript Notes Mobile allowed a choice from alternatives. However SNote had the better digital notebook user interface (6.1). It is notable that even with a small form factor an active digitizer enables the Galaxy Note to function very effectively as a handwriting capture device.

At the bottom of Table 7 and Table 8 there was further evidence that a plain capacitive screen is not the best choice for handwriting capture and recognition tasks. The AndyPad, with a plain resistive screen, performed slightly better than the more expensive AndyPad Pro, with a capacitive screen. The resistive screen led to better glyph quality (2.3) and words per line (2.4). The AndyPad Pro capacitive screen would not respond well to any of the capacitive styluses tried; only a finger worked reliably.

The final significant divide in the results is between OneNote and other note taking software. The top four devices all used a full version of OneNote. Even on the older HP Slate 500 OneNote 2013 clearly outperforms MyScript Notes Mobile and SNote. Oddly OneNote 2010 scores slightly better than OneNote 2013 on the same Samsung 700T tablet, though running on a different version of windows. The reason for this is that when testing the Samsung 700T with Windows 7 and OneNote 2010 it was possible to choose between different predictions for recognised words, and to add new words to the handwriting dictionary. This only worked for text where the original ink had been written into, and recognised by, OneNote. Text written using the handwriting input panel, and inserted into OneNote, did not store alternative choices. Under Windows 8 with Office 365 OneNote 2013 the situation is reversed: text recognised from ink written in OneNote does not have choices, text from the input panel does. It is not clear why this difference exists, it may be a difference between the professional and home/student editions of the MS Office suite. However, it is certainly confusing for end users.

Conclusions and recommendations

Providing immediate, hand-written feedback to students on in-class presentations provides one approach to ensuring students get timely feedback on their work. The outcomes of this study suggest that the best technology for handwriting capture and recognition using a tablet computer is a combination of a tablet with an active digitizer and either OneNote on a Windows tablet or MyScript Notes Mobile on an Android tablet. If you must use a capacitive screen for handwriting capture and recognition choose a high quality one and use good software. The quality of the capacitive screen and app will help compensate for the shortcomings of capacitive screens for handwriting capture. If only handwriting capture is required then an iPad or good quality Android capacitive tablet (e.g. the Samsung Galaxy Tab) with MyScript Notes Mobile are good solutions. The quality of the captured handwriting should be high enough to send the notes directly to students.

Both Microsoft OneNote (2010 and 2013) and MyScript Notes Mobile or MyScript Memo from Vision Objects proved effective for both handwriting capture and recognition. For capture only you might try a selection of the free apps to see whether they work for you, although with free versions of either MyScript Memo or the OneNote Windows Store app available for all three tablet operating systems the alternatives need to offer something distinctive to compete.

With all but the bottom three ranked tablets the quality of the captured handwriting was good enough to send direct to the students, and the apps provided an easy way to do this. When emailing recognised text from the Lenovo Thinkpad using MyScript Notes Mobile the author tended to send it to their own email first to correct errors in recognition, since this version of the app did not accept keyboard input. The iPad version of MyScript Notes Mobile does allow the recognised text to be corrected before emailing. It is worth checking whether this is possible before purchasing a copy of an app; many have a “try before you buy” option.

The inconsistency between versions of handwriting recognition software is perhaps one of the most annoying aspects of trying to use a tablet computer to capture and recognise handwritten feedback. Otherwise the technology seems usable and ready for the classroom.

Finally, the research extends Nielsen’s original usability heuristics, providing specialist criteria for the evaluation of mobile devices used for handwriting capture and recognition tasks. This small project has demonstrated that they form a workable set of criteria, with some consistency in outcomes across capture and recognition tasks. We hope to further validate their utility in future work, and hope they will prove useful to other researchers.

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Tables

Table 1 Specifications of the tablets

	Operating system	Screen	Capacitive / Resistive	Multi-touch	Active digitizer	Processor
AndyPad	Android 4.0.3	7”	Resistive	No	No	RK2918 Cortex A8 1.2GHz clocked at 1GHz
AndyPad Pro	Android 4.0.3	7”	Capacitive	Yes	No	RK2918 Cortex A8 1.2GHz clocked at 1GHz

Apple iPad2	iOS 6.0.1	8.9"	Capacitive	Yes	No	A5 1Ghz
Apple iPad Mini	iOS 6.1.3	7.9"	Capacitive	Yes	No	A5
Armor X7	Windows 7	7"	Resistive	No	Yes	Intel® Pineview-M 1.6GHz Single Core
Asus Transformer	Android 4.0.3	10.1"	Capacitive	Yes	No	1Ghz Tegra 2
Blackberry Playbook	Blackberry OS	7"	Capactive	Yes	No	1Ghz A9
HP Slate 500	Windows 7	8.9"	Capacitive Pen Hybrid (N-Trig)	Yes	Yes	Atom Processor @ 1.8Ghz
Lenovo Thinkpad	Android 4.0.3	10.1"	Capacitive	Yes	Yes	Tegra 2 Dual-Core 1GHz processor
Microsoft Surface RT	Windows RT	10.6	Capacitive	Yes	No	Tegra 3 Quad-core
Samsung Galaxy Note	Android 4.0.4	5.3"	Capacitive	Yes	Yes	Exynos 1.4Ghz Dual Core A9
Samsung Galaxy Tab 7.7	Android 4.0.4	7.7"	Capacitive	Yes	No	Tegra 3
Samsung 700T	Windows 7 SP1 Windows 8 Pro	11.6"	Capacitive	Yes	Yes	Intel® Core™ i5 Processor 2467M

Table 2 Apps for Windows, iOS and Blackberry tablets

	Input method apps	**Note taking apps Capture only**	**Note taking apps Capture and recognition**
iOS	None available	Use your handwriting (Gee Whiz Stuff) Notability (Ginger Labs) Jotter (groosoft) Noteshelf (Rama Krishna)	MyScript Memo (Vision Objects) Notes Mobile (Vision Objects) Notes Plus (Viet Tran) WritePad (PhatWare)
Blackberry	None available	SketchBlock (Mike Barkin)	
Windows 7	Built-in		OneNote (Microsoft) MyScript Notes (Vision Objects)
Windows 8 Desktop mode	Built-in		OneNote (Microsoft) OneNote 2013 RT (Microsoft)
Windows 8 Tablet mode	Built-in	Advanced Notes Pro (Angelo G Del Regno) Note Anytime (MetaMoji Corp) OneNote app (Microsoft)	PhatPad (PhatWare)

Table 3 Apps for Android tablets

	Input method apps	**Note taking apps**	**Note taking apps**

		Capture only	Capture & recognition
Google Play	Graffiti Pro (Access) Pen Reader (Paragon) G-board (AppScore) WritePad (PhatWare)	Antipaper Notes (Hubert OG) Handrite (NC Corp) FreeNote (Flyable) Genial Writing (Zenpie Studio)	MyScript Notes Mobile (Vision Objects)
GetJar	Graffiti	GNotes Handrite Genial Writing Antipaper Notes	
Galaxy Note pre-installed	Samsung keyboard (Samsung)		SNote (Samsung)
Samsung Apps		Handrite (Furong Li)	PhatPad (PhatWare)
Thinkpad pre-installed			MyScript Notes Mobile (Vision Objects)
Lenovo Marketplace	MyScript Stylus Mobile (Vision Objects)	Quill (Volker Braun) FreeNote (suishouxie)	

Table 4 The selected combinations of tablet and handwriting app

	Tablet	Operating system	Note taking app	Recognition
01	AndyPad	Android 4.0.3	Antipaper Notes	No
02	AndyPad Pro	Android 4.0.3	Antipaper Notes	No
03	Apple iPad 2	iOS 6.0.1	MyScript Notes Mobile	Yes
04	Apple iPad Mini	iOS 6.1.3	MyScript Notes Mobile	Yes
05	Armor X7	Windows 7 SP1	OneNote 2010	Yes
06	Asus Transformer	Android 4.0.3	Handrite	No
07	Blackberry Playbook	OS 2.1	SketchBlock	No
08	HP Slate 500	Windows 8	OneNote 2013	Yes
09	Lenovo Thinkpad	Android 4.0.3	MyScript Notes Mobile	Yes
10	Microsoft Surface	Windows 8 RT	OneNote Windows Store app	No
11	Samsung Galaxy Note	Android 4.0.4	SNote	Yes
12	Samsung Galaxy Tab 7.7	Andriod 4.0.4	Handrite	No
13	Samsung 700T	Windows 7 SP1	OneNote 2010	Yes
14	Samsung 700T	Windows 8 Pro	Office 365 OneNote 2013	Yes

Table 5 Usability criteria for evaluation of classroom based note taking technologies

		Aspect of digital inking technology	Hardware Software	Rationale
Visibility of system status	1.1	Battery life (indicator)	H	System should keep user aware of remaining battery life to avoid unexpected loss of system and data
	1.2	Sleep mode	H	User should be able to tell quickly if the hardware is on / off / sleeping

	1.3	Inking mode	S	It should be clear whether the system is simply capturing handwriting, or doing text recognition
Match between system and real world	2.1	Digital notebook UI (Pages)	S	The software should mimic a pen-and-paper experience with choice of lined, graph, plain etc.
	2.2	Digital notebook UI (Books)	S	The software should allow users to group notes into notebooks
	2.3	Handwriting capture (glyph quality)	H & S	The software should mimic a pen-and-paper experience with smooth lines and variable thickness/density due to nib pressure. It should respond quickly and accurately to inking
	2.4	Handwriting capture (font size and words per line)	H & S	The software should mimic a pen-and-paper experience capturing typical letter sizes and fitting typical words per line
	2.5	Size and weight	H	Similar weight/size to comparable paper notebooks
	2.6	Handwriting recognition (ink to text ability)	H & S	The handwriting capture device should support handwriting recognition to mimic typing, though possibly via third-party software
	2.7	Handwriting recognition (accuracy/quality)	S	The handwriting recognition software should accurately recognise written glyphs; writing should be as easy as typing
User control and freedom	3.1	Sharing (Collaboration)	S	Users should be able to share notes and notebooks. The software should allow other user's to annotate already inked pages, clearly distinguishing the different author's e.g. by different ink colour
	3.2	Cross platform support (Devices)	H & S	Users should be able to access their notes from a range of devices

	3.3	Battery life	H	Battery should last for a typical working day
	3.4	Handwriting capture (error correction)	H & S	Allow the user to easily erase digital ink, ideally with an "eraser" on the pen, otherwise with a software eraser
Consistency and standards	4.1	Cross platform support (OS)	S	The software should ideally be cross-platform and should adapt to follow local OS conventions
	4.2	Handwritten annotation of images/documents	S	Inking on an image or other document should be the same as inking on a blank page
Error prevention	5.1	Palm rejection / masking	H & S	Resting the hand on the writing surface should not interfere with writing, or cause smudges
	5.2	Handwriting recognition (Word prediction)	S	System should keep user informed of the predicted word and allow choice between alternative predictions
Recognition rather than recall	6.1	Digital notebook UI (Books)	H & S	The software should mimic a pen-and-paper experience in terms of inking and page navigation
Flexibility and efficiency of use	7.1	Sharing (export)	S	Users should be able to share notes and notebooks, e.g. by email, in a range of standard file formats
	7.2	Sharing (Print)	S	Users should be able to easily print notes and notebooks
	7.3	Digital notebook UI (alternative input methods)	H & S	Users should be able to use traditional input methods, e.g. a keyboard to type on notes pages
Aesthetic and minimalist design	8.1	Mobile device	H	Device should be comfortable to hold and use within a classroom environment. This includes the overall shape, non-slip surfaces, "curves", thickness, bezel width, placement of hardware / software buttons, etc.
	8.2	Digital notebook UI	S	The UI should make locating

				notebooks and notes intuitive without laboured metaphors
Help users recognise, diagnose, and recover from errors	9.1	Handwriting recognition (error correction)	S	For converted text the system should remember the alternative predicted words and allow user change their choice
Help and documentation	10.1	Help and documentation	H & S	Help should provide task-focused support to both novice and experienced users

Table 6 Scoring system for the usability criteria

	0	**1**	**2**	**3**
1.1	No indicator	Hardware low battery warning	Software charge indicator	Both hardware low battery warning and software charge indicator
1.2	No indicator	Hardware sleep mode indicator	Software sleep- mode indicator	Both hardware and software sleep- mode indicator
1.3	No indicator	Hardware inking mode indicator	Software inking mode indicator	Both hardware and software inking mode indicator
2.1	No choice of page style	Page style available using image import	Built in page styles only	Built in and custom page styles available
2.2	No mechanism for grouping notes	Multi-page notes	Can group notes into books, and manage separately	Full ability to group notes into books, sections and subsections
2.3	Unusable due to poor quality glyphs (e.g. Artefacts, jagged)	Effective capture when writing slowly, but low detail glyphs.	Effective capture at normal speed.	Paper like detail at normal speed. Nib pressure adjusts ink thickness / density
2.4	Poor words per line (<=3)	Acceptable words per line (~5). (e.g. like writing on a	Reasonable words per line (>5) (e.g. like writing on paper with	Paper like i.e. normal size writing, with similar words per line for same size paper

		chalk slate)	a felt tip pen)	(e.g. like writing on paper with a biro)
2.5	>1kg	>800g	>600g	<600g
2.6	No recognition	Post capture recognition using separate software or different device	Post capture recognition built into the software	Real-time recognition
2.7	It would be quicker to type	Recognition is acceptable (i.e. faster than typing) but corrections needed even with reasonably neat handwriting	Recognises most words correctly with reasonably neat handwriting	Recognises most words correctly even with slightly scrappy handwriting
3.1	No sharing ability within the software, though files can be saved locally and then shared	Ability to share a notebook from within the application using e.g. email, Evernote, Drop-box	Ability to access and modify a notebook in a shared location from within the application (e.g. Drop-box, SkyDrive)	Ability to collaborate using a shared notebook, with multiple author support and real-time sync
3.2	Single device	Single manufacturer	Available on all devices running a given OS	Available on all devices running two or more OS
3.3	< 4hrs	4 hours but unable to charge over lunch for another 4 hours in same day	All day battery life (always on wifi and screen) top-up charge required	All day battery life (always on wifi and screen, continuous use) no top-up charge
3.4	No erase or undo / redo	Supports one of erase or undo / redo, but not both	Undo / redo and software eraser	Undo / redo and both software and hardware pen eraser
4.1	Single platform	Multi-platform for text but cannot view hand written notes	Multi-platform; hand written notes view only on some of the platforms	Multi-platform with few limitations
4.2	No ability to annotate	Ability to use handwriting to annotate screenshots or	Ability to use handwriting to annotate screenshots or other images, and	Ability to use handwriting and text and highlighting to annotate screenshots

		other images	documents	or other images, and documents
5.1	Poor palm rejection or ineffective masking	Ability to effectively mask area of screen	Good palm rejection (some errors)	Excellent palm rejection (no errors)
5.2	No word prediction.	Ineffective or intrusive mechanism for choosing between predicted words.	Predicts words and offers choices using an effective mechanism. Does not adapt choices based on previous user input (no learning).	Predicts words and offers choices using an effective mechanism. Adapts choices based on previous user input.
6.1	No "book" metaphor	Uses a familiar metaphor for inking (e.g. lined pages) or for page navigation (e.g. address-book style tabs)	Uses a familiar metaphor for inking and page navigation	Uses a familiar metaphor for inking and page navigation and adapts effectively to smart-pen input device
7.1	No sharing options in the software	Save to a common format and then email or move file	In-app export and sharing using a limited range of formats	In-app export and sharing using a wide range of formats
7.2	No direct ability to print (export first)	Printing via connected device	Printing via local network	Printing via the cloud
7.3	No support for keyboard input into digital notebook	Software keyboard only	Keyboard/mouse (possibly requiring separate charge) but impairs the tablet experience in use	Integrated keyboard/mouse combo which does not affect the use of the tablet in tablet mode
8.1	Poor in majority of categories	Good in some, poor in others	Good in most categories	Exemplar in each of the categories
8.2	Unclear (e.g. cluttered) or poorly organised UI	Some problems with clarity or organization	Clear and well organised UI. However, does not follow OS user interface conventions	Clear and well organised UI. Follows OS user interface conventions

9.1	Word recognition is final; original ink and alternative predicted text are not linked to the text, or no alternatives are available	Undo facility allows the last recognised word to be reverted to the original ink, and a different choice of predicted text made	Individual words within recognised text can be selected and a different choice of predicted text made	In addition any word can be selected and compared to the original ink (makes subsequent editing of the text easier)
10.1	No, or poor, documentation	Clear and easy to use documentation accessible at a separate location (e.g. online, paper)	Clear and easy to use documentation accessible within the software	Clear and easy to use documentation accessible within the software with appropriate additional materials online

Table 7 Summary results in order of their score

	Tablet	Score	Missing	Mode	Median	Mean
13	Samsung 700T Win7	65	0	3	3	2.5
14	Samsung 700T Win8	62	0	3	2.5	2.4
05	Armor X7	60	1	3	2	2.3
08	HP Slate 500	54	1	2	2	2.1
09	Lenovo Thinkpad	47	4	2	2	1.8
03	Apple iPad 2	46	3	2	2	1.8
04	Apple iPad Mini	46	3	2	2	1.8
11	Samsung Galaxy Note	45	6	2	2	1.7
10	Microsoft Surface	40	8	2	2	1.5
12	Samsung Galaxy Tab 7.7	31	10	0	1	1.2
06	Asus Transformer	30	10	0	1	1.2
01	AndyPad	25	12	0	1	1.0
02	AndyPad Pro	22	13	0	0.5	0.8
07	Blackberry Playbook	18	17	0	0	0.7

Table 8 Summary of results excluding handwriting recognition criteria (1.3, 2.6, 2.7, 5.2 and 9.1)

		Score	Missing	Mode	Median	Mean
13	Samsung 700T	52	0	3	3	2.5
14	Samsung 700T	52	0	3	3	2.5
05	Armor X7	48	1	3	2	2.3
08	HP Slate 500	45	1	2	2	2.1
11	Samsung Galaxy Note	40	3	2	2	1.9
03	Apple iPad 2	38	2	2	2	1.8

04	Apple iPad Mini	38	2	3	2	1.8
09	Lenovo Thinkpad	37	4	2	2	1.8
10	Microsoft Surface	36	5	2	2	1.7
12	Samsung Galaxy Tab 7.7	30	6	2	2	1.4
06	Asus Transformer	29	6	2	2	1.4
01	AndyPad	25	7	2	1	1.2
02	AndyPad Pro	22	8	0	1	1.0
07	Blackberry Playbook	18	12	0	0	0.9