Taking class notes by hand compared to typing: effects on children's recall and understanding

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Abstract

The increasing adoption of educational technology in school classrooms has resulted in greater use of electronic devices to take lesson notes. Recent research comparing performance of adult students who recorded lecture notes using computer keyboards or by handwriting reports somewhat conflicting findings on their factual recall and conceptual understanding. There is very little, if any, research in children on the effect of mode of note-taking on recall and understanding. The present study compared the recall and understanding of children taking handwritten notes or typing their notes. Twenty-six boys aged 10-11 years old participated in the study. Factual recall and understanding of a history and a biology lesson were assessed using multiple choice questions (MCQ). MCQ tests were carried out both immediately after each lesson and one week later. Factual recall was not affected by the mode of note-taking but, in both lessons, children who handwrote notes had greater conceptual understanding one week after viewing their lesson, compared to those who typed notes. This is the first study to assess the effect of mode of note-taking on children's understanding and our findings have implications for educational policy on the use of keyboards to take notes.

Keywords: handwriting, typing, understanding, recall, children

Introduction

Note-taking is a commonly observed classroom behaviour and plays an important role in student learning (Palmatier & Bennet, 1974). Many adult learners take notes using educational technology such as laptops (Morehead, Dunlosky, Rawson, Blasiman, & Hollis, 2019). There is some debate about the benefits provided by educational technology in the lecture room or school classroom, but it must be applied usefully and appropriately to impact positively on learning (Bouygues, 2019). In the case of children in schools, around the world areas are implementing policies that phase out handwriting and encourage children to keyboard instead (Russell, 2015; Shapiro, 2013). Some recent studies in adults have found that the mode of note-taking – by keyboard or by hand – can impact on learning (Morehead, Dunlosky, & Rawson, 2019; Mueller & Oppenheimer, 2014, 2018). However, no studies to date have considered how children's learning is affected when they keyboard or handwrite their notes. The aim of our studies was to investigate the effect that different modes of note-taking have on children's learning about facts and concepts, both immediately after learning and after a delay.

Note-taking has been a common classroom behaviour for many years (Palmatier & Bennet, 1974). A recent survey reported that students today still take notes during classes, a process which they believe is important for their own effective learning (Morehead, Dunlosky, Rawson, et al., 2019). In contrast to the traditional mode of note-taking that used notebooks to record notes by hand, many of today's students engage with educational technology to record notes, using for example, laptop computers (Morehead, Dunlosky, Rawson, et al., 2019). The use of educational technology in university lecture halls and school classrooms has been growing over recent years. Around the world, there has been an increasing move to embed educational technology in schools for children to use while learning through the early years before further and higher education. In the USA, the National Educational Technology plan details policies for learning enabled by technology (US

Department of Education, 2017). Recently in the UK, there has been a call for new technology to spearhead a classroom revolution (Department for Education, 2018).

In order that educational technology, such as laptops and other devices, to be a success in the classroom in that it supports students learning, it is important that it is applied appropriately (Luckin et al., 2012). Just introducing technology into classrooms, without thought to how it will be used, may not result in positive impacts on learning. One reason for this is that computers can be distracting as they allow access to off-task activities such as games, email and/or social media (Glass & Kang, 2018; Hembrooke & Gay, 2003). For example, one study found that students who used laptops for lecture note-taking were off task for nearly two thirds of the time (Ragan, Jennings, Massey, & Doolittle, 2014), and others have reported that students using computers in university classrooms is associated with lower grades (Carter, Greenberg, & Walker, 2017; Patterson & Patterson, 2017). Simply being able to see the screen of a multi-tasking student can negatively affect test performance (Sana, Weston, & Cepeda, 2013). However, Luckin et al (2012) argue that it is the way in which educational technology is used that influences the question of whether it will positively impact learning. For example, the use of interactive whiteboards can support learning by incorporating digital materials and encouraging discussion between teachers and learners (Hennessy, 2011); using innovative online games to practice mathematical principles such as division and multiplication (Habgood & Ainsworth, 2011); and learning about animal behaviour via a computer game (Facer et al., 2004).

The question of whether the use of educational technology in the classroom, such as laptop computers, results in gains in student learning is complex. An analysis of international data is possible by analysing the performance of students on the Programme for International Student Assessment (PISA) in 30 countries, alongside national computer-to-student ratios and reports of student internet use (Bouygues, 2019). The results showed a complex relationship between these variables. For example, while an increase in the number of computers available in schools is associated with poorer PISA scores, this relationship is not linear and a low-to-moderate use of school computers is linked to the best PISA test performance. Internet use was also related to PISA results; for example, in French schoolchildren, less than 30 minutes per day was linked to better scores compared to children who did not use the internet, but in contrast, excessive internet use (more than 6 hours a day) was linked to poorer PISA scores. Bouygues (2019) suggest that if not applied in a useful and appropriate way, educational technology may not result in richer forms of learning, and teachers should deploy it carefully in the classroom.

One application of educational technology in schools that is pertinent to the present studies is the increased use of computers in the classroom, with children keyboarding where traditionally they may have handwritten their notes. Some educational systems have encouraged this to the extent that they are phasing out the teaching of handwriting in favour of developing keyboarding skills. In many US states, cursive writing is no longer taught because it is not compulsory under the US Common Core Standards for schools. Instead, once printed writing is introduced, schools promote the use of keyboards (Shapiro, 2013). Similarly, in Finland, cursive writing is no longer taught and pupils are taught how to use keyboards instead (Russell, 2015). In contrast, in the UK, developing handwriting skills remains a key part of the national curriculum (Department for Education, 2013).

While the introduction into classrooms of laptop computers for note-taking may be a growing trend across age groups, the impact of taking notes either by hand or by keyboard on learning has recently been considered. Mueller and Oppenheimer (2014) compared the performance of university students who took notes by hand with those who made notes on a laptop (also see Mueller & Oppenheimer, 2018). They found that both handwriting and keyboarding students performed equally well when tested on factual recall of the lecture after an “immediate” test (that occurred after a 30 minute break), but the group who took handwritten notes performed significantly better when tested on their conceptual understanding. When tested one week later using the same questions, students who made handwritten notes performed better at both factual recall and conceptual understanding. A replication of Mueller and Oppenheimer’s study found slightly different results. Morehead, Dunlosky, and Rawson (2019) reported a handwriting advantage for factual recall at an immediate test (after 30 minutes, where Muller & Oppenheimer found no difference), and no differences in mode of note-taking when conceptual understanding was assessed after 30 minutes (in which Mueller & Oppenheimer found an advantage for handwriting). After 2 days delay, Morehead, Dunlosky, and Rawson (2019) found no difference in factual or conceptual understanding by mode of note-taking, in contrast to Mueller and Oppenheimer who, after a delay of one week, found an advantage for handwriting in both factual and conceptual understanding, when participants were given the opportunity to review their notes

What could explain the differences in results between these two studies? While the methods might at first glance appear to be very similar, there was one major differences in the procedures that might explain the differences in results. The length of the delay between the immediate and delayed test was not the same in the two studies; in the case of Mueller & Oppenheimer the delay was one week, but in the case of Morehead et al the delay was 2 days. These differences in study timings could have impacted on learning across the delay, that might vary by the note-taking condition in which participants took part. It is plausible that a shorter delay offers less opportunity to review notes. If handwriting were particularly likely to be associated with improved learning over time, differences in the interval between learning and test could explain why the study with the longer delay found a handwriting advantage (Mueller & Oppenheimer, 2014), while the study with the shorter delay found no such advantage (Morehead, Dunlosky, Rawson, et al., 2019).

Why might handwriting result in improved learning compared to keyboarding, particularly with regards to conceptual learning? One suggestion is that this is related to the quality and quantity of notes taken under the two note-taking regimes. Adults record more notes when using laptops and these tend to be more verbatim in style, compared to notes taken when handwriting (Luo, Kiewra, Flanigan, & Peteranetz, 2018). Verbatim note-taking is indicative of more shallow processing, and as a consequence, is less likely to be remembered (Craik & Lockhart, 1972; Kiewra, 1985). In contrast, handwritten notes often include generative, non-linear notes, such as concept maps, which require a selective and thoughtful approach to their creation (Piolat, Olive, & Kellogg, 2005). However, there is not consensus on the benefit of concept mapping, with some studies showing it is inferior to retrieval practice for recall of material (Karpicke & Blunt, 2011; Lechuga, Ortega-Tudela, & Gómez-Ariza, 2015), but this is also influenced by prior training in concept mapping (Lechuga et al., 2015).

Rationale of the present studies

While there is a clear drive to increase the use of educational technology, including laptops, in schools, there is limited research examining how making notes using different methods might affect children's understanding. The effect of taking classroom notes either by keyboarding or handwriting on understanding has been examined in adults and has suggested some advantages for handwriting, although the findings are mixed. It is of note that, to date, the effect of mode of note-taking on children's understanding has not been explored. The present studies broadly replicate the procedure outlined by Mueller & Oppenheimer (2014); children used either keyboards or handwriting to take notes, and factual and conceptual understanding was assessed immediately after the lesson and after a delay of one week. There are two notable differences in the present studies. Firstly, instead of testing in the lab using TED talks, in the present studies, material usually used in teaching was presented to the children. Secondly, the teaching and testing took place in the children's regular classroom, and they were instructed by their regular classroom teacher.

Study 1 examined mode of note-taking in a History lesson and Study 2 was based in a Biology lesson that took place one month later. Participants used one note-taking method in Study 1 and switched to the other method in Study 2.

As studies examining immediate recall (after 30 minutes) show inconsistent findings concerning whether or not handwriting notes leads to better factual and conceptual understanding, there is no consensus about the likely direction of the effect of mode of note-taking at immediate test. Instead, our results will add to the body of evidence. However, we can make directional predictions for the delayed test. Our delayed condition took place after one week, and thus consistent with Mueller and Oppenheimer, we expect to show a handwriting superiority effect at one week post lesson, for both factual and conceptual understanding. Previous studies reported that adults made more notes when typing, we predict that is it likely that a similar finding will be observed in children.

Method

Participants

Twenty-six participants took part in Study 1 and 23 participated in Study 2: this reduced number was a result of absence from lessons. All participants were boys aged between 10 and 11 years of age. Participants had undertaken basic touch typing training at school when they were aged 8 and 9 years old. This allowed them to know the position of letters on a standard QWERTY keyboard, but they had not had formal touch typing training at the school for at least one academic year. None of the boys had been identified as having a special educational need or disability. Informed consent was obtained from all parents/caregivers and informed assent was obtained from all children. Full ethical approval for this study was granted by the School of Psychology UEL ethics committee.

Materials and Procedure

Lesson materials. The three videos were selected from those already in use in the school's curriculum. For the History lesson, two videos about the Black Death plague were presented, which were 18 minutes and 12 minutes long (CwnEnvironment, 2012; RonRbc, 2011). For the Biology lesson, a single video about cells was shown, which was 19 minutes in duration (Lammas Science, 2012).

Multiple-choice questionnaires were prepared for the History and Biology lessons by the children's regular history and science teachers. Questions were designed to ensure recall of important facts (e.g. Where is it thought that the Black Death started?) and understanding of their importance and relevance (e.g. Why were the wealthy less likely to be afflicted by plague?). These were not standardised tests and thus the actual scores are not directly comparable, which is why data for history (Study 1) and biology (Study 2) are presented separately.

The history study used 28 questions with four possible answer options. Of these questions, 18 were designed to test factual recall of the material and 10 to test conceptual understanding. These questions were inter-mingled.

The biology study used 25 questions with four possible answer options. Of these questions, 17 tested factual recall of the material and 8 tested conceptual understanding; they were intermingled.

The varying number of questions between the history lesson assessment and the biology lesson assessment reflected the longer video material that was shown to the participants in the history lesson. The larger number of factual questions compared to understanding questions reflected the content of the videos and the skills required for learning at this stage of the participants' schooling.

All pupils were provided with Chrome Book laptop computers on which they recorded lesson notes in the keyboarding condition. Notes were taken using the Google Docs application.

Procedure

For Study One: History, the participants were randomly allocated into conditions by class (group n=13) and both watched two videos on the "Black Death". One group recorded notes about the lesson using pen and paper. The other took their notes using laptop computers. The handwriting and keyboarding groups were assessed in separate rooms. In line with normal lesson procedure, no advice was given to the participants as to the amount of detail or structure required in the notes. They were informed that there would be a test immediately after the lesson. All participants watched the lesson in their normal classroom environment.

Immediately after the video lesson, participants completed a multiple-choice questionnaire to test their knowledge and understanding. No feedback was given. Participants were allowed to take either their handwritten notes or a printed copy of their laptop notes away with them after the lesson for revision purposes. Thus, they were told that they could revise but were not instructed to do so – all participants in each condition and study were given the same information about revision.

The second test took place one week later, prior to which, pupils were encouraged, though not required, to review the notes that they had made. All children received the same instructions about reviewing notes. They were retested using the same questions. At the end of the second test, participants' notes were collected to monitor the length of notes in words.

Study Two: Biology took place one month later. The same children took part in Study 2 and the note-taking mode was swapped. Due to pupil absence, the group sizes were slightly smaller (Keyboard, n=12; Handwriting, n=11). The same procedure regarding questionnaires, feedback, re-testing and collection of notes was used as that adopted in Study 1.

Statistical Analysis

In order to assess participants' understanding, a series of mixed model Analyses of Variances (ANOVAs) were conducted: Mode of note-taking (handwriting, keyboarding) was a between subjects factor, and time of test (immediate, delayed) was a within subjects factor. Four such mixed model ANOVAs were conducted; assessing factual understanding in Study 1 and Study 2, and conceptual understanding in Study 1 and Study 2. Planned comparisons compared handwriting and note-taking at each timepoint and the Bonferroni correction for multiple tests was employed with an alpha level of 0.025 (0.05/2 comparisons). Note quantity under the two conditions was compared by summing the number of words recorded and conducting independent samples t-tests.

Results

Study One: History

Mean scores and standard deviations for factual and conceptual understanding in the two note-taking conditions are shown in Table 1.

[Table 1 near here]

History: Factual understanding. Visual inspection of the means suggests that scores were very similar across mode of note-taking conditions and time of test. These impressions were supported by the analysis. There was no effect of time of test, F (1,24) = 0.933, p = 0.344, Ƞp^2 = 0.037, no effect of mode of note-taking, F(1,24) = 0.532, p = 0.473, Ƞp^2 = 0.022, and the interaction was not significant, F(1,24) = 2.31, p = 0.142, Ƞp^2 = 0.088.

History: Conceptual understanding. In contrast, looking at the mean scores for conceptual understanding, it would seem that higher scores were obtained when handwriting, and that scores in the handwriting condition improved after a week. These interpretations were supported by the analysis, with a significant main effect of mode of note-taking, F(1,24) = 7.70, p = 0.011, Ƞp^2 = 0.243, with higher scores under conditions of handwriting compared to keyboarding. This main effect should be interpreted in the light of the significant interaction, F(1,24) = 11.542, p = 0.002, Ƞp^2 = 0.325. Follow up tests showed no difference between note-taking groups immediately after the lesson, t(24) = 0.75, p = 0.461, but the handwriting group significantly outperformed the typewriting group one week later, t(24) = 3.99, p = 0.001. The main effect of time of test was not significant, F(1,24) = 0.196, p = 0.662, Ƞp^2 = 0.008

History: Word Count. The mean word count in the handwriting condition was 201.92 words (*SD* = 66.52) and in the keyboarding condition, the mean word count was 223.31 words (*SD* = 70.72). Although the mean word count is slightly higher in the keyboarding condition, the difference was not statistically significant, t(24) = 0.79, p = 0.436.

Study Two: Biology

The mean scores for the factual and conceptual understanding scores under the two note-taking conditions are shown in Table 2.

Biology: Factual understanding. Visual inspection of the data presented in Table 2 suggests that scores improved after one week compared to immediate test in both note-taking conditions, and that scores were higher for children who handwrote notes. These impressions were supported by the analyses, with significantly higher scores at the second test, one week after the lesson, $F(1,21) = 24.83$, $p < 0.001$, $\eta p^2 = 0.542$. The difference between mode of note-taking was marginal, $F(1,21) = 4.15$, $p = 0.054$, ηp^2, and the interaction was not significant, $F(1,21) = 3.59$, $p = 0.072$, $\eta p^2 = 0.146$.

Biology: Conceptual understanding. Examining the conceptual understanding scores for the biology lesson suggests that notes taken when handwriting result in higher scores. Furthermore, there appears to be an increase over time for the handwriting group, while the keyboarding groups' scores do not change over time. The analyses supported these impressions. The handwriting group outperformed the keyboarding group on conceptual understanding scores, $F(1,21) = 8.18$, $p = 0.009$, $\eta p^2 = 0.280$. The main effect of time of test was not statistically significant, $F(1,21) = 1.06$, $p = 0.316$, $\eta p^2 = 0.048$. The interaction between time of test and mode of note-taking was not significant, $F(1,21)$ 4.23, $p = 0.052$, $\eta p^2 = 0.168$. Visual inspection of data presented in Table 2 suggests an advantage for handwriting over keyboarding in the delayed test, thus we completed planned comparisons to fully explore the data. Immediately after the lesson, there was no significant difference in conceptual understanding between the two note-taking groups, $t(21) = 1.32$, $p = 0.203$. However, one week later, the handwriting group understood had significantly higher conceptual understanding scores compared to the keyboarding group, $t(21) = 3.26$, $p = 0.004$.

Biology: Word Count. The mean word count for those who took notes by handwriting was 224.82 words (SD = 31.57) and for the keyboarding group, the mean word count was 213.25 words (SD = 37.42). There was no statistically significant difference in word count between conditions, $t(21) = 0.80$, $p = 0.434$.

Post-hoc cross-study comparison. While the actual scores achieved on the two tests are not directly comparable, having slightly different numbers of factual and conceptual questions, and examining quite different material, it is interesting to informally consider whether mode of note-taking and time of test affected performance in a similar manner for both subjects. To summarise, our results did not show a significant effect of mode of note-taking on factual understanding in either the history or the biology lesson. In contrast, conceptual understanding, was better in children who handwrote notes compared to typing, in both history and biology lessons, when tested one week after the lesson. In order to make a fair cross-study comparison of the effect of note-taking on conceptual understanding scores at one week post-lesson, we calculated effect sizes (Cohen's d) for this comparison in each study. Thus, we can compare the effect sizes across studies without directly comparing the scores. The effect size for this comparison in the history lesson was 1.597, while in the biology lesson it was 1.346. Both of these Cohen's d values can be categorised as "very large" (Sawilowsky, 2009). This suggests that children's conceptual understanding was similarly affected by the model of note-taking, regardless of the material that was taught (history or biology), with children have higher conceptual understanding when handwriting notes compared to keyboarding notes in both lessons.

It is possible that there are differences in difficulty in the history and science lessons, in either the teaching or questions, or both. While these are not directly comparable, it can be considered by comparing the percentage correct means across for factual and conceptual understanding in both lessons, collapsing across conditions. For the history lesson (Study 1), 82.3% of factual questions and 67.5% of conceptual questions were answered correctly overall. For the biology lesson (Study 2), 71.6% of factual questions and 76.6% of conceptual questions were answered correctly overall. These data could be interpreted as showing that the children found the history factual questions easier to answer than the biology factual questions, with the reverse pattern for conceptual understanding questions. Importantly, there is no evidence of a ceiling effect for either subject.

Discussion

Our study adds to the growing literature concerning the effects on learning of taking notes either by typing or by handwriting. It extends research on this topic by examining the effect of modes of note-taking on schoolchildren's understanding, using their regular learning materials, and in their own classrooms. Our results show that there were significant differences in children's conceptual understanding when different modes of note-taking were used when tested after a one week delay. At one week after history and science lessons, children who had made notes by handwriting had better conceptual understanding than children who made notes using a laptop computer. Calculating effect sizes revealed that there was a large effect size of mode of handwriting on conceptual understanding, regardless of lesson content. There were no differences in mode of note-taking on conceptual understanding when tested immediately after the lesson. In contrast, there was some indication that the effect of mode of note-taking on factual understanding was dependent on the lesson. Note-taking method did not affect factual understanding of the history lesson, but for the science lesson, children had better recall of facts when tested one week following the lesson compared to the immediate test. In addition, there was a marginally significant advantage in factual understanding in the science lesson in the case of children who handwrote notes.

The results of our study broadly support the findings of similar studies in adults (Morehead, Dunlosky, & Rawson, 2019; Mueller & Oppenheimer, 2014, 2018). Firstly, we consider how our findings at the immediate test fit with the literature. We found no strong differences in factual or conceptual understanding by mode of note-taking at immediate test (outside of the marginally significant effect observed in the biology lesson). As the literature reports inconsistent findings at immediate test, we did not predict a directional hypothesis and our findings add to the body of evidence. For factual understanding, our findings are in line with Mueller and Oppenheimer's (2014) study (who also found no such effect), but not with Morehead, Dunlosky and Rawson's (2019) results (who found a handwriting advantage for immediate test of facts). In contrast, the lack of a handwriting superiority effect on conceptual understanding is in line with Morehead, Dunlosky and Rawson's study (who also found no such effect), but not with Mueller and Oppenheimer (who did find a handwriting advantage for immediate conceptual understanding). The differences between published studies were considered by Morehead, Dunlosky and Rawson (2019) as minor discrepancies. We agree that, in a small but growing literature, replication is necessary to establish effects, and minor methodological differences such as the interval between teaching and test, test materials, the age group assessed, all could potentially impact on the results. The small differences in the pattern of results for History and Biology lessons could occur as a result of different learning materials, but there are few differences between lessons and it may be an artefact of our study. The difference in findings between our study and previously published work could be explained by differences in the timing of the immediate test compared to published studies. While both Mueller and Oppenheimer's and Morehead, Dunlosky and Rawson's "immediate" test took place after a 30 minute delay, ours directly followed the lesson. It is possible that this minor difference in procedure may have impacted on the results, and we suggest that the effect of time of test is systematically evaluated in future work

Now we consider our results in the delayed condition, which provide more consensus with the study to which they are most directly comparable. In line with data reported by Mueller and Oppenheimer (2014, 2018), we found that conceptual understanding was better than when children handwrote their notes than when they typed them. While Morehead, Dunlosky and Rawson (2019) did not find this longhand superiority effect at their delayed test, one methodological difference that could explain this is the difference in the length of the delay, which was shorter at 2 days, rather than one week. Why might conceptual understanding be heightened after one week and not two days? It could be that this is related to the increased amount of time available to revise, which may combine with differences in the quality of notes, to lead to handwriting superiority. In support of this argument, Luo, Kiewra, Flanigan and Peteranetz (2018) reported that students who handwrote notes performed better than those who typed notes in a condition in which they were asked to review their notes before taking the test. The interaction between mode of note-taking and revision should be systematically evaluated by future studies that manipulate the availability of notes for revision.

Considering now the length of notes, in contrast to published studies (Morehead, Dunlosky, & Rawson, 2019; Mueller & Oppenheimer, 2014), we found no difference in the length of notes generated by hand or by keyboard, and we suggest that this is likely to be a result of the age of our participants. Previous studies suggest that adults write more when typing and this is likely to be a result of skilled touch typing. In contrast, the children in the current study were less likely to be expert or fluent touch typists and we did not formally assess their skill. Lacking this automaticity would be expected to slow the rate of note-taking, which may explain the similarity in note lengths between our two conditions. It is striking that, in our study, the two modes of note-taking had such different effects on understanding when the same amount of notes were recorded under both conditions. If the effect of mode of note-taking we observed was primarily a result of the children's lower familiarity with typing, we might have expected to observe an effect of mode of note-taking on factual understanding as well as conceptual understanding. Touch typing skill could be formally assessed in future studies, in both adults and children, in order to consider whether or not this mediates the relation between mode of note-taking and type of understanding.

What is going on under different conditions of note-taking that might explain the reported differences in factual and conceptual understanding? A range of factors have been considered. In adults, it has been proposed that typing notes encourages verbatim recording and less active processing (Luo et al., 2018). This reduces the amount of encoding that takes place during the lesson, with the result that conceptual understanding is lessened (Kiewra, 1985). It has been reported that the type of notes taken varies by the medium by which notes are recorded. For example, Luo, Kiewra, Flanigan, & Peteranetz (2018) found that adults who recorded notes by hand recorded more visual notes (such as arrows and images) than those using a laptop, while laptop note takers recorded a greater quantity of notes and verbatim notes than those who handwrote. They concluded that the type of material being taught, and whether or not notes are reviewed, impact on the success rate of different modes of note-taking. In particular, handwritten notes resulted in better test performance than typed notes when reviewing was encouraged (Luo et al., 2018). Morehead, Dunlosky, and Rawson (2019) also suggest that future research should consider whether the note-taking method encourages student to include the important material in their notes that will form part of the subsequent test; in their comparison of taking notes by computer or by hand, one of the best predictors of test performance was whether students included in their notes material that was relevant to the factual or conceptual test questions. Furthermore, the relative merit of handwriting and typing may be affected by factors related to the timing of test and ability to revise. One study that compared the taking of strategic, organised notes, with transcription and handwriting, found that performance on test varied according to whether the test was immediate or delayed, and whether or not students were allowed to study their notes (Bui, Myerson, & Hale, 2013). In addition, the way in which different types of notes are reorganised while revising affects how much is recalled after a delay (Kiewra, 1983).

In children, who as we have reported here, showed poorer conceptual understanding under keyboarding, this may occur for the same reasons as those identified in adults (e.g. related to active processing, or types of information recorded) or it could occur because they are less skilled typists and need to use greater cognitive capacity to enter information via the keyboard. This in turn may reduce opportunities for deeper encoding of information into long-term memory. We cannot distinguish between these two candidate explanations. The children in our study had received some training in touch typing, but in line with other studies (e.g. Mueller & Oppenheimer, 2014), we did not assess typing speed or accuracy. This limitation should be addressed in future studies. Thus, the route to understanding under conditions of typing and handwriting may be different for adults and children. However, we suggest that typing skill cannot fully explain the effect of the manipulation; if that were the case, we might have expected to see the note-taking differences observed for conceptual understanding, also observed for factual understanding. One limitation of our study is that we were not able to analyse the quality of notes produced by each mode of note-taking. An assessment of note quality would allow us to evaluate the type and structure of information recorded under different conditions, and should be included in future studies.

One of the strengths of our study was that it utilised course-related material that was presented in a manner that was conventional (for our participants), by their own classroom teachers, who also designed the assessment. The lessons and assessments that we employed were designed by the children's classroom teachers who teach and assess material regularly taught in the classroom. Children were also both taught and assessed in their regular classroom. These factors heighten the ecological validity of the study as it directly assesses the impact of our manipulations on everyday educational practice. While examining the effect of mode of note-taking on different lesson topics extends the literature, our measures were not standardised assessments (in line with the two studies on which our study was modelled) and, as our results suggest, may differ in difficulty. Data presented in Tables 1 and 2 shows that the scores for factual understanding were higher at both immediate and delayed test for History compared to Science. In contrast, scores for conceptual understanding were more similar over the two topics when the respective study cells are compared. Thus, our data suggest that the children may have found the history facts easier than the biology facts, and it could be that this rendered their factual understanding of the history lesson less susceptible to the manipulation. It is a strength of this study that similar effect sizes were observed in the two studies, despite these differences.

Limitations and future directions

The sample size in the present study is relatively small, but the effect sizes are large and aided by the within subject study design. As the present study included only boys, the results may not generalise to a sample of girls, or a mixed gender sample, thus, future work should replicate the study, but in a larger, and more representative sample. In adults, there is some evidence that the note-taking skills of males and females differs. Studies have shown that female undergraduate students, when recording notes by hand, recorded more information and better quality notes (Reddington, Peverly, & Block, 2015), than male students. Little research appears to have been carried out on gender differences in note-taking using keyboard devices, and while Mueller and Oppenheimer's (2014) set of studies on the effects of keyboarding and handwriting on understanding included mixed gender groups of participants, they did not examine any effect of gender. Morehead, Dunlosky, Rawson, et al., (2019) found that female students were more likely than males to revise notes. In addition to potential gender differences in note-taking skills, there may be gender differences in the type of computer-related distractibility. In a sample of secondary school students, although the majority of pupils reported that they remained on task when using electronic devices in the classroom, there were differences in the type of off task behaviour in which they engaged; females were found to engage in off task social media, while males engaged in gaming (Kay, Benzimra, & Li, 2017). In university students, similar findings are reported (Barker & Aspray, 2006; Sanders, 2006). With regards to children, there is evidence that the type of computer-related activities in which children engage differs by gender (Colley & Comber, 2010). Questions about gender differences in note-taking, and in computer engagement and skills, remain empirical questions that should be addressed by future research.

In the present studies, the same set of questions were used at immediate and delayed test. This was consistent with the key studies being replicated (Morehead, Dunlosky, & Rawson, 2019; Mueller & Oppenheimer, 2014, 2018). However, it is important to note that testing and retesting of material can influence learning. The "testing effect" describes how performance is improved by taking a test on the material (Roediger & Karpicke, 2006). Studies examining this phenomenon have compared performance under different learning conditions, such as repeated testing and repeated studying (Roediger & Karpicke, 2018). For example, after a one week delay, adults who had more retrieval practice (repeated testing) and less studying, outperformed those who simply studied (Karpicke & Roediger, 2008). This testing effect has been shown in adults and children (Roediger & Karpicke, 2018). We did not show a straightforward testing effect, because performance was impacted by the mode of note-taking. However, it is possible that note-taking method may interact with the testing effect. In our study, we offered the children the opportunity to use their notes for revision, but did not formally record their participation in revision. Children in our handwriting condition may have revised more than those who keyboarded their notes. The effect of revision and re-testing under different note-taking conditions should be formally evaluated in future work.

Our findings could present a start off point for many additional follow up studies. For example, alongside the question of how revision and re-testing impacts on learning under different modes of note-taking, familiarity with different types of note-taking could be explored. This familiarity may affect the impact of note-taking methods and may differ across geographical location, the age of the children and/or gender. Lesson topic may also influence how model of note-taking affects learning, with some topics perhaps particularly suited to more visual notes. The type and number of factual and conceptual questions might also impact on learning. Importantly, as suggested above, future work should also consider note quality, both in terms of systematically exploring the effect of encouraging children to take different types of notes, and analysing the type of notes that they make. All of these factors could be explored in children across all years of school education, in order to fully examine the developmental progression, and to be able to make appropriate recommendations for policy and practice.

Educational Implications

There are educational implications that follow from this study for the inclusion in the classroom of technology such as laptops for note-taking. As outlined earlier, educational technology must be employed in a manner that supports students' learning (Luckin et al., 2012). Part of preparing children for the workplace, and/or the demands of further study, is to offer students touch typing training and clear advice on the best way to produce notes. Since these areas are not always explicitly included in official guidelines, such as the National

Curriculum in the UK (Department for Education, 2013), individual schools will need to consider individually their policies about introducing touch typing and reducing handwriting.

Conclusions

In conclusion, our study found that conceptual understanding was significantly better after a delay of one week in schoolchildren who handwrote their lesson notes, compared to those who typed them on a laptop. We assessed their performance in the children's usual classroom, with their usual class teacher and teaching materials, thus reproducing the normal day-to-day school environment. Previous studies have examined the influence of mode of note-taking on understanding in university students and, to the knowledge of the authors, this is the first time that a study comparing the effects of type of note-taking equipment on the performance of schoolchildren has been carried out. While there are some limitations in our study design, this paper contributes to the debate on the manner by which children should take notes in class. The optimal note-taking strategy may depend on skill with keyboards, mode of presentation, and time between learning and test, amongst other factors. All of these should be systematically explored by future work.

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Table 1: Mean factual and conceptual understanding scores, and standard deviations, in the history lesson by mode of note-taking and time of test.

Time of test	**Mode of Note-taking**	***n***	**Factual Understanding**		**Conceptual Understanding**	
			Mean	***SD***	***Mean***	***SD***
Immediately post-lesson	Keyboard	13	15.2	1.07	6.6	1.33
	Hand	13	14.2	2.52	7.0	1.29
One week post-lesson	Keyboard	13	15.00	1.53	5.6	1.56
	Hand	13	14.9	2.10	7.8	1.17

Table 2: Mean factual and conceptual understanding scores, and standard deviations, in the biology lesson by mode of note-taking and time of test.

Time of test	**Mode of Note-taking**	***n***	**Factual Understanding**		**Conceptual Understanding**	
			Mean	***SD***	***Mean***	***SD***
Immediately post-lesson	Keyboard	12	9.9	2.07	5.6	1.44
	Hand	11	12.4	2.98	6.3	1.01
One week post-lesson	Keyboard	12	12.8	1.49	5.3	1.91
	Hand	11	13.6	2.06	7.3	0.79