PAEDAGOGIA
2026, Vol 6, No 1, 433 – 449
DOI: 10.6084/m9.figshare.28821920

LAKE FOREST COLLEGE

Does Writing Modality Affect Writing Quality in Upper Elementary Students?

Isabella Wojewski
Department of Education, Lake Forest College

Abstract

The present quasi-experimental study investigates the impact of writing modality (typing versus handwriting) on writing quality in upper elementary-age students to better understand how technology in the classroom affects student performance. Focusing on the same group of fourth-grade students over an eight-week period, I observed and evaluated student reading responses when typed and handwritten. I evaluated each reading response using a scale consisting of four categories: grammar, sentence structure and variety, length, and flow. After reading responses were evaluated, the averages for each category were compared in the typing condition and the handwriting condition using a paired sample t-test. While only one category showed a significant difference, this study contributes to prior research focused on the impact of handwriting and typing on writing performance. This study is important in understanding how we can best foster student writing development as technology-based writing modalities become more popular

Keywords: writing modality, handwriting and typing, writing quality, literacy development, educational technology integration

Introduction

The ubiquity of technology integration in elementary classrooms today differs notably from the classrooms that even new elementary teachers experienced as students when access to cutting edge instructional technologies required a visit to the computer lab. By the time new elementary teachers were in seventh grade, one-to-one device access was the norm. It is rare to see classrooms where students do not have access to a technological device such as a tablet or a computer. With

this rapid rate of technology integration in classrooms, it is hard for research to keep up with the current evidence that can support any benefits or expose drawbacks.

With much of classroom technologies requiring some input interface, it is now common for schools to provide students both handwriting and typing instructions, with some schools implementing typing alone. While it may be true that the professional world prioritizes typing abilities over handwriting abilities, handwriting may offer more than just a person's ability to put letters on a page. My pre-service classroom observations revealed that students, including fourth graders, were typing or using the voice-to-text feature on their iPads when asked to complete a writing assignment. Seeing that their writing was, at times, incoherent, I committed myself to understanding the relative impact of typing and handwriting on students' writing quality. Not only was the students' writing in my earlier observation incoherent, their responses to writing prompts were riddled with run-on sentences, grammatical mistakes, and lacked clarity. As I got to know the students, it became increasingly clear to me that their writing performance was not accurately reflective of their capacity.

Additional observations of how they used the digital tools on their devices showed patterns of circumventing design features intended to support their learning. For instance, when confronted with an unfamiliar spelling task, most students relied on the spell-check feature rather than attempt to master the spelling. Similarly, if they struggled to finish a sentence, they utilized the predictive text feature. When unsure of a word's meaning, they used the "lookup" feature that pops up when a word is highlighted. These tools replaced the skills that students would have developed without access to this technology. While the usage of such tools is more relevant in our technology-reliant society, it may be denying students the opportunity to practice necessary literacy skills that would otherwise be natural absent an assistive device.

Subsequent efforts to understand the role of one-to-one technology in the classroom broadly highlighted benefits, such as higher student engagement and opportunities to differentiate instruction (Delgado, 2015; Sandberg et al. 2022). However, focusing on writing more specifically suggested that handwriting (as against typing) activates a neural network called the reading circuit, which is also activated when we read (Wandall and Le, 2017). This circuit connects our senses, language, and memory, resulting in our ability to understand and remember letters and words. The movement involved with handwriting is specific, and therefore, easier for our brains to remember each different letter. James (2017) hypothesized that the action of typing is too general and non-specific to each letter, making it difficult for the brain to differentiate and retain the letters. The way that handwriting taps into our senses makes it a tool for learning.

Research evidence on the effects of handwriting appears to focus more on handwriting development and letter retention in young children in the elementary (K-2) grades as well as on writing quality in older students, with less known about handwriting and the production of writing during the intervening stages, especially when students are in the intermediate grades. My teacher action research aims to address the possible effect of typing versus handwriting on the quality of a written piece. Developing writing skills is complex and takes years for students to master. As students develop their writing at different rates, standardizing research processes for understanding and supporting student writing development can be complicated by the rapidity of technology innovations and classroom integration.

To date, there is not enough research evidence to support using one modality over the other for helping young writers develop their skills. The literature review shows that on one hand, there is evidence for a technology-based modality to support writing development in students with underdeveloped fine motor skills. On the other hand, other research suggests that handwriting serves more for the brain than just the ability to write letters on a page. The combination of the variability in student writing development and rapid increase of technology integration has made it difficult to study this area.

In this paper, I discuss existing literature on the integration of technology in the classroom as well as the neurological processes involved in handwriting to contextualize the teacher action research evidence reported here. My research aims to address whether the modality of writing affects the quality of writing. I hypothesize that handwritten responses will have better writing quality due to the neural pathways triggered when a person writes by hand. I define "quality" in terms of grammatical accuracy, sentence variety, and clarity of organizational flow throughout a written piece. Additionally, I hypothesize that the length of the reading responses will be shorter in the handwriting condition than the typing condition due to the absence of assistive tools such as speech-to-text and predictive text. Writing by hand forces one to slow down, because one must write each symbol and letter, potentially resulting in a more carefully thought-out responses in fewer words.

Literature Review

While this project focuses specifically on the massive shift towards one-to-one classroom technology, such as computers and tablets, it is important to note that schools have been integrating analog precursors in various forms of digital technology since the early 20th century, from radio and film to projection systems. Those earlier analog technologies were designed largely for centralized and passive learning, focusing mostly on whole-class instruction. Public attitude in the early 2000s toward the digital turn was largely positive, as people believed that digital technology assisted in making instruction decentralized, interactive, and personalized, with more individualized opportunity for learning to occur outside the classroom (Muir-Herzig, 2003; Delgado, 2015). However, as more technology was introduced, teachers felt unprepared to teach with these technologies as they were not given the proper training (Ertmer and Ottenbreit-Leftwich, 2010). Most of the research on the potential downsides of technology integration focused on teacher preparedness, rather than the actual impact of technology on student learning itself (Njiku et al., 2019; Tondeur, 2016). Only more recently have more studies been published that delve into the specific relationships between technology use and student performance.

The integration of technology in the classroom reflects the progression of technology usage in our society. While digital technology integration was not a new idea at the start of the 21st century, the increase in individualized accessibility marked a major a shift. The availability of one-to-one technology allowed for an increase in legibility of student writing, made fewer demands of cognitive resources, and required simpler motor skills (Spilling et al. 2021; Mayer et al. 2020; Cheung, 2016; Nobles and Paganucci, 2015). This was especially helpful for students with motor skill deficiencies. Without having to expend the cognitive resources to form a letter using fine motor skills, it has been argued that students could then focus on the content of what they were

writing (Spilling et al. 2021). If a student struggles with their ability to put together their thoughts in the form of writing, they are unable to express what they know, potentially resulting in a reduced self-esteem and difficulty for the teacher to understand what a student knows or does not know (Hoy et al. 2011).

It could be argued that the availability of technology allows students to perform a task more efficiently with the same results. Ouellette and Tims (2014) found that when second-grade students practiced for a spelling test by typing or printing, both groups achieved similar scores, suggesting the modalities could be interchangeable. Cheung (2016) reported that secondary students who wrote on a computer produced higher quality writing than the pen-and-paper group, while also expressing a preference for using computers over pen and paper. Based on this research evidence, one might assume that a total abandonment of handwriting with the ever-growing presence of digital technology in our daily lives was inevitable. It is important to note that the students involved in the aforementioned studies likely received handwriting instruction in the primary grades. While this research demonstrates that technology could be an effective tool for writing as students advance through school, it does not address the potential cumulative effect of an abandonment of handwriting entirely on student learning.

Handwriting is more than just putting letters on a page. It requires a complex system of neurological processes and motor skills. In addition to letter formation, handwriting helps children develop motor skills needed for cutting, drawing, and other manual activities (Marano et al. 2025). When a person writes by hand, their brains are engaged with memory retention, comprehension, critical thinking, and creativity (Marano et al. 2025). The act of handwriting is a sensory-motor experience that taps into Broca's area in the brain, which is responsible for speech and language production. To handwrite effectively, one must have orthographic-motor integration: the ability to recall and write down letters without allocation of cognitive resources (Doug, 2019). To obtain orthographic-motor integration, one must be able to master the specific movements required to form each letter.

As humans, we learn about our surroundings through our senses and behaviors. The specific movements required of each letter allows for our brains to categorize and retain the shape, resulting in the immediate recall of letters (James, 2017). James (2017) hypothesized that the reason that handwriting helps us retain our letters is due to the variation that we naturally create when learning to produce letters. When a child is learning their letters, the way that they write the letter *a* may look different every time but is still recognized as the letter *a* (Srihari et al. 2016). As the brain sees multiple variations of the same item, we are able to put more "examples" into the categories that our brains create and therefore can quickly recognize what is seen before us (James, 2017). This hypothesis came after a study conducted by Englehardt and James (2012) that tracked the activation of the reading circuit when children printed, traced, or typed letters. The reading circuit is a neurological network that is activated when we read or write, and connects the visual, auditory, and language circuity in the brain (Wendall and Le, 2017). In the Englehardt and James (2012) study, the only group that showed an activation of the reading circuit was the self-producing letter group. However, if letter retention was dependent on the practice of repeating the specific movements required by different letters as mentioned prior, the tracing condition and handwriting condition should have yielded the same results. The difference

between the tracing group and the self-producing letter group was the variability of the letters when they were written by students without a guide to trace, revealing that there could potentially be an important element missing when students are not given the opportunity produce letters on their own.

The reading circuit may be responsible for storing our letter knowledge. For example, a study conducted by Ihara and colleagues (2021) investigated how writing with a digital pen, typing, or handwriting impacts the learning of a foreign language in adults. While each group eventually learned the language, the typing group's ability to accurately recognize words accurately declined significantly three weeks after the training, whereas the rate of recognition was consistent in the handwriting group. Another study found that when adults handwrote notes for learning Arabic versus using visual processing tools or typing, they were able to retain the information faster than the other conditions; all groups were able to learn the Arabic allographs, but the typing and visual processing group took more training sessions than the handwriting condition (Wiley and Rapp, 2021). These findings in conjunction with the results from Englehardt and James's (2017) study suggest that the activation of the reading circuit is crucial in knowledge acquisition and is only activated when letters are self-produced. With the growing integration of technology, it is likely that typing on a digital device may not be activating this reading circuit. While studies have found that groups in the typing or tracing conditions were able to learn the information presented to them, they also found that the information took longer to retain, and was retained temporarily. Opting for a technological modality could promote short-term goals rather than fostering long-term retention required for writing.

Thus far, the research discussed has focused on the ability to self-produce letters rather than the production of sentences and paragraphs. However, it is crucial that children are comfortable with their ability to recall letters so they may use their cognitive resources to focus on the formation of words and sentences (Skar et al. 2021). Learning how to write appears to be similar to learning how to read. When reading, students must first learn to decode the words before they can devote their cognitive resources towards understanding what the text is saying. In both contexts of reading and writing, if a student is struggling to retrieve their letter knowledge, this disrupts the flow of their thinking as the cognitive resources now have to be shared. A study conducted by Skar and colleagues (2021) investigated the individual differences in handwriting fluency and how it affected writing skills. Those who had fluent handwriting produced writing of a higher quality, as they did not have to spend their cognitive resources on the act of handwriting itself. It could be argued that typing is the solution, as a keyboard presents the letter in front of a person, possibly cueing retrieval (Spilling et al. 2021). However, it is also possible that children would only have to recognize the letter as opposed to retrieving it, which may not activate the same neural networks (Spilling et al. 2021; Englehardt & James, 2012).

If students do not retain letters, it becomes difficult to form words and sentences, especially at the rate of idea generation. While it could be argued that typing addresses this problem, research shows that typing does not activate the neural regions required for letter retention (Marano et al, 2025; Englehardt & James 2012). Typing may be a solution down the line, but students must receive explicit handwriting instruction first to ensure proper letter retention (Feng et al. 2017; Englehardt & James, 2012; Skar et al. 2021). Additionally, handwriting requires

one to slow down and think about how articulate their thoughts in their own words. When individuals type, they are more inclined to type verbatim as they can keep up with the speed, while individuals who handwrite are more likely to process what is being said and construct ideas in their own words (Marano et al. 2025; Wiley & Rapp, 2021).

There is ample research regarding letter learning and handwriting in the primary grades, as well as several studies supporting higher writing quality when performed on a technological device in secondary grades on students who likely received handwriting instruction (Spilling et al. 2021; Mayer et al. 2020; Cheung, 2016; Nobles & Paganucci, 2015). However, the transition from letter recall to writing skill development, especially in the intermediate elementary grades (3-5), is still under-researched. Additionally, there seems to be a lack of research regarding any link between the several cognitive processes that are required for handwriting and writing development. For there to be so many processes activated during letter learning, it is possible that exercising these areas of the brain contributes to increased ability to articulate one's ideas on paper? School curricula are slowly getting rid of handwriting instruction before there is enough research to support this decision. Arguments of efficiency seems to be more compelling in favor of digital technology usage in the classrooms, and this compels us to ponder whether in this context, efficiency can become inefficient. It is possible that creating shortcuts too early on in a child's writing development may be detrimental to their overall brain development. For students who may not have received adequate handwriting instruction, it is crucial to examine how this potentially impacts their writing performance at the intermediate grade levels.

Methods

Research Design

This teacher action research uses a within-subjects quasi-experimental design since the relatively small class size makes it impractical to create two subsamples for a control and experimental intervention. Instead, the same group of students were observed in the treatment and control conditions. During the first four weeks, students typed their reading responses, just as they had been doing all year long. After four weeks, students began to handwrite their reading responses and continued to do so until the eight weeks were over. Reading responses were collected, graded, and evaluated using a four-point scale I created (Appendix I).

At the fourth-grade writing level, students should be able to use a variety of transition words, convey information clearly, use correct capitalization, and form complex sentences (CCSSW.4.3.c, CCSS.W.4.1.a, CCSS.L.4.2.a-c, CCSS.L.4.1.F). Using these standards, I narrowed my focus to grammar, sentence structure and variety, length, and flow. While there is no writing standard for how long fourth grade writing should be, it seemed useful to observe whether there would be any changes from the typing condition and the handwriting condition, considering that handwriting takes more motor involvement than typing does. Similar elements were used to evaluate quality writing in a study conducted by Spilling et al. (2021). An example of an evaluated response can be found in the Appendix (Appendix II).

Due to the nature of the environment, it was difficult to have consistent controls. To clarify, writing instruction did not pause over the duration of this study and reading response questions changed daily. However, the time the lesson was given (afternoon) and the frequency with which

the responses were written (one per day) stayed the same. The reading responses varied based on the reading of the day, which came from the Houghton Mifflin Harcourt (HMH) curriculum.

Participants and Context

Participants in this study consisted of nineteen fourth grade students (ages 9-10) who attended a public elementary school in an affluent northern suburb of a Midwest city in the US. The school's students population is 75% Caucasian, 12% Hispanic or Latino, 0.05% Asian, 0.05% two or more races, and 0.02% Black. Additionally, a large proportion of the students are from military families that tend to move every three years. This particular class was composed of students of varying writing levels, both in the content of their writing and their ability to handwrite. It may be important to note that this cohort of students started Kindergarten during the COVID-19 pandemic, where students experienced a hybrid learning environment as an introduction to school. Students who could not write legibly were excluded from the study, as they were unable to participate in the handwriting condition. All ethical procedures for this study were followed, including informed parental consent and student assent.

Data Collection and Analysis

Reading responses were collected and evaluated using a four point scale that I created (Appendix I). As mentioned, the categories I chose to focus on were grammar, sentence structure and variety, length, and flow. Within each of these categories, I assigned different criteria for each respective category. After evaluating each essay, I used Microsoft Excel to run a paired samples *t*-test (p-value = 0.05) to compare the means of each modality by category. I compared the weekly average scores of grammar, sentence structure and variety, length, and flow in the typing and handwriting conditions for any differences.

The quantitative analysis for the four categories (grammar, sentence structure and variety, length, and flow) used scoring criteria that are adapted to the relevant skill. Grammar was scored based on their correct usage of punctuation, subject-verb agreement, and correct verb tense. Sentence structure and variety were scored based on the completion of sentences, run-on sentences, and repetition of sentence stems. Length was scored based on the number of sentences written. Flow was scored based on the usage of transition words and the connection of ideas between sentences. Additionally, I conducted anecdotal observations of student behaviors and attitudes during both conditions and reported my findings below.

Observations

During the first four weeks, I observed students while they typed their reading responses. At the very beginning, most students opted to use the speech-to-text feature because "it was faster." Students who struggled to complete their work in the allotted time often asked to use this feature on their iPads as they felt that it would take them too long to type. With support from my cooperating teacher, students were not allowed to use this feature without prior accommodations. In the absense of the speech-to-text feature, students generally opted for the predictive text feature which provides three words that the software "thinks" should come next in a sentence. This tool

also reduced the time it took for responses to be produced. I would notice several students tapping these buttons to create a somewhat coherent sentence, but I seldom saw students go back and make necessary edits to improve the flow of writing. Upon observing this use pattern, I was curious about how students would perform without access to them.

Qualitative observations also revealed superficial cognitive engagement among some students. In one instance when I offered ways one student could improve theirwriting, they responded with, "I am just going to get a four out of six anyway, because I always do." This limited motivation associated with the use of speech-to-text when completing his responses in a very short time, suggests that digital technologies might be linked to reduced investment and a lack of deep cognitive engagement with additional affective association of handwriting with difficulty.

The introduction of the handwriting condition was unsurprisingly frustrating and challenging to students as they thought that their writing responses would take too long to complete, would be illegibly, or would tire their hands. One student insisted that his writing would stay the same on paper as it would on the iPad every time I handed out the writing prompt. Another student would put her head down in frustration because she "couldn't read [her] own handwriting." The switch from typing to handwriting was met with a much more emotionally charged response than I had expected. It is possible that their reactions influenced the quality of their writing, as their emotions took up cognitive resources.

As the weeks unfolded, students eventually stopped complaining about having to handwrite their essays and soon became accustomed to it. Students started to grab more response sheets to write more, and were excited to show off how much they were able to produce. A few students even got excited when I reminded them that their responses had to be handwritten. On one occasion, due to time constraints, I told students that they had the option to type their responses, and only two students opted to do so. Even the student who lamented the supposed illegibility of her handwriting was able to recognize her improvements and started to opt for handwriting in every other subject. Towards the end, I had several students, including the one that "always got a four out of six," come up to me to show me what they had written before turning it in, demonstrating a sense of pride in the students that I seldom observed when they would type their responses.

Results

The anecdotal observations outlined above suggest that there was a budding shift from frustration to excitement in students' attitudes towards handwriting. This is notable considering the solidified habits of typing that students had developed over a longer period than the current research intervention. However, it is important to note that the quantitative evidence showed a significant difference between the two treatment conditions only for the flow category. As outlined below, grammar, sentence structure and variety, and length did not differ based on the modality of writing.

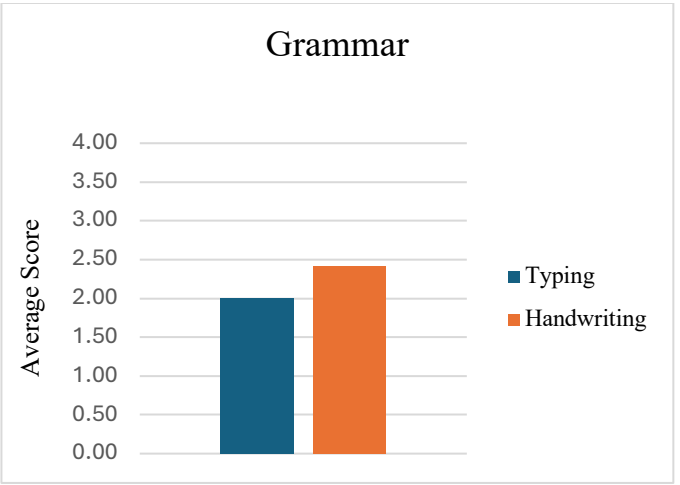
Grammar

Scores for grammar were averaged for the four weeks of typing and the four weeks of handwriting. A paired samples *t*-test was performed to evaluate if there was a significant change

in grammar scores between the typing condition and the handwriting condition. The results indicated that while students scored higher in the handwriting condition, there was no significant difference between the typing (M = 2.01, SD = 0.29) and the handwriting condition (M = 2.40, SD = 0.39), $t(3) = -1.89$, $p = 0.15$ (Figure 1). Overall, students were using appropriate punctuation (periods and commas) throughout their written responses, but still struggled with proper capitalization in both the written and typed responses.

Figure 1

Means comparison for grammar scores



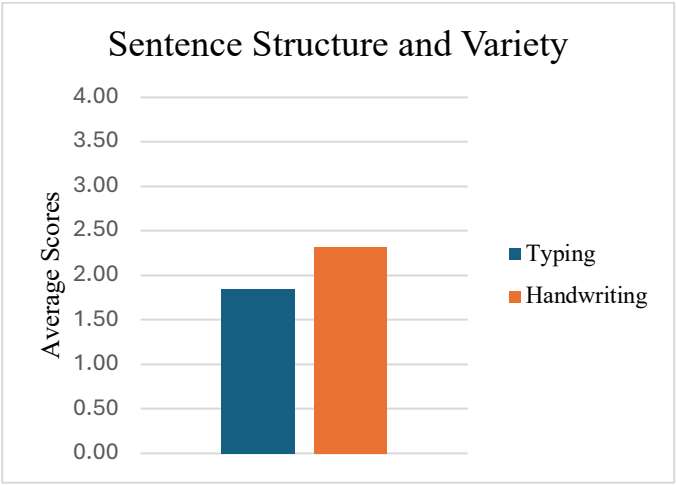
Note. The differences in grammar scores were not significant ($p>0.05$).

Sentence structure and variety

Scores for sentence structure and variety were averaged for the four weeks of typing and the four weeks of handwriting. A paired samples *t*-test was performed to determine whether there was a significant change in sentence structure and variety scores between the typing condition and the handwriting condition. The results indicated that while students scored higher in the handwriting condition, there was no significant difference between the typing (M = 1.84, SD = 0.29) and the handwriting condition (M = 2.31, SD = 0.16), $t(3) = -2.11$, $p = 0.13$ (Figure 2). In both conditions, students stuck to using simple sentence stems to convey their answers. Few students experimented with more complex sentences in their written responses than the typing responses but seemed to overall avoid complex sentences.

Figure 2

Means comparison for sentence structure and variety scores



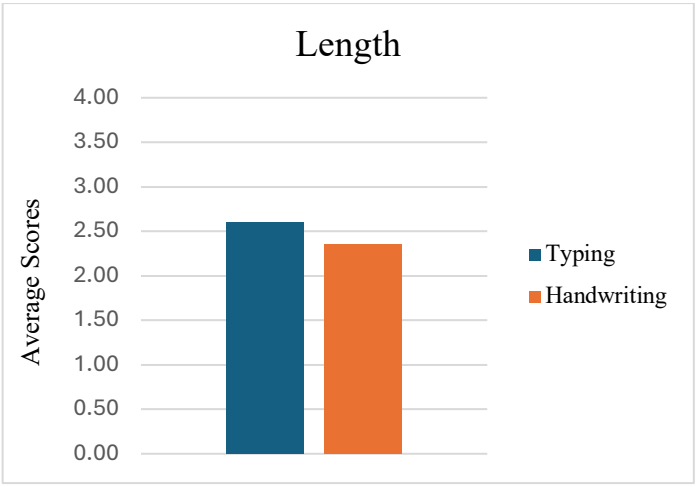
Note. The differences in sentence structure and variety scores were not significant ($p>0.05$).

Length

Scores for length were averaged for the four weeks of typing and the four weeks of handwriting. A paired samples *t*-test was performed to see if there was a significant change in length scores between the typing condition and the handwriting condition. The results indicated that there was no significant difference between the typing ($M = 2.60$, $SD = 0.40$) and the handwriting condition ($M = 2.35$, $SD = 0.12$), $t(3) = 1.41$, $p = 0.25$ (Figure 3). Indeed, the students scored higher in the typing conition. While student responses appeared to be longer on paper, this was likely attributed to their variability in handwriting. Some students needed multiple sheets of paper to accommodate their large handwriting rather than needing more space for more sentences.

Figure 3

Means comparison for length scores



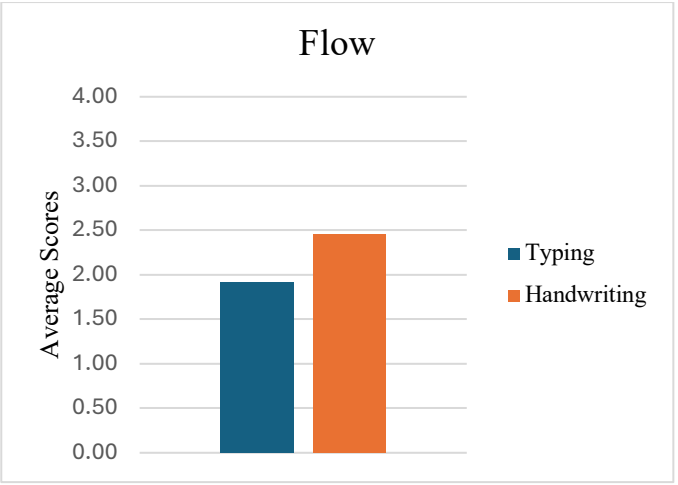
Note. The differences in length scores were not significant ($p>0.05$).

Flow

Scores for flow were averaged for the four weeks of typing and the four weeks of handwriting. A paired samples *t*-test was performed to evaluate if there was a significant change in flow scores between the typing condition and the handwriting condition. The results indicated that the flow scores in the handwriting condition ($M = 2.45$, $SD = 0.11$) were significantly higher than the typing condition ($M = 1.92$, $SD = 0.24$), $t(3) = -5.06$, $p = 0.01$ (Figure 4). In the handwritten responses, students used more transition words and connected their ideas between sentences more frequently than in the typing condition. It is possible that this was attributed to the absence of the predictive text feature, as students had to develop sentences organically instead of selecting one of three words offered.

Figure 4

Means comparison for length scores



Note. The differences in flow scores were significant ($p>0.05$).

Discussion and Action Plan

This study hypothesized that handwritten reading responses would have higher writing quality than typed reading responses. Based on the results of this study, it is unclear whether the handwriting or typing condition produced higher quality writing. Previous studies in this area have found mixed results, neither confirming nor denying that handwriting may produce better writing (Spilling et al. 2021; Feng et al, 2017; Ihara et al, 2021).

The data suggests that the flow of writing was improved in the handwriting condition, while grammar, sentence structure and variety, and length did not differ significantly. This mixed result might suggest a more positive association bewteen handwriting and writing quality when understood in the unique context of the study. For one, this study was conducted on one group of nineteen students over a period of eight weeks. During these eight weeks, I continued to provide feedback for student writing, and students participated in writing instruction. It is possible that student writing performance, especially in the grammar and sentence structure and variety categories, reflected that they needed further writing instruction, and the modality of writing did not matter if the students lacked the necessary writing skills. Additionally, the students in the study sample were of various writing levels; some students were already writing at or above grade level when the study began, resulting in their scores staying relatively consistent throughout the study.

Moreover, I was the only one that evaluated the responses. While I attempted to evaluate them blindly by scoring them at a later date and out of order, obtaining scoring from multiple teachers would increase the inter-rater reliability of the scores and could affect how significant the differences in the results are. Finally, students have had a longer familiarity with typing in school and likely in other non-school contexts. It would arguably take a much longer time of practice with handwriting to equalize exposure and more accurately measure the outcome in writing quality. Indeed, students' own affective response to handwriting suggests not only familiarity with but preference for typing at the initial phase of the handwriting condition, and how this affected students' engagement with handwriting might need a corresponding emotional and motivational rebalancing.

Despite the quantitative results, I observed a change in students' attitude throughout this study. At the beginning, students seemed unmotivated and disinterested in writing, which turned into frustration when switching to handwriting. I was shocked to see such a reaction but was pleased to see that frustration change into students taking ownership of their writing. While the quantitative data may suggest there was no difference between the typing and handwriting condition, the shift in student confidence when they handwrote their responses was palpable. More students took their time in the handwriting condition while demonstrating a greater sense of pride in their work. While not quantifiable, these observations are worth considering when investigating the potential impacts of selecting writing modalities.

As I transition into my first year as a teacher of record, I would be eager to continue this exploration with several improvements. First, I would start with the handwriting condition and finish with the typing condition to determine if typing played a significant role in writing production. This would address whether the continued writing instruction also influenced the quality of student work. Secondly, a larger sample size could potentially produce more compelling results; it would be interesting to look at all sections of a grade level, rather than one class alone. Furthermore, I would have multiple people evaluate the responses in order to increase the reliability of the scores. As for the observational aspect of this study, I would have liked to conduct a survey that asked students how they felt about their writing in order to get more concrete evidence of any change in confidence. I observed a change in their attitude towards writing, but lacked any solid data that I could analyze.

As we become more reliant on technology, it is crucial that we understand what we gain and lose as we make relevant instructional changes. As mentioned, handwriting is beginning to be taught less in schools, and this may be attributed to the heavy use of digital technology with built-in text-input and interactive interfaces in the professional world. However, handwriting may contribute to our brain development in a way that is not as simple as writing words on paper. There is still developing research on whether typing or handwriting produces better writing results, but, as teachers, we need to pay attention to classroom and pedagogical dynamics that could offer a wealth of empirical data for addresing this question. Denying students ample handwriting instruction may impact their ability to write and communicate to the best of their ability. Understanding the way our brains work when we handwrite or type is important in developing a curriculum that helps students form the skills required for them to reach their greatest potential.

References

Cheung, Y. L. (2015). A comparative study of paper-and-Pen versus computer-delivered assessment modes on students' writing quality: A Singapore study. *The Asia-Pacific Education Researcher*, 25(1), 23-33. https://doi.org/10.1007/s40299-015-0229-2

Delgado, A., Wardlow, L., O'Malley, K., & McKnight, K. (2015). Educational technology: A review of the integration, resources, and effectiveness of technology in K-12 classrooms. *Journal of Information Technology Education: Research*, 14, 397-416. https://doi.org/10.28945/2298

Dhanya, M., & Alamelu, C. (2019). Influencing skills—report writing. *Leadership for Sergeants and Inspectors*. https://doi.org/10.1093/oso/9780198719939.003.0020

Doug, R. (2019). Handwriting: Developing pupils' identity and cognitive skills. *International Journal of Education and Literacy Studies*, 7(2), 177. https://doi.org/10.7575/aiac.ijels.v.7n.2p.177

Ertmer, P. A., & Ottenbreit-Leftwich, A. T. (2010). Teacher technology change. *Journal of Research on Technology in Education*, 42(3), 255-284. https://doi.org/10.1080/15391523.2010.10782551

Feng, L., Lindner, A., Ji, X. R., & Malatesha Joshi, R. (2017). The roles of handwriting and keyboarding in writing: A meta-analytic review. *Reading and Writing*, 32(1), 33-63. https://doi.org/10.1007/s11145-017-9749-x

Hemlata, H., Manoj, M., & Kumar, S. (2018). Personality detection using handwriting analysis review. *Seventh International Conference on Advances in Computing Electronics and Communication* ACEC2018. https://doi.org/10.15224/978-1-63248-157-3-33

Hoy, M. M., Egan, M. Y., & Feder, K. P. (2011). A systematic review of interventions to improve handwriting. *Canadian Journal of Occupational Therapy*, 78(1), 13-25. https://doi.org/10.2182/cjot.2011.78.1.3

Ihara, A. S., Nakajima, K., Kake, A., Ishimaru, K., Osugi, K., & Naruse, Y. (2021). Advantage of handwriting over typing on learning words: Evidence from an N400 event-related potential index. *Frontiers in Human Neuroscience*, 15. https://doi.org/10.3389/fnhum.2021.679191

James, K. H. (2017). The importance of handwriting experience on the development of the literate brain. *Current Directions in Psychological Science*, 26(6), 502-508. https://doi.org/10.1177/0963721417709821

James, K. H., & Engelhardt, L. (2012). The effects of handwriting experience on functional brain development in pre-literate children. *Trends in Neuroscience and Education*, 1(1), 32-42. https://doi.org/10.1016/j.tine.2012.08.001

Marano, G.; Kotzalidis, G.D.; Lisci, F.M.; Anesini, M.B.; Rossi, S.; Barbonetti, S.; Cangini, A.; Ronsisvalle, A.; Artuso, L.; Falsini, C.; et al. The Neuroscience Behind Writing: Handwriting vs. Typing—Who Wins the Battle? *Life* 2025,15,345. https://doi.org/10.3390/life15030345

Mayer, C., Wallner, S., Budde-Spengler, N., Braunert, S., Arndt, P. A., & Kiefer, M. (2020). Literacy training of kindergarten children with pencil, keyboard or tablet stylus: The influence of the writing tool on reading and writing performance at the letter and word level. *Frontiers in Psychology*, 10. https://doi.org/10.3389/fpsyg.2019.03054

Muir-Herzig, R. G. (2004). Technology and its impact in the classroom. *Computers & Education*, 42(2), 111-131. https://doi.org/10.1016/s0360-1315(03)00067-8

Njiku, J., Maniraho, J. F., & Mutarutinya, V. (2019). Understanding teachers' attitude towards computer technology integration in education: A review of literature. *Education and Information Technologies*, 24(5), 3041-3052. https://doi.org/10.1007/s10639-019-09917-z

Nobles, S., & Paganucci, L. (2015). Do digital writing tools deliver? Student perceptions of writing quality using digital tools and online writing environments. *Computers and Composition*, 38, 16-31. https://doi.org/10.1016/j.compcom.2015.09.001

Ouellette, G., & Tims, T. (2014). The write way to spell: printing vs. typing effects on orthographic learning. *Frontiers in psychology*, 5, 117.

Sandberg, G. (2022). The use of digital technology for differentiation of teaching in early school years. *Nordic Journal of Literacy Research*, *8*(1). https://doi.org/10.23865/njlr.v8.3104

Skar, G.B., Lei, PW., Graham, S. et al. Handwriting fluency and the quality of primary grade students' writing. *Read Writ* 35, 509–538 (2022). https://doi.org/10.1007/s11145-021-10185-y

Spilling, E. F., Rønneberg, V., Rogne, W. M., Roeser, J., & Torrance, M. (2021). Handwriting versus keyboarding: Does writing modality affect quality of narratives written by beginning writers? *Reading and Writing*, 35(1), 129-153. https://doi.org/10.1007/s11145-021-10169-y

Srihari, S. N., Xu, Z., & Hanson, L. (2014). Development of handwriting individuality: An information-theoretic study. 2014 14th International Conference on Frontiers in Handwriting Recognition, 601-606. https://doi.org/10.1109/icfhr.2014.106

Tondeur, J., Pareja Roblin, N., Van Braak, J., Voogt, J., & Prestridge, S. (2016). Preparing beginning teachers for technology integration in education: Ready for take-off? *Technology, Pedagogy and Education*, 26(2), 157-177. https://doi.org/10.1080/1475939x.2016.1193556

Wandell, B. A., & Le, R. K. (2017). Diagnosing the neural circuitry of reading. *Neuron*, 96(2), 298-311. https://doi.org/10.1016/j.neuron.2017.08.007

Wiley, R. W., & Rapp, B. (2021). The effects of handwriting experience on literacy learning. *Psychological Science*, 32(7), 1086-1103. https://doi.org/10.1177/0956797621993111

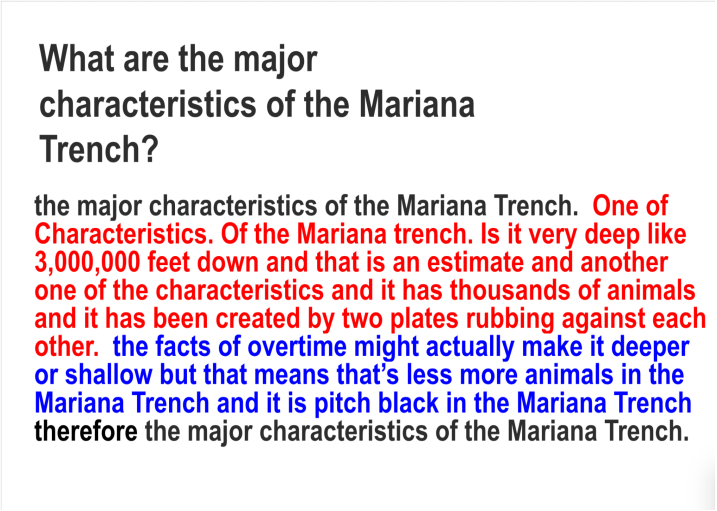
Appendix I

The scale and descriptions used to evaluate reading responses

Category	1	2	3	4
Grammar	No punctuation or punctuation used incorrectly. Most words are spelled incorrectly	Some punctuation, but there are still several grammatical errors, including misuse of punctuation and spelling errors.	Punctuation used mostly correctly, with few errors. Fewer than three words are spelled incorrectly.	No grammatical errors nor spelling errors. Students also attempt more complex grammar styles (semicolons or colons).
Sentence Structure and Variety	Several run-on sentences or incomplete sentences.	Complete, but short sentences. Repeat the same sentence starter throughout the response.	Sentences are complete, but simple. Students use more variety in sentence starts.	Use of complex sentences and uses a variety of different sentence starts that connects ideas together.
Length	1-4 sentences.	5-7 sentences.	8-9 sentences.	10 or more sentences.
Flow	Sentences are choppy and ideas do not flow from one sentence to the next. There are no transition words used.	Sentences are somewhat choppy, but there are no transition words used to connect ideas.	Some transition words. Writing is still less choppy. Students are not completely connecting ideas between sentences.	Ideas flow together between sentences with frequency use of transition words.

Appendix I

Sample of student response



Note. This student's response got an average score of 1.25 (grammar score of 1, a sentence structure and variety score of 1, a length score of 2, and a flow score of 1).