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WRITING VERSUS TYPING DURING SCIENCE TEACHING: CASE STUDY IN SLOVENIA

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Abstract. *In a case study conducted in a biology class in Slovenia, six grade students participated in a biology project Writing Versus Typing in a Biology Class. The final task in this project was to write a chapter for a biology textbook with the title Urtica dioica. The task was performed twice: firstly, the text was written by the hand and secondly it was typed on the computer keyboard. Handwritten and keyboard typed scientific texts, textbook chapters, were compared with the special focus on the lexical, syntactic, and semantic level of the text. The purpose of this research was to find out the effect of replacing handwriting with typing in the process of teaching/learning science subjects, where the understanding of texts is of crucial importance. A closer look at the students' text products in the typing modality reveals that students, while typing, seem to be cognitively overloaded. One of the consequences of this is a lower level of cognitive achievement in their typed text: students show less knowledge, less terminological accuracy, and, above all, a lesser understanding of the interconnection between the items of information provided.*

Keywords: *biology science class; embodied cognition, handwriting, keyboard writing.*

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Introduction

There is no doubt that in present-day society, including the media, politics and education science, digital immigrants (i.e. teachers) have to adopt their teaching paradigm, the learning environment and curricula to the Generation Z, called also digital natives. An international consensus on this matter was confirmed within the document: Policy Brief *Digital Natives: How do they learn How to teach them,* published by the UNESCO Institute for Information Technologies in Education (Cornu, 2011). According to this concept, the school has to move from 'paper pedagogies' to 'digital pedagogies', because 'paper pedagogies' cannot adopt to digital tools (Cornu, 2011).

One of the first pedagogical changes in this direction was the demand for a shift from an offline reading to an online reading curriculum. According to early reading research theories, the so-called "old literacies" are useless in e-learning environments, especially for learning from the World Wide Web (Spiro, 2004). Later research rejected this theory. Reading online was confirmed as an active, constructive, and meaning-making process, in which readers actively construct meaning. According to the theory of *new literacies of online research and comprehension*, the online reading competence is structured (Leu, Forzani, Burlingame, Kulikowich, Sedransk, Coiro, & Kennedy, 2013). It contains in the frame of each structural element skills, very similar to those particularly useful in the process of linear reading, and additional complexities needed for internet reading comprehension (Kordigel Aberšek, Dolenc, Flogie & Koritnik, 2015).

The situation in writing research seems to be very similar to the situation of where reading research was two decades ago: the public opinion (the media) advocates abandoning handwriting from curricula, and replacing it with keyboard typing. On the other hand, theoretical scientists and empirical researchers are warning against mindless curriculum changes. As A. Mangen says, "The marginalization of handwriting invites a number of reflections concerning practical and pedagogical as well as cognitive aspects of writing" (Mangen, Anda, Oxborough, & Brønnick, 2015, p. 228).

The Cognitive Aspect of Marginalization of Handwriting in the Curriculum

Replacing handwriting with typing is, according to contemporary cognitive science, not only an act of adjusting the writing curriculum to new, predominantly technical devices. It will have, with high probability, implications for high-level cognitive processes of the Generation Z (Kiefer & Trump, 2012). Cognition, namely, does not take place only in our brain, but also in our perceptual and motor systems (Calvo & Gomila, 2008). According to the *embodied cognition theory*, the processes of perception (visual, audio, tactile), motor action and cognition are strongly and reciprocally connected (Gibbs, 2005; Shapiro, 2010). Embodied cognition is an active, sensory probing of the lifeworld surrounding humans. According to the embodied cognition theory, cognitive development is not exclusively brain activity. Learning and cognitive development are processes, in which we develop representations by – haptically – interacting with the environment, by exploring our surroundings with all our sensory modalities. In other words, theoretical and empirical knowledge about cognition and the human brain points out the necessity of acknowledging that hands have a role to play in teaching and learning (Goldin-Meadow, 2003) – not only in gestures and non-verbal communication, but also, and more specifically, in the haptic interaction with different technologies (Mangen & Velay, 2010).

The connection of cognitive processes with external (perception) and internal (proprioception, emotion and introspection) as well as bodily actions that produce simulations of previous experiences, takes place also in the process of writing acquisition (Kiefer & Trump, 2012). Although alphabetic characters are not physical objects, we can assume that motor-perceptual links contribute to their representation, since they are associated with specific handwriting movements. These movements entail producing graphic forms as close as possible to the corresponding visual model. Handwriting movements are thus associated with consistent spatial information about the letter. In short: we apply knowledge about the implicit motor rules involved in writing by hand, during the perception of handwritten traces. (Mangen et al., 2015).

The Sensorimotor Aspect of Writing

Writing is by definition the production of some kind of text onto some kind of surface, by employing some kind of technical device. Changing the technologies of writing has significant implications, because different technologies are materially configured in different ways. That is, different writing technologies set up radically different spatial, tactile, visual, and even temporal relations between the writer's material body and his or her text. In the process of writing, the body is the mechanism by which the mediation of the mental and the material occurs (Haas, 1996).

The act of writing is a complex cognitive process relying on intricate perceptual sensorimotor combinations. Writing is the process of externalizing the content of our thinking, what we know, what we think, what we feel… Writing always involves the skilful handling of some mechanical/technical device, and necessarily results in a visuographic representation – some kind of readable text in the form of letters or symbols (Mangen & Velay, 2010). As neuroscientific research points out, writing is a process that requires the integration of visual, proprioceptive (haptic/kinaesthetic), and tactile information in order to be accomplished (Fogassi & Gallese, 2004).

The acquisition of writing skills in previous generations involved a perceptual component, learning the shape of the letter, and a graphomotor component, learning the trajectory producing the letter's shape (Van Galen, 1991). This is a process, which is probably going to change with Generation Z. Today, most of that is written with the help of some kind of digital device, a laptop, tablet or smart phone. Computers and keyboards are replacing pen and paper and children are increasingly encouraged to type instead of writing by hand. With the emergence of new technologies, hands play a different role for the new generation. They click and scroll using a computer mouse, and tap keys on keyboards and screens, instead of putting pen or pencil to paper. This switch from pen and paper to mouse, keyboard, and screen entails, according to Mangen and Velay (2010), major differences in the haptics of writing at several levels. When writing by hand, we use only one hand, whereas typewriting typically involves both hands. Handwriting is commonly experienced as a slower and more tiresome process than writing with a keyboard. Writing by hand requires the writer to shape each letter, whereas in typewriting, obviously, there is no such graphomotor component involved. Moreover, a child's visual attention is commonly restricted to precisely the point where the pencil hits the paper during handwriting, while during typewriting there is a distinct spatiotemporal decoupling between the visual attention and the haptic input. And finally: word processing software provides a number of features, which might radically change the process of writing, from autocorrect and spell-check options to large-scale genre templates (Mangen & Velay, 2010).

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The Pedagogical Aspect

The pedagogical aspect of the dilemma of typing versus writing should be considered from two aspects. The first one is the aspect of writing acquisition (*learning to write*) and the second one is the aspect of *writing to learn*. This *writing to learn* has a significant role in the process of learning (Lund, 2014). It has to be seen as an important tool in the process of constructing new knowledge, understanding, and skills. It can be used to reproduce and to reflect the facts, to reformulate issues, and help to develop and organize one's thinking (Langer & Applebee, 1987). In combination with reading, writing can be used to take notes for later use in the function of extended memory, to interpret sources and perspectives, to organize materials, to structure new knowledge, and to share this knowledge with others.

For the pedagogical aspect of the dilemma of typing versus writing, it is an important assumption, derived from embodied cognition theory (Calvo, & Gomila, 2012; Gibbs, 2005) that the two processes of *learning to write* and *writing to learn* are connected and interdependent. Empirical research on this question is still scarce, but the existing results of experimental studies seem to confirm the connection. Research related to the dilemma of typing versus writing in connection to learning, can be divided into three groups, according to the linguistic level on which cognitive results have been measured. Some studies measured the influence of typing and writing on letter acquisition (phonological, or grapheme level), others focused on word recall (morphological level), and still others on the connection between writing/typing and the quantity and quality of knowledge (semantic level).

Phonological Level

Longcamp, Anton, Roth, & Velay (2005) studied how children memorized letters. In the experiment, one group learned letters by using the pen and the other by using the keyboard. The results of children who learned letters by handwriting showed better memorization and recognition when compared to the results of the children using a keyboard. Three years later (2008), Longcamp conducted the same experiment using neuroimaging methods (functional magnetic resonance image – fMRI). The fMRI data showed that processing the orientation of handwritten and typed characters/graphemes did not rely on the same brain areas. In the case of handwriting, the activity of the brain was more pronounced in several regions known to be involved in the imagination, observation and execution of actions (Broca's area and bilateral inferior parietal lobules). These results confirm Griffin's assumption (1998) that the sensorimotor movements in writing by hand contribute to the memorization of the shape and/or orientation of characters, facilitating later perception and categorization, which seem to be an important predictor of later reading skills.

A recent experiment by Li and James (2016) confirmed the important role of handwriting in contributing to children's symbol categorization (Mangen & Balsvik, 2016). In the experiment, five-year-olds were taught the names of Greek symbols – in six learning conditions. Three of them involved motor production (copying symbols, tracing typed symbols, and tracing handwritten symbols), the other three involved only visual and auditory practice. Subsequently, the children's categorization performance was tested. Results showed that children who studied multiple instances of the symbols performed better than the children who studied only a single prototypical example of the symbol.

Morphological Level

Smoker's research (2009) examined potential associations between writing modalities and memory on the word level. In the research, he compared the recall and recognition of words on a sample of 61 adults, in two writing modalities, pen on paper, and keyboard. The recall task asked participants to remember, in a period of five minutes, as many as possible of the words that were presented to them by writing them on a blank sheet of paper, while the recognition task presented a mixed list of 36 words consisting of stimuli words and new words. Participants were asked to indicate which words were stimuli words. In the second test, they performed the same task, but with the use of a keyboard. Results showed that memory on the recall task approached significance in favour of the handwritten words, while writing was significant in the recognition task. The number of errors in the recall task was significantly higher for the typing condition (Smoker, Murphy & Rockwell, 2009). According to the authors of the research "these findings support our hypothesis that the increased kinaesthetic information from handwriting creates a more complex memory trace than created by typing" (Smoker et. al, 2009, p. 1746).

Mangen, Anda, Oxborough and Brønnick (2015) performed a similar but extended experiment: they addressed the question of whether people (sample: 36 college students) remember words written as parts of lists better when they are written by hand than when they are typed using a virtual touch keyboard, or a mechanical laptop keyboard. In order to measure the effect of the writing modality on a central cognitive outcome, the research team used a word list paradigm, used in cognitive psychology to measure episodic verbal memory (Tulving & Thomson, 1973). The results show there is a statistical difference free recall, which was better in the handwriting condition than in both the keyboard, and the iPad typing condition. The authors of the research thus summed up the results: handwriting is associated with better free recall of hand-written material as compared to material written using conventional keyboards on PC's and virtual keyboards such as those in iPads (Mangen et al., 2015).

Semantic Level

Interdependence between the modality of the writing process and the learning result (semantic level) has rarely been the topic of scientific research. Mueller and Oppenheimer (2014) presented the results of such research in a paper with a straightforward title: *The Pen Is Mightier than the Keyboard: Advantages of Longhand over Laptop Note Taking*. They conducted some experiments to investigate whether taking notes on laptops versus writing longhand affects academic performance. Participants of their research were 67 students from Princeton University. In the first research, students listened to a fifteen minutes long lecture. They were instructed to take notes in the way they usually do (handwriting or laptop). A qualitative content analysis of their notes showed several differences: laptop notes were longer, students used more words, recorded more information. On the other hand, a closer analysis revealed that the notes taken by laptops contained an average of 14.6 % verbatim overlap with the lecture, whereas longhand notes averaged only 8.8 %. Later research showed that these results are a significant predictor of academic performance. Authors of the research interpret these results as a consequence of less cognitive effort in the process of note taking (they speak of 'mindlessness'). They conclude this part of the experiment with the following statement: "although taking more notes, and thereby having more information, is beneficial, mindless transcription seems to offset the benefit of the increased content" (Mueller & Oppenheimer, 2014, p. 4). This assumption was confirmed in a subsequent research conducted by the team. Again, students were free to choose the modality of their note-taking, and again, a qualitative analysis of notes showed the same results. After a week, the students' academic performance was tested. Students were divided into two groups. The first group answered a set of 40 questions, which accessed recall and understanding of lecture content, a lecture the students attended a week ago. The second group had the opportunity to study their notes before answering the same set of questions. In both groups, there were students who took notes by laptop, and those who took notes by handwriting. Results showed that participants who took longhand notes and were able to study them, performed significantly better (*z*-score $M = 0.19$) than the participants of any other group (*z*-score $Ms = --0.10, --0.02, 0.08$). The authors conclude that, when participants had the opportunity to study, longhand notes led to superior performance. In this context, it is important to point out the results of those students, who took notes on their laptops. They performed worse on conceptual questions than students who took longhand notes. This is suggestive evidence that longhand notes may have a superior external storage, as well as superior encoding functions, despite the fact that the quantity of notes was a strong positive predictor of performance. To sum up, Mueller and Oppeheimer's research suggests that even when laptops are used solely to take notes, they may still be impairing learning because their use results in shallower processing.

Results from the studies by Lund, Longcamp et. al, Smoker et al., Mangen et al., and Mueller and Oppeheimer, showed that there is an interdependence between the mode of writing and cognitive performance, i.e. the outcomes of the learning process. In all experiments, the participants who used handwriting, and in this way received additional kinaesthetic information, achieved significantly better learning results, which can be explained only at the account of a higher quality of cognitive processes.

The research in the field of interdependence between writing modality and cognitive achievement has been performed mainly with a focus on performance on the morphological and lexical levels, while the impact on performance on the semantic level has been investigated mostly among adults. The present research was designed with the motivation to explore the interdependence between writing modality and achievements on the lexical, syntactical, but also on the semantic level – the level of constructing and recording knowledge. Unlike Mueller and Oppenheimer, we did not use a questionnaire, which would investigate the quantity of the knowledge gained, and the quality of that knowledge (questions on a different level). To determine the interdependence between writing modality and cognitive achievement, we decided to observe texts created by students following a learning process

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during biology class. The observed text was a text defined as *a chapter in the biology textbook*. The task was to write a non-fictional text, *a description of a plant*, which should be structured according to the rules previously learned in the students' mother tongue and biology classes. In such a text, the writer should explain the facts learned about the plant, he should put these facts in logical order, and he should use the correct terminological vocabulary. Unlike in literary texts, no imagination could be used, and metaphorical language could be used only if standardized.

Methodology of Research

General Background

A qualitative and quantitative research approaches were adopted, since the main aim of the research was rather exploratory, due to a lack of extensive data, which is the consequence of the effort to exclude the influence of other factors than writing modality on the quality and quantity of the written text. A text analysis was undertaken according to categories defined in the focus of research questions. The research was performed on a sample from the younger population (5th grade of a primary school), since it was noticed that the majority of existing research was performed on samples from the adult population (university students).

Following research questions were addressed:

1. How does the written text differ from the typed text? Are the differences equally noticeable on the quantitative as well as on the qualitative level?
2. Are the differences between the written and the typed text interdependent with the level of acquired basic computer skills?

According to theoretical background and previous research, quantitatively and qualitatively better results in the writing modality than in the typing modality were assumed:

1. students would write more words and more different words than later in the typing situation, and that they would write more terms (and more correct terms) than in the typed text.
2. On the syntax level, there was assumed that students would write more sentences, that the sentences would contain more words; and also that the written text would have a more advanced syntax structure than the typed text.
3. A better performance on the level of coherence of the text was also assumed. In the writing modality a more consistent use of the features of text structure.
4. In the written texts, better performance in the use of cohesive means to create coherence was expected.
5. The greatest differences between the written and typed texts were expected on the semantic level. In the written texts were expected more knowledge and a deeper understanding of knowledge than in the typed ones. The research was performed in April 2017.

Participants and Context

In the pilot research, the participants were 26 children, aged between 10 years 9 months, and 11 years 9 months. The sample is rather small. The purpose for choosing a small sample, students' of one class, was a deliberate decision made to narrow the influence of other factors, which could have had an influence on research results. All children were students of the same class (5th grade of primary school). This was important to guarantee the same educational context for the entire research: all children had the same computer education (delivered by the same computer skills teacher). All students had the same number of hours spent on the computer device, which they used for typing their text in the present research; all children participated in the same biology research project and had the opportunity to construct the same amount of knowledge about *Urtica dioica*.

At the beginning of the research, a pre-test (TICA Basic Skills Checklist (Leu et al., 2008)) of the students' basic computer skills was performed. Students evaluated their own basic computer skills. They were told the results of the survey will be kept anonymous, so instead of signing their name, they should mark them with a special (self-invented) code. The pre-test consisted of a list of 21 basic computer sub-skills, and on the list the students were asked to mark whether *they know*, *they do know but sometimes need the help of the teacher*, or *they do not know yet*. Following the triangulation approach, the computer skills teacher was asked to re-evaluate the students' self-evaluation. According to these results, students were divided into three groups, considering whether their basic computer skills were good, modest, or poor.

Research Procedure

All 26 students participated in the biology project – they were divided into groups according to their own choice. After being informed they are going to perform a research project about the plant stinging nettle (Lat. *Urtica dioica*), they were asked to use a KWL scaffolding method (what I already **k**now, what do I **w**ant to learn about it, what did I **l**earn) (Sadler, 2011). According to this learning strategy, they first produced a list of *what do they already know* about the plant, followed by the second one where they wrote down *what do they want to learn* about it. In the next stage, the groups began to collect information and knowledge about the *Urtica dioica* using a research-based learning approach. They gathered information and knowledge in the school library, home libraries, and on the World Wide Web. Every second day they began their schoolwork with a biology class. They shared the newly gained knowledge with schoolmates from their group. Together it was decided whether the information was correct and important and how it should be recorded on the graphic organizer they designed together (Fisher et al., 2009). After a week, each group presented their findings about *Urtica dioica* to all the other groups.

Data Collection

After studying their own graphic organizers, after 24 hours, the students were asked to write a *textbook chapter* for their future colleagues, who will attend the same biology class next year and learn about *Urtica dioica*. Together with the textbook chapter, a text sample was defined in terms of correctness of information, terminological accuracy, and structure of the text: *description of the plant* (the students already knew this from their mother tongue class, and also from previous uses of this type of text structure in their biology class).

After another day, the students had a computer science class in the computer classroom. They studied their graphic organizers once again. The next step was turning on their computers and writing the biology textbook chapter about *Urtica dioica* again. When they finished, each student saved and printed his text and marked it with a special (self-invented) code, the same one he had used for coding his written text and his basic computer skills evaluation sheet.

Two instruments were used in the process of this research: a pre-test with a Computer Basic Skills List (CBSL) for each student, and a final test for evaluating the impact of the writing modality (IWM) on the lexical, syntactical, and semantic features (quantitative and qualitative knowledge about *Urtica dioica*). The students' basic computer skills were measured by means of an adopted TICA Basic Skills Checklist (Leu et al., 2008), a checklist consisting of 21 items related to basic computer skills. These skills were divided into three groups: computer basics, web-searching basics, and general navigation basics.

The quality of the written and typed "textbook chapters" on the subject of *Urtica dioica* was measured with the use of the *Impact of Writing Modality* (IWM) test that was developed by a research team (Kamiloff, & Kamiloff Smith, 2001) and focused on the linguistic and thematic achievement level of such student texts. IWM was developed to precisely observe which type of knowledge students demonstrate in the text, and how they understand that knowledge, by observing the language they use for expressing it, since texts are always a means of externalizing human thought. IWM consisted of five sets of criteria and evaluated the text on the lexical, syntactical, and semantic level.

1. On the lexical level, the number of used words and the number of different words was counted according to the supposition that typing, as the more demanding writing modality, will cause more lexical repetitions (i.e. less different words in the text). Further, a terminological accuracy was observed on the lexical level: the number of used terms and the number of correct terms were counted and compared.
2. For evaluating the syntax level, sentences and the syntactic structure of sentences was observed. These criteria gave us an insight into the students' quantitative, but also their cognitive achievement. Compound sentences were assumed as a cognitively more demanding text feature than simple sentences. An even deeper insight into the students' cognitive achievement provides a comparison of the number of coordinate and subordinate clauses used to construct complex sentences. Including complex sentences with subordinate clauses points to a cognitively more advanced level of narrative.
3. Criterion, included in the test was coherence of the text. According to Kamiloff and Kamiloff Smith (2001), coherence and cohesion are the key criteria for evaluating storytelling, and consequently the explicatory text in the biology textbook. The coherence of a text refers to the meaningful connections that readers perceive in a written (or oral) text.
4. Cohesion within a text was the 4th criterion. Cohesion is the process of linking and connecting sentences

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together through a variety of linguistic and semantic ties, which can be broken into three types of semantic relationships: immediate, mediated, and remote ties. In writing, the author can choose among several devices for creating cohesion, called cohesive clues. In the IWM survey, we defined three groups of cohesive clues: repetition, pronouns and synonyms, and hypernyms and homonyms in the function of transitional expressions.

5. The 5th criterion measured the knowledge about *Urtica dioica*, which the students have constructed during the biology project and which they expressed in their written or typed textbook chapter. The number of correct thematic items and the number of incorrect thematic items were observed and compared. Finally, the survey focused on the students' understanding of the interconnectedness of thematic items. Understanding the interconnectedness of thematic items and including this understanding into the text in such a way that the reader can understand the logical relationship between the information, demands from the student a high level of cognitive involvement – which would not be possible if the student would struggle at the same time with his basic computer skills.

Data Analysis

Typed and handwritten texts were studied and evaluated according to verbal, syntactic, and semantic elements with the help of the IWM survey, developed for this purpose. Data obtained from the written text of each student was compared to the data obtained from their typed texts, and all results were observed and evaluated from the perspective of the students' basic computer skills list. Quantitative data in the research groups were collected, reviewed, and evaluated by a group of experts from the field of educational science. Quantitative data collected in the research groups was statistically analysed to get better insight in research problems according to the following phases: encoding, defining, and organizing the data, and interpreting the results with SSSP program.

Research Results

To evaluate the quantity and quality of the written and typed non-fictional texts about *Urtica dioica* from the perspective of students' basic computer skills, the sample was devided according to the number of collected points in the students' Computer Basic Skills List CBSL. Three groups were formed: students with good computer basic skills (21–18 skills), students with moderate computer basic skills (17–14 skills), and students with poor basic computer skills (13 and less skills).

Results in Tables 1–5 show differences between two writing modalities in the amount of knowledge gained in biology classes during the research project *Urtica dioica*, and in the level of understanding that knowledge, and differences in achievements regarding the basic computer skills.

Table 1. Lexical level: number of words and number of terms.

Basic computer skills	Good				Moderate				Poor			
Writing modality	Writing		Typing		Writing		Typing		Writing		Typing	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
1.1 Number of used words	152.5	29.67	166	36.2	132.4	49.7	146,2	49.4	103.6	31.6	107.3	40.1
1.2 Number of different words	143.5	33.85	159	31.97	121	46.0	134.2	48.0	102.6	34.7	98.3	36.6
1.3 Number of used terms	15.7	3.3	14.1	3.92	13.2	2.1	11.7	2.5	9.2	3.5	7.3	3.2
1.4 Number of correct terms	14.3	3.86	13.7	4.79	11.3	3.1	10.4	3.1	8.3	2.3	6.2	2.6

The results in Table 1 show that even younger students can type faster than they can write, which could be a consequence of the differences in the haptics of writing and typing. Students with good and students with moderate basic computer skills used more words in their texts about *Urtica dioica*, and also used more different words. Only the group with poor basic computer skills used fewer words and less different words in the typing modality. Counting the number of terms and the number of correct terms gives different results: all groups of students used less terms in the typing modality than in the writing modality. And all groups made more mistakes in the process of using correct words to explain their knowledge – when the typing process was not only a question of fluency, but also a question of recalling new words for signing the newly-learned topic (for example: hollow stinging hairs, called trichomes). A slower writing process seemed to be of advantage.

Table 2. Syntax level.

Basic computer skills	Good				Moderate				Poor			
Writing modality	Writing		Typing		Writing		Typing		Writing		Typing	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
2.1. Number of clauses	23.2	5.7	26.5	5.4	20.4	5.9	19.2	5.2	18.3	3.2	17.2	6.6
2.2. Number of clauses per sentence	2.33	0.65	1.74	0.4	1.9	0.1	1.65	0.03	1.48	0.2	1.13	0.2
2.3. Number of coordinate clauses	1.25	0.5	4.25	3.5	2.1	0.6	2.3	1.7	2.3	2.5	2.5	2.5
2.4. Number of subordinate clauses	4.75	1.22	3.25	1.53	3.7	1.6	3.1	1.53	3.0	0.0	1.43	0.6

The results in Table 2 on the syntax level point to similar conclusions as the results on the lexical level. More clauses in typed texts, written by students skilled in the use of the computer were observed. There was almost no impact of the writing modality on the number of clauses in texts by students with moderate computer skills, and there was a slightly smaller number of clauses in texts by students with poor basic computer skills.

A closer look at the quality of the written and typed clauses on a syntactic level provides a different picture: observing the compound sentences, we calculated the number of clauses per sentence, and found out that sentences in texts written in the typing modality have a simpler structure. All groups of students used a type of narrative with a lower number of clauses per sentence.

Even more persuasive is the result of observing the number of coordinate and subordinate clauses. In English grammar, a coordinate clause is a clause belonging to a series of two or more clauses which are not syntactically dependent and are introduced by one of the coordinate conjunctions – most commonly 'and', 'but', or 'or'. A subordinate clause or a dependent clause is a clause that cannot stand alone as a complete sentence. It is always used together with the so-called main clause and is introduced by a subordinating conjunction, such as 'because', 'when', 'unless'… A subordinating conjunction is a grammatical means, which links constructions by making one of them a constituent of another. The subordinating conjunction typically marks the incorporated constituent. Most common subordinating conjunctions are adverbializers, which indicates, that the subordinate clause they introduce has an adverbial relation to the main clause, indicating purpose, condition, time, or location.

In the typing modality the number of coordinate clauses in texts written by all three groups of students increased, while the number of subordinate clauses decreased. This can be understood as a consequence of a lower cognitive involvement in text production, since we know from grammar that complex sentences consisting of subordinate clauses express some kind of logical interdependence between two facts, items, or events.

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Table 3. Text coherence.

Basic computer skills	Good				Moderate				Poor			
Writing modality	Writing		Typing		Writing		Typing		Writing		Typing	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
3.1 Narrative without structure	0	0.0	0	0.0	0		0	0.0	0	0.0	0	0.0
3.2 Narrative partly uses features of text structure	0	0.0	0	0.0	1,33	0.6	3	1.0	3	1.0	5	2.0
3.3 Narrative consistently uses features of text structure	9	1.7	9	2.0	9	1.7	7	3.5	4	1.0	2	1.6

Coherence (see Table 3) increases directly with the amount of guidance a writer provides to the reader, either through context clues or through direct use of transitional phrases to direct the reader through an argument or narrative. Coherence is mainly the result of adequate paragraph structuring. The students in our survey have already learned previously about the adequate text structure for a description of a plant, which includes parts of scientific classification (family), description, distribution, usage, and interesting facts.

Results concerned with text coherence clearly show that none of the students had submitted a text without any kind of text structure. The narrative structure, which partly uses general features of text structure, was more frequently observed in texts written in the typing modality. These skills, which naturally employ features of text structure, were more frequently observed in texts written by students with a good level of basic computer skills, regardless of the writing modality.

Table 4. Cohesion.

Basic computer skills	Good				Moderate				Poor			
Writing modality	Writing		Typing		Writing		Typing		Writing		Typing	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
4.1 Thematic distribution												
4.1.1. Leap of thought	0	0.0	0	0.0	2	0.5	5	1.2	6	1.2	7	1.8
4.1.2. No leap of thought	9	1.2	9	1.8	8	1.1	5	2.2	1	0.5	0	0.0
4.2 Cohesive clues												
4.2.1. Repetition	4.2	1.2	6.3	1.4	4.9	1.2	7.0	2.1	5.7	1.0	7.8	1.0
4.2.2. Pronouns	15.7	4.4	13.2	3.8	14.2	1.5	12.1	3.8	10.2	1.7	8.4	2.9
4.2.3. Synonyms, hypernyms	1.25	0.5	0.25	0.5	0.7		0.2	0.6	0.9		0	0.0

Results regarding the thematic distribution of knowledge, learned in biology class, in the frame of each paragraph show a lower level of achievement in typed texts, written by students with moderate or poor basic computer skills. Because of a cognitive overload in the typing modality, the student forgets to put down everything he had learned about *Urtica dioica*, and has to be written on that subject in that particular paragraph. Students proceed to the next paragraph and then he/she remembers what he/she should have written in the previous one. However, student does not return to that particular paragraph (even though the word processor makes it possible), but rather adds the forgotten information to the paragraph he is currently writing.

Cognitive processes involved in the two modalities, typing and writing, were also observed through the perspective of the students' choice of cohesive clues. A writer creates cohesion by choosing from a variety of the so-called cohesive clues: he can for instance use repetition, pronouns, transitional expressions, or other devices to guide readers and show how parts of text relate to one another. In the IWM we counted the number of repetitions (as the simplest cohesive means), the number of pronouns, and the number of synonyms and hypernyms (as a highly cohesive means). Results show a great impact of the writing modality on the choice of cohesive means: students in all three groups used, in the typing modality, a greater number of repetitions, a slightly smaller number of pronouns, and a considerably smaller number of synonyms or hypernyms.

Table 5. Semantic level (thematic items and understanding the interconnectedness among them).

Basic computer skills	Good				Moderate				Poor			
Writing modality	Writing		Typing		Writing		Typing		Writing		Typing	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
5.1 Number of correct thematic items	42.7	6.6	40.5	7.3	30.6	14.2	26.3	10.1	15.3	2.1	12.6	1.2
5.2 Number of incorrect thematic items	1.25	0.5	2.5	0.5	2.6	1.5	2.9	2.3	2.6	1.5	4.1	1.5
5.3 Understanding interconnectedness of thematic items	2.5	1.3	1.0	0.5	1.6	0.6	1.0	1.0	1.3	1.0	0	0.0

The results of texts produced in different writing modalities were compared on the semantic level (see Table 5), which is closely connected to cognitive processes that are involved in the verbalization of knowledge. Results show consequences of cognitive load and cognitive overload in all three groups of the sample. In all three groups, the number of correct thematic items presented in the text was lower when students used a keyboard. In the typing modality, students also listed a greater number of incorrect thematic items. However, the most meaningful observation regarding the cognitive level of achieved knowledge on the level of syntax is the difference in understanding the interconnectedness of thematic items expressed in the text. (For example: "Stinging hairs are very fragile. This is why when touching them, they transform into needles that can inject several different types of chemicals into the skin. These chemicals cause a burning, painful stinging on the skin. This is the reason why the common name for *Urtica dioica* is a stinging or burning nettle.") Using these criteria for the typed and written texts, we established the greatest difference between the two writing modalities. The number of expressed understanding of interconnectedness between information in the typing modality was meaningfully lower also among students with good basic computer skills, while such understanding was entirely absent (i.e. the number was zero) from the typed texts produced by students with poor basic computer skills.

Discussion

The obtained results only partly confirmed research assumptions. More precisely, the results on the lexical and partly on the syntax level showed a different picture than was initially expected. The writing modality seemed to have no influence on the number of words used, on the number of different words used, nor on the number of sentences. On the contrary, some students wrote more words and more sentences in the typing modality. However, the typing modality does seem to have an influence on cognitive achievement: in comparison to the typed texts, the syntactic structures of written texts show a more elementary use of sentence structure. In addition, on the semantic level more knowledge and a deeper understanding of knowledge were detected in the written texts than in the typed texts.

Evidently, students were able to express new scientific knowledge about *Urtica dioica* better in the handwriting than in the typing modality. In the handwriting modality, they also expressed a higher level of understanding of this knowledge – which is the most important curriculum goal of science education.

Finally, a stronger influence of the writing modality on the quantity and quality of texts by students with a lower level of basic computer skills was observed. Results of the present research thus partly confirm the expectations based on theoretical background, i.e. embodied cognition and neuroscience. According to the embodied cognition theory, as already mentioned, cognitive development is not only an activity of the brain: when we learn,

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we develop representations in the process of interacting with the environment, through experiencing our surroundings with all our sensory modalities. Goldin-Meadow (2003) points out in this context: "hands simply have an important role in the processes of teaching and learning." According to Haas (1996), writing is a complex cognitive process of externalizing the content of our thinking, which requires the integration of visual, proprioceptive and tactile information in order to be accomplished (Fogassi & Gallese, 2004). Based on neuroscientific research, we can assume that such a change in the visual, proprioceptive, and tactile stimuli, which occurs with the switch from pencil and paper to keyboard, influences, with high probability, the writers' thinking processes, and consequently their learning achievements and cognitive development. The results of presented research confirm this assumption: in the typing modality, the number of coordinate clauses increased and the number of subordinate clauses decreased – a consequence of lower cognitive involvement while using the keyboard.

The results of research also confirm expectations derived from previous experimental research: Longcamp et al. (2005) compared the memorization of letters by children. Her results confirm a better learning outcome in children who used the pencil in their learning process. Smoker (2009), and Mangen et al. (2015), also proved the same influences of the writing modality on learning results. The results of research thus correspond with results discovered by Longcamp, Smoker and Mangen. Students wrote more terms and terms that are more correct in the paper writing modality than in the typing modality. They used a greater number of correct thematic items and a smaller number of incorrect thematic items while using paper and pencil, and they were more often able to express their understanding of the interconnectedness between thematic items.

The present research also corresponds with the results presented in Mueller and Oppenheimer's research (2014). Similarly, to their survey, our students also wrote more words (also students with poor basic computer skills) and more different words (the exception were students with poor basic computer skills). Although this should be a strong predictor of higher learning outcomes, this is not the case. In both their studies, Mueller and Oppenheimer's students learned less when using the keyboard: in presented research, they not only wrote down a smaller number of thematic items and a greater number of incorrect thematic items, while using the keyboard, they also failed to express their understanding of the fact that particular aspects of knowledge are interdependent – logically connected. A similar cognitive result was observed in Mueller and Oppenheimer's research, which underlined lower results in the category of answering conceptual questions. Typing obviously impairs the learning process, because its use results in shallower processing.

In addition, the results regarding the interdependence between the level of basic computer skills and its influence on the lexical, syntax and semantic levels of the typed text are in correspondence with previous research. DeStefano and LeFevre (2009) conducted research concerned with the idea of cognitive overload in the process of reading texts from the screen. They assumed that reading hypertext would cause a cognitive overload in students with a low working memory, and that they would have substantially more problems with this type of reasoning than those who have a high capacity of working memory. Their results show that students with a large working memory have the mental energy required for the metacognitive processing of learning/reading, i.e. the processing and thinking about what they understand. On the other hand, students with a small working memory, it seems, do not possess this mental energy. The situation with cognitive overload seems to occur with students with poor basic computer skills. They use a great amount of mental energy for the technical part of text production on the computer. Consequently, they do not have enough energy left for coding (writing) their knowledge. They do not remember the thematic items, they do not remember how these thematic items are logically connected or interdependent, they do not have the mental energy to remember and follow the text structure, and their typed texts evidently demonstrate leap of thought.

Conclusions

The results of presented research can be interpreted as confirming the expectations based on theoretical background (embodied cognition), as well as expectations based on previous research concerned with the interconnection between writing modality and cognitive achievement. Generation Z evidently uses the keyboard with greater ease than the pencil, and they are able to type a greater number of words on the computer in the same period as they are able to write them with a pencil. A closer look at their text products, however, shows a different picture: in the typing modality, they seem to be cognitively overloaded. In addition, one of the consequences of this is a lower level of academic achievement in their typed texts: they show less knowledge, less terminological accuracy, and, above all, less understanding of the interconnection between listed information. This can be seen as important information related to the processes of learning and cognitive development. According to various theories, *writing to learn* has a significant role in the processes of constructing new knowledge, understanding, and skills. It is used to reproduce and reflect facts, to reformulate issues and help to develop and organize one's thinking. Consequently, the school system has to slow down in its readiness to abandon handwriting and substitute it with keyboard writing. Teachers have to consider the influence of this kind of shift on the students' cognitive development and knowledge construction, as well as the influence it has on the outcomes of educational goals, concerning the curricula of their natural science classes. Presented case research conducted in a biology class, confirms such considerations: replacing handwriting with keyboard writing has, as proven by presented research, implications for high-level cognitive processes of the future generation.

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