Handwriting-based Learning Materials on a Tablet PC: A Prototype and its Practical Studies in an Elementary School

Naomi Iwayama, Katsuhiko Akiyama, Hiroshi Tanaka, Hiroaki Tamura, Kazushi Ishigaki
Fujitsu Laboratories Ltd., 64 Nishiwaki, Ohkubo-cho, Akashi, Hyogo 674-8555, Japan
iwayama.naomi@jp.fujitsu.com

Abstract

This paper presents handwriting-based learning materials (HLMs) on a Tablet PC and their practical studies in an elementary school. We designed HLMs to be created using HLM components or a HLM template for teachers to create their original materials. Practical studies demonstrated that HLMs could be effectively used when children expressed and presented their ideas in a classroom and when they practiced calculations and characters by hand. We also investigated the application of a handwriting recognition technique to automatically check children's handwritten answers to drill materials. Using questionnaires, we confirmed that automatic checking not only saved time but also improved the children's motivation to learn. HLMs were enthusiastically embraced by both field teachers and children.

1. Introduction

A crucial advantage of pen-based computers is that they support the use of handwriting. We have been studying handwriting recognition [1-4] in attaining our goal of developing handwriting-based input technologies that will offer huge benefits to many users. Factors affecting the achievement of our goal have been a handwriting recognition engine, handwriting-based interfaces, and the development of a handwriting-based "killer application" [5]. We believe that a killer application would have to satisfy two conditions. The first is that there is no means of accomplishing the task in question other than through the application. The second is that field users have a genuine need for the application. Which handwriting-based application would be a "killer application"? The goal of this paper is to provide one answer to this question.

At this point, we should mention that the use of computers has been proven to be of considerable benefit to education. However, a computer with an interface based on a keyboard and mouse restricts practical use in school education to narrow limits. This is because such a computer cannot be used when children learn with handwriting. For example, the only way to learn more than one thousand Kanji characters (ideographic characters of Chinese origin) taught in Japanese elementary school is to repeatedly write them.

One solution to this problem is handwriting-based digital learning materials (HLMs). Since Tablet PCs have come onto the market, some HLMs for them have been developed [6]. A field-test on Tablet PCs in conjunction with the Microsoft Journal was done in a primary school [7]. These applications are ready-made and work well in a specific situation. Since children have many opportunities to learn by writing in school, field teachers desire varied and abundant HLMs. They also expect to be able to create and customize them. Teachers take on the job of teaching hoping to generate imaginative and original materials.

To enable HLMs to satisfy filed teachers' needs, we took the following three steps. First, we studied the necessary conditions to develop HLMs in collaboration with teachers. Second, we developed HLM components and HLM templates that corresponded to the necessary conditions. Last, we created HLMs with the templates. Through this approach, teachers can efficiently create or customize HLMs with the components or the templates.

To verify whether there was strong demand for HLMs, we put our experimental HLMs into practice in a Japanese elementary school for a four-month period. Practical studies revealed that our HLMs contributed to children's learning in various situations. HLMs, which allowed children to write freely, were useful for sharing ideas with classmates. Drill materials for learning Kanji characters, which determined whether handwritten Kanji characters were correctly formed both in shape and stroke order, provided a solution to a long-standing educational problem. We also applied handwriting recognition to automatically check children's handwritten answers to maths materials. The maths materials made children want to learn more.

In Section 2 of this paper, we describe our goals for HLMs. We describe their components in Section 3 and in Section 4, we introduce our HLMs. In Section 5, we report on their practical studies. In Section 6, we discuss the impressions teachers and children had of HLMs as reported on a questionnaire. Our conclusions are presented in Section 7.

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2. Our HLM Goals

We will begin by describing our goals for HLMs. We feel that HLM should be used in various situations for education in schools. We studied the necessary conditions for HLMs in collaboration with teachers and set ourselves the following four goals for introducing them.

(1) HMLs should enable children to write freely according to their thinking processes.
(2) HLMs should enable children's handwritten answers to be checked.
(3) HLMs should enable children's handwritten Kanji characters to be checked for correctness both in shape and stroke order. HLMs should consequently enable children to be advised on how to write their characters correctly.
(4) HLMs should be easy for teachers to create and customize.

We set the first goal because children often have the opportunity to express their ideas by writing in their notebooks. If children could also use HLMs to record their ideas, it would be possible to project these ideas onto a whiteboard so that they could be easily shared with their classmates.

We adopted the second goal because we believed that immediate automatic checking would offer greater advantages over paper learning materials. It is obvious that automatic checking saves time. We also expected that this interactivity would motivate children to learn more.

The rationale behind our third goal was the fact that Kanji is one of the most important things taught in Japanese elementary schools, and the only effective way of learning them is to write them repeatedly. Each Kanji character has an accepted stroke order. Teachers are expected to assist children in writing Kanji characters correctly both in terms of shape and stroke order. Nevertheless, there has been no really effective method of correcting incorrect stroke order to date. Furthermore, it is important for HLMs to enable the student to be advised on how to write the character correctly at that instant. The reason for this is that the child may not always notice how his or her handwritten character is incorrect when the HLMs point out that a mistake has been made.

The fourth goal relates to the practical use of HLMs. Teachers use original learning materials to instill their ideas in students. Therefore, for HLMs to be used successfully for education in schools, it is essential that teachers be able to easily create and customize them.

Our approach to HLMs, to achieve these four concrete goals, is described in the following section.

3. Our HLM approach

3.1. Structure of HLM

To prepare HLMs that achieved the four goals, we selected functions that they had in common, developed constituent elements corresponding to the functions, and designed an HLM by integrating the elements. Figure 1 outlines the structure of our HLM.

Elements that are connected in the non-interface function of the HLM were developed as Windows applications. They are Recognize/Judge/Model server software (RJM server software) and Record server software. The elements that are connected in the interface function of the HLM were implemented on Macromedia Flash MX. In the following sections, we describe the main elements of the HLM.

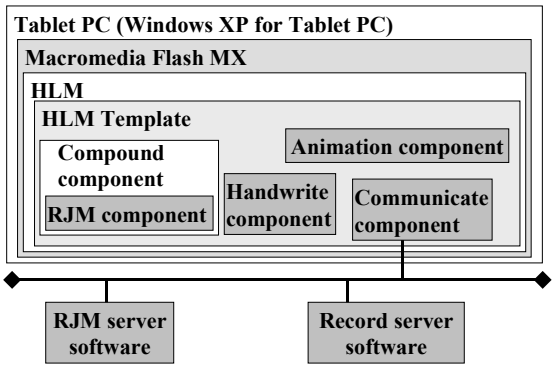

Figure 1. Structure of our HLM

3.2. Recognize/Judge/Model Server Software

The RJM server software has three functions to achieve the second and third goals for HLMs. The first recognizes a character pattern or string pattern. This function is attained by an online handwriting recognition module, which we developed in-house. The second function determines whether handwritten Kanji characters are correct. We developed a new character assessment module for the HLM. The mechanism used to evaluate characters cannot be discussed here for lack of space. The final function returns the model pattern for a designated character. The model pattern indicates the correct way the character is written and therefore has the correct stroke order.

3.3. Handwrite and RJM Components

This section describes the Handwrite and RJM components that achieve basic interfaces for the HLM. First of all, the HLM should be able to be written at will with a stylus pen. Consequently, we developed a Handwrite component that has writing and erasing functions. It is usually arranged over the entire surface of the HLM. We added functions for changing the color and width of the handwriting to enthuse children by providing varied choices in expression. In continual use, the

Handwrite component also saves and loads handwriting by communicating with the Record server software.

The RJM component provides an interface for attaining the second and the third goals. To treat handwritten strokes that are partially outside the RJM component, we related a Handwrite component and RJM components. As a general rule, the RJM components are placed on a Handwrite component. The Handwrite component distributes the input strokes into the correct RJM components on the HLM according to the way RJM components are arranged.

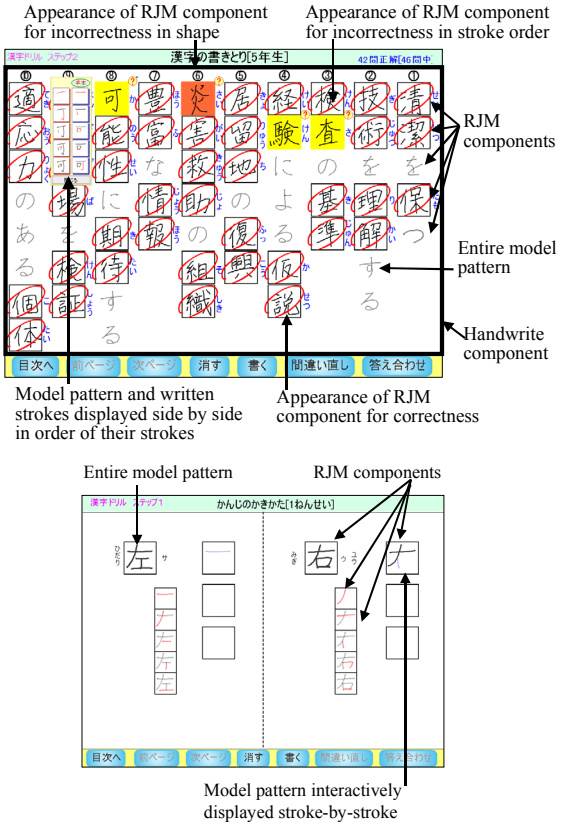

Figure 2. Examples of Handwrite and RJM components

The RJM component has three functions. The first recognizes the handwritten strokes distributed by the Handwrite component. Each RJM component sends its handwritten strokes to the RJM server software. The HLM can do an automatic check by comparing the correct answer to be input on the RJM component with the recognition result received from the RJM server software.

The second function assesses the handwritten Kanji character from both its shape and stroke order. Each RJM component sends a pair of the correct character code and handwritten strokes to the RJM server software. The RJM component receives the evaluation result from the software and changes the appearance to conform to the result (see top of Fig. 2).

The last function displays the model pattern for a given character. The RJM component sends a character code to the RJM server software and then receives the model pattern. The RJM component can display the model pattern and handwritten strokes side by side, in the stroke order (top of Fig. 2). The RJM component can display the entire model pattern. The RJM component can also interactively display the model pattern stroke-by-stroke (bottom of Fig. 2).

3.4. Compound Components and Templates

Compound components are special-use components that incorporate the RJM component. They enable teachers to easily create HLMs for a specific purpose. We developed two types of compound components for maths classes in practical studies. The first was for doing division by hand, which we called the division component. It consists of RJM components and special boxes for the decimal point. The division component automatically sets the correct numbers for the calculation process when a divisor and a dividend are provided to the division component. The second component was for fractions, called the fraction component. We developed a range of fraction components such as to add and subtract fractions, to transform fractions to decimals, and to transform decimals to fractions. These fraction components made it easier to create the HML for a mathematical unit. Figure 3 has examples of compound components.

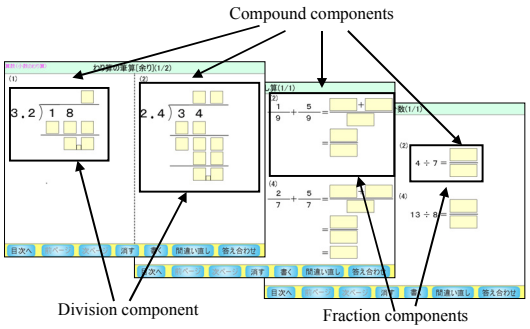

Figure 3. Examples of compound components

An HLM template that consists of the above components plus an animation component makes HLM customization easy and efficient. Teachers can create a new HLM simply by applying the templates to actual problems. The animation component enables cheerful animation to be played according to the results of automatic checking.

4. HLMs

We initially planned to apply HLMs to Japanese language and maths classes during the second term of fifth

grade elementary school. According to the plan, we created the following three kinds of HLMs. The first was an HLM for all subjects, called Note material. The second was an HLM for maths. The third was for practicing Kanji characters. We created about one hundred HLMs in total.

4.1. Note Materials

Children can write their ideas or attempt calculations on the Note materials exactly the way they like. The Note material uses a Handwrite component. The teacher can place a background image on the Note material as their needs demand. As the material can save children's handwriting, they can refer back to earlier ideas at any time. Figure 4 shows sample Note materials.

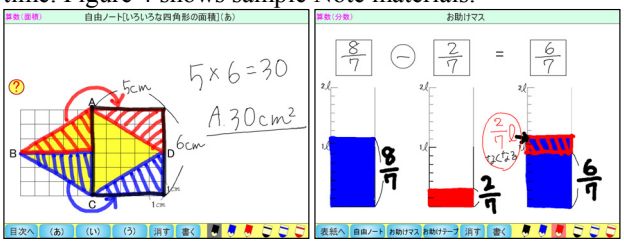

Figure 4. Sample Note materials

4.2. Maths Materials

We developed three kinds of maths materials. Figure 5 has some sample maths materials.

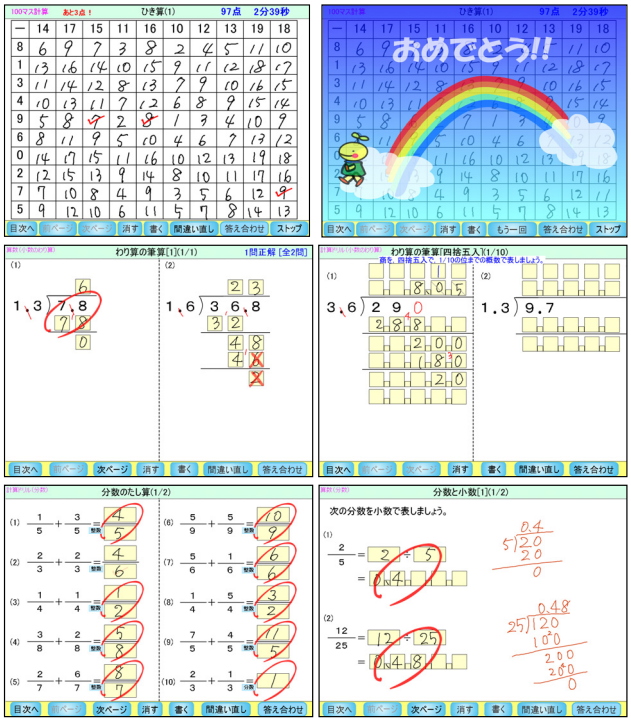

Figure 5. Sample maths materials

The first was used for the calculation exercises, and was called the "100-box" calculation material (see top of Fig. 5). This material was based on the RJM component. The child wrote his or her answers in the boxes of the material. When the child pushed the check button, the answers in all boxes were checked in about a second. Ticks were placed in all boxes in which the handwritten number was judged to be incorrect, according to handwriting recognition results. (In Japan, a tick is used to indicate an incorrect answer.) If all the answers were correct, one of fifteen congratulating animations was displayed.

The second material was used for division exercises that used the Division and Handwrite components (see middle of Fig. 5). These materials enabled children to do division by hand. The materials enabled not only the answer but also the calculation steps to be checked. By placing the Division components on the Handwrite component, the child could write down the numbers needed for carrying and borrowing.

The last material was for fraction exercises that used the Fraction and Handwrite components (see bottom of Fig. 5)

4.3. Kanji Practice Materials

We developed two kinds of materials for practicing Kanji characters. Both used RJM components. The first was for learning how to write Kanji characters. Only the first stroke for the model pattern was initially shown on the material. When the child traced the stroke for the model pattern, the next stroke was displayed. In this way, the child could write Kanji in the correct stroke order.

The second material was for checking written Kanji characters. The child wrote Kanji characters in the boxes of the material. When the child next pushed the check button, the characters in all the boxes were checked. Any box in which the handwritten character was assessed to be incorrect in shape was colored in orange. Any box in which the handwritten character was determined to have the incorrect stroke order was colored in yellow. A hint button was displayed beside any incorrect handwritten character. If the child pushed the hint button, the model pattern appeared side-by-side with the child's handwritten pattern in order of stroke order. Figure 6 shows sample practice materials for Kanji characters.

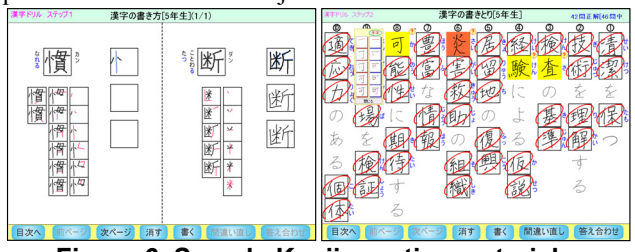

Figure 6. Sample Kanji practice materials

5. Practical Studies in an Elementary School

Practical teaching with our HLMs was done in an elementary school from November 2003 to February 2004. Fifth grade (eleven-year-old) children used the HLMs in their Japanese language and maths classes. In total, the HLMs were used for fifty-eight periods. In addition to this, children did homework with the HLMs at home. In practice, we also confirmed that a field teacher could create HLMs with the HLM templates.

A Tablet PC was given to each child in the classroom and the teacher. All the Tablet PCs were connected to a local area network and the teacher's Tablet PC was connected to a projector.

Two maths classes using the HLMs were viewed by the public. Details on the class are as follows. First, the children attempted a calculation exercise on their Tablet PCs with the 100-box calculation material. After the teacher set the children a task related to fractions, each child expressed his or her ideas on the Note material. Some children used a ruler to draw a straight line on their Tablet PCs. Then, they discussed their ideas in groups by comparing their Tablet PCs. Some presented their ideas by projecting their Note materials onto a whiteboard. Toward the end of the class, the children did drills related to fractions on their Tablet PCs. Children who completed all their drills then automatically had their work checked. Those who had answered all the drills correctly then moved on to the next, and more difficult, drill. Figure 7 shows photographs of the class using the HLMs.

Figure 7. Photos taken during open class

6. Evaluation

6.1. Accuracy of Automatic Checking

Using logging data, we evaluated the accuracy of automatic checking. The recognition results for handwritten one-digit numbers and multiple-digit numbers in the maths materials were compared with the correct answers automatically. The Kanji practice materials had automatic checking through the character evaluation.

Automatic checking is required to determine whether a handwritten pattern is a correct rendition of the character that was requested to be input. Therefore, the accuracy of automatic checking refers to the number of correct handwritten answers that were judged to be correct and how many incorrect handwritten answers are judged to be incorrect. The accuracy of automatic checking is summarized in Table 1.

Table 1. Accuracy of automatic checking

	Number of sample items	Number of correctly checked items	Rate of correct checking
Single-digit numbers	2420	2380	98.3%
Multiple-digit numbers	3174	3109	98.0%
Kanji characters	3166	3023	95.5%

As a basis for evaluating handwriting, the false rejection rate (FRR) and the false acceptance rate (FAR) are important in establishing accuracy. The FRR and FAR were as follows.

FRR = Number of false rejection data/Number of correctly input data = 98/2447 = **4.0%**

FAR = Number of false acceptance data/Number of incorrectly input data = 45/719 = **6.3%**

We also tried to determine the children's level of satisfaction with HLM checking and evaluation through a questionnaire. Figure 8 has the results. We should note that the FRR and FAR need to be improved further.

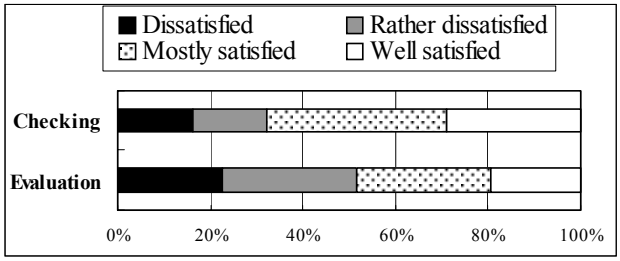

Figure 8. Children's satisfaction with checking and evaluation

6.2. Results of Questionnaires

We gave the teachers questionnaires to learn their impressions of the HLMs. Table 2 lists the results. We used a sample of four teachers who had used HLMs in the classroom. All questions were in the form of a four-point Likert scale with 1=disagree, 2=somewhat disagree, 3=somewhat agree, and 4=agree.

Table 2. Teachers' impressions of HLMs

Question	Mean response
Were the HLMs useful in helping your pupils with their thinking processes?	3.0
Was automatic checking helpful?	4.0
Was the function for assessing stroke order effective?	4.0
Was it easy to teach with the HLMs?	3.8
Do you want to continue teaching with the HLMs?	3.8

We also collected children's impressions of the HLMs. We used a sample of thirty-one children who had often used HLMs to answer the questionnaire. Twenty-five children answered that they wanted to continue learning with HLMs in the classroom and at home. Table 3 indicates characteristic comments by children extracted from the questionnaire.

Table 3. Characteristic comments by children

The HLMs did a great job of correcting my stroke order.
The HLMs were stricter than my teacher at correcting my Kanji characters.
Automatic checking saved time and made me want to learn more.
I also want to use the HLMs in other subjects.

From the results of the questionnaires, we found that the teachers and children were really enthusiastic about the HLMs. They were a great aid to the teachers in giving instructions.

7. Conclusion

We presented HLMs and their practical studies. The Note materials achieved a unique style of teaching and teachers adopted that style with a great deal of satisfaction. Kanji practice materials brought about a solution to the long-standing educational problem of correcting a child's stroke order. The results of the questionnaires revealed that automatic checking of drill materials not only saved time but also improved the children's motivation to learn. We also confirmed that a field teacher could create HLMs with templates. To sum up, we concluded that HLMs were enthusiastically received by both field teachers and children.

The results of the questionnaires also revealed that the accuracy of automatic checking needs to be improved. For educational purposes, it is not necessary to recognize quickly scribbled characters but to determine whether a handwritten character corresponds to the character that was to be written as part of the drill.

Acknowledgement

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