Improvement of Digital Pen Learning System for Daily Use in Classrooms *

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In this paper, we describe an improvement to AirTransNote, a student note-sharing system that facilitates collaborative and interactive learning during a regular lecture in conventional classrooms. The former AirTransNote system employed ultrasonic pens and PDAs for collecting student notes on paper sheets. However, this process required special skills and posed difficulties for learners. We then introduced Anoto-based pens to reduce these difficulties, and compared this with the former system during experimental lectures. We confirmed that the simplicity and stability of the Anoto-based pen facilitates active participation of low-performing students, while high-performing students felt less uneasy about the system checking their notes. The original system also required teachers to manage the relationship between a pen ID, a learner, and a seat position. To resolve this difficulty, we developed an instant sheet-mapping method. This method utilizes learners’ signatures on a special seat-map sheet, and dynamically relates the pen IDs and the seat positions with the signatures. We conducted an experimental lecture session at an elementary school, and confirmed that this method functions effectively with younger school children.

Key words: educational media, teaching tool development, communication, human interface, computers in classroom

1. INTRODUCTION

Mobile computing and wireless networking technologies have been used to facilitate computer-supported collaborative learning (CSCL), even in mobile/ubiquitous learning environments (Ogata and Yano, 2003; Yang and Chen, 2006). Such advanced environments can enrich the learning resources and communications in both quality and quantity. However, Oviatt et al. (2006) reported that low-performing students using greater cognitive load tools (pen/graphical tablet interface) found that the tools disrupted their performance on math problem solving. We have to carefully design the learning space, interface, and media to consider the cognitive load that this adds to student learning.

To reduce the cognitive load and improve the learning resources and communication quality/quantity, we have developed a student note-sharing system named “AirTransNote” (ATN) (Miura et al. 2004; Miura et al. 2007). ATN provides the function of instantly collecting student notes written on papers through a wireless connection, and projecting the notes and/or a simplified view of the student progress on a screen. Students as well as teachers can then view the answers and opinions of other students.

Through these functions, ATN can facilitate collaborative and interactive learning during regular lectures in conventional classrooms. Interactive learning was proposed by Maruno (2005) as a way to enhance the thinking and understanding of students by means of deeper communication among students and teachers. In order to pose proper problems and examples, it is necessary to understand the learners’ status precisely and quickly. Since ATN provides teachers with a simplified view of the learners’ status, ATN enables the teachers to quickly grasp the necessary next steps. Thus, ATN facilitates interactive learning. Also, communication among students can be enhanced by the notes and the simplified view. While notes can be collected on real paper, collecting digitized note data contains several advantages: (1) the digitized note is suitable for summarizing and providing a simplified view, (2) the data can be resubmitted quickly, and (3) it does not disturb continuous learning as would physical note gathering. The digital method offers significant benefits over the paper system.

Several research studies and activities have been conducted utilizing wireless digital pens such as Anoto. WAO Corporation (2008) introduced case studies involving the collection of student notes.
which was shown to enhance students’ interest through presentation and discussion of the notes. Kawamura et al. (2008) employed the student notes for English learning in elementary school classes, and describes the advantages of teaching by sharing handwritten notes. Regarding an extracurricular lesson, Imai et al. (2008) studied remedial classes using digital pens and found that the students could stay on task during the class. Misono and Akahori (2008) also studied a remedial class using their system that sends digitized note images to the learners’ mobile phones on the day before the lecture. The note images remind the learners about the previous lessons. This research is gradually contributing to the knowledge of the learning effects of using digital pens.

However, utilizing digital pens for daily use in regular classrooms has not yet become popular due to the extra difficulties encountered with preparing and setting up the digital pen systems. Therefore, we improved the digital pen learning system (Miura et al. 2005) in order to make it more practical for daily use in regular classrooms.

2. IMPROVEMENT 1: THE UTILIZING ANOTO PEN

The former ATN system utilized ultrasonic digital pens (Inklink) and PDAs to collect student notes (Fig. 1). The PDA transmitted student note data from Inklink, to the teacher’s PC via a wireless LAN. A student could then confirm his/her notes on the PDA screen. However, the student needed to connect the PDA and the digital pen, then start our application for transmitting notes. To overcome these difficulties, we have modified our system to utilize Anoto digital pens (Fig. 2). The Anoto digital pen (ex. DP-201 Bluetooth + USB model manufactured by Hitachi Maxell Ltd) can collect student notes from various positions on a special dotted paper with less than a one millimeter error. Although the Anoto pen requires the special dotted paper, the precise note data shows high accuracy in automatic recognition on the teacher’s PC. The Anoto pen can also transmit the note data via the Bluetooth wireless network. The self-sending capability can easily transfer many students’ notes directly to the teacher’s PC.

On the other hand, a function providing visual feedback to students cannot be supported without other display devices such as a projector screen. Table 1 shows a comparison of the former and current ATN systems.

2.1. Experiment

To assess the effect of the new ATN system on learners by contrasting this method with the former ATN system, we conducted experimental lectures and a questionnaire survey in a mathematics class. The participants of the experimental lecture included 40 high school students. The scene of the lecture is shown in Fig. 3.

The first lecture was conducted in December 2006 and the topic was introducing extended definitions of trigonometric functions where they exceed 90 degrees. The students had already learned the basic definitions of the trigonometric functions. During this lecture, they utilized ultrasonic pens to solve introductory sample problems. The day before this lecture, we explained how to calibrate/utilize the ultrasonic pens for all students operating the pen and the PDA. However, due to wireless network trouble, only 22 students could transmit their notes during the lecture.
The second lecture was conducted in February 2007 for the same students but this time they used Anoto pens. The main activity of the second lecture was an exercise wherein the students solved problems using the trigonometric functions to calculate surface area/volume of three-dimensional shapes. For the second lecture, we did not explain the usage of the Anoto pen because we believed that the operation was simple and intuitive.

During both lectures, the ATN system provided instant correct/incorrect answer feedback generated by an automatic recognition function using a projected screen. The function recognized numbers written in specified answer boxes, and compared those with the prepared answers. When an answer was correct, corresponding answer boxes were painted green, while wrong answers were indicated in red. The teacher checked the feedback color and the amount of the written notes using a thumbnail note view during a brief inspection (interval was approximately two minutes). During this time, the teacher guided a low-performing student who could not solve the problems. Also, the teacher picked up some frequent/typical mistakes among the students’ notes, and revealed these mistakes by zooming in to the digitized notes. The following instructions were posed by the teacher: (1) ask the students to find the mistakes in the answer, (2) indicate the mistakes, and (3) explain the cause and points to note.

Note that the number of questions in the second lecture was greater than that during the first lecture. During the first lecture, we observed position errors for some notes within 1 cm. Some students noticed and pointed out the errors; however, this did not disturb the lecture itself.

We conducted a questionnaire survey during the following math class. The questionnaire items were prepared by referring to items from the article "Research for promoting ICT enhanced learning" provided by the National Institute of Multimedia Education (NIME).

Fig. 4 shows the results of the questionnaire survey compared to the former ATN. Note that five of 22 students in the first lecture and two of 40 students in the second lecture did not submit the survey; thus, the total number of responses was 17 and 38, respectively. We set the significance level as 5%. According to the chi-square test, the rating distributions differed significantly in two of the items: “Q2: The pen was useful for lecture.” ($\chi^2 (3) = 8.10, p = 0.044$), “Q5: I was nervous due to the teacher’s checking.” ($\chi^2 (3) = 8.85, p = 0.031$). Questionnaire items labeled with * in Fig. 4 denote significance less than the 5% level. Considering the Q2 result, more students felt that the pen was useful for the second lecture because of the new system’s simplicity, the unexpected trouble during the first lecture, and the position errors.

Table 1. Comparison of student note capturing and collection

<table>
<thead>
<tr>
<th>Item</th>
<th>Ultrasonic pen and PDA</th>
<th>Anoto pen and projected screen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setup</td>
<td>Hold paper by clip sensor and connect</td>
<td>None</td>
</tr>
<tr>
<td>Calibration</td>
<td>Tap three points on the paper</td>
<td>None</td>
</tr>
<tr>
<td>Send cue</td>
<td>Automatic, when the pen tip left</td>
<td>Manual, tap on “SEND” box</td>
</tr>
<tr>
<td>Connection</td>
<td>IEEE802.11b (embedded in PDA)</td>
<td>Bluetooth (embedded in Pen)</td>
</tr>
<tr>
<td>Available sheet</td>
<td>Any</td>
<td>Specific dotted paper sheet</td>
</tr>
<tr>
<td>Multiple sheet</td>
<td>Manually set on PDA</td>
<td>Automatically detection</td>
</tr>
<tr>
<td>Position error</td>
<td>Approx. 0–20 mm (caused by obstacles)</td>
<td>None in principle</td>
</tr>
<tr>
<td>Feedback</td>
<td>On PDA screen</td>
<td>On projected screen</td>
</tr>
</tbody>
</table>

Fig. 3. Scene of the second lecture. The teacher confirmed the feedback.
The result of Q5, which extracts the uneasy feeling from sharing and checking of notes found that this uneasy feeling tended to be relieved in the second trial. We consider that the simplicity of the Anoto pen, the reduced position errors, and the easier questions could be the possible reasons (see Note 1). However, the result could be influenced by the difference in the main activity (introduction/exercise) and/or the numbers of correct/incorrect answer feedback. Therefore, it is difficult to specify the causal factors from the results.

Fig. 5 shows the comparison of attitudes towards each of the two systems. According to the chi-square test, the rating distributions of three items differed significantly: “Q9: Did you enjoy the lecture?” ($\chi^2(2) = 10.1, p < 0.010$), “Q10: Did you understand the contents?” ($\chi^2(3) = 10.1, p = 0.018$), “Q13: Did you actively participate in the class?” ($\chi^2(3) = 7.41, p = 0.025$). We consider that the significant differences in enjoyment (Q9) and activeness (Q13) were caused by the simple device, the stable note data, and the difficulty level of the content. In regard to the understanding (Q10), the difference in the main activity would influence this result.

The above significant differences could be affected by differences not only in the pen devices but also from other uncontrolled factors, such as the number of note sharing experiences and the difficulty level of content. However, regarding the number of note sharing experience, we have conducted other case studies at an elementary school and noted that some reserved students could not relieve their uneasy feeling even when using the Anoto-based system repeatedly. Thus, we ignored the former factor, and tried to normalize the latter factor (“the level of difficulty of the lecture”). We consider that the level of difficulty factor varies among individuals, even in the same lecture. Therefore, we define the answer of Q10: “Did you understand the contents?” as personal difficulty level, and calculate Pearson’s correlation of the level with other questionnaire answers (see Table 2). We investigate the effects of the error reductions and the simplicity from the differences of the correlations.

A significant positive correlation was observed in “Q4: I got nervous due to system check” with the ultrasonic pen. The result revealed that higher-performing students felt more nervous than lower-performing students did under the condition of low-stability of notes and the system difficulty. The reason was that the higher-performing students were more concerned as to whether the ultrasonic pen system exactly transmitted their notes without position errors. On the contrary, the Anoto-pen system relieved the anxiety of the note position error. Consequently, the correlation between the feelings of understanding and nervousness was canceled (see Note 2).
Regarding activeness (Qs 8 and 13), the correlations with understanding were significantly strong under the ultrasonic pen system, whereas this correlation under the Anoto pen was not observed. This result can be explained by the difficulty of using the ultrasonic pen system which disturbed the active participation of lower-performing students. The simple and stable Anoto system could facilitate the active participation of both the higher- and lower-performing students without discrimination. In summary, we confirmed that the simplicity and stability of the Anoto-based system does not disturb the active participation of the lower-performing students, and relieved the anxiety of higher-performing students regarding note position errors. We continue to validate the effect by considering the lecture’s difficulty level and the experience aspects.

### 3. IMPROVEMENT 2: INSTANT SEAT-MAP FUNCTION

The Anoto digital pen described in Section 2 can reduce the burdens of managing devices and distribution since the wireless network connection is embedded in the pen. However, our experience uncovered a problem in managing note data. In this section, we describe an instant seat-map function that solves the note management issue.

#### Table 2. Pearson’s correlations with “Q10: Did you understand the contents?”

(* denotes 5% significant, ** denotes 1% significant)

<table>
<thead>
<tr>
<th>Item</th>
<th>Ultrasonic pen (1st) (n = 17)</th>
<th>Anoto pen (2nd) (n = 38)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q1. The lecture with the pen was fun.</td>
<td>0.474</td>
<td>0.248</td>
</tr>
<tr>
<td>Q2. The pen was useful for lecture.</td>
<td>0.480</td>
<td>0.307</td>
</tr>
<tr>
<td>Q3. I want to take the lecture with the pen again.</td>
<td>0.585* (p = 0.014)</td>
<td>0.268</td>
</tr>
<tr>
<td>Q4. I got nervous due to system check.</td>
<td>0.513* (p = 0.035)</td>
<td>−0.094</td>
</tr>
<tr>
<td>Q5. I got nervous due to the teacher’s check.</td>
<td>0.289</td>
<td>−0.121</td>
</tr>
<tr>
<td>Q6. I got nervous due to other students’ check.</td>
<td>0.461</td>
<td>−0.130</td>
</tr>
<tr>
<td>Q7. I prefer anonymous note sharing.</td>
<td>0.413</td>
<td>−0.271</td>
</tr>
<tr>
<td>Q8. I could actively participate in usual lectures.</td>
<td>0.840** (p &lt; 0.001)</td>
<td>−0.215</td>
</tr>
<tr>
<td>Q9. Did you enjoy the lecture?</td>
<td>0.456</td>
<td>0.498** (p = 0.001)</td>
</tr>
<tr>
<td>Q11. Were you satisfied with the lecture?</td>
<td>0.621** (p = 0.008)</td>
<td>0.512** (p = 0.001)</td>
</tr>
<tr>
<td>Q12. Did you concentrate on the lecture?</td>
<td>0.614</td>
<td>0.258</td>
</tr>
<tr>
<td>Q13. Did you actively participate in the class?</td>
<td>0.728** (p = 0.001)</td>
<td>0.063</td>
</tr>
</tbody>
</table>

#### 3.1. Problems of Fixed Seat Mapping

Not only our ATN, but also other systems utilizing digital pens to collect student notes will require that pens are distributed to students. The teacher can allow the students to manage their pens but, in general, the pens are distributed at the beginning of the lecture and returned at the end of the lecture. This is necessary because the pen is still expensive and each pen requires that its battery be charged. There are two general ways to distribute pens; the teacher can deliver one to each student or the students can pick up their own pens. Now we pose a problem: how do we identify a pen with the student using it? Each pen has a unique ID, but a student cannot modify the ID since the pen does not have any buttons on the device.

Considering the above restrictions, when the teacher accepts the former method (deliver to each student), the teacher needs to arrange the pens in seat order to efficiently distribute them. If the teacher accepts the latter method (students take their own pens), the students need to know his/her own pen ID. Also, the time for each student to pick up the pen should be considered. We often chose the latter method, and we usually asked the students to pick up their pens before the lecture.
However, in both methods, managing the student seat position and the pen ID has the following two issues. First, the teacher needs to prepare a “configuration file” to describe the mapping of each student and the pen ID. Second, to provide the “seat map” (see Fig. 6), the teacher needs to input the position of each student. For teachers, the seat-map function is useful to zoom in on a specific student note. However, the seat position is often changed in Japanese elementary schools and junior high schools. The teacher must update the student position data for each position change. Additionally, if an unexpected issue occurs with a digital pen, the teacher is required to reconfigure the pen mapping. To minimize the extra time and effort, it is crucial to reduce this influence on the lecture schedule.

We first attempted a post mapping method using portable RFID readers (Miura et al., 2005). This method can relieve the above issues, but the digital pen is too small to install an RFID tag. The RFID tag may also disturb student writing ability. The post mapping still requires the teacher to walk around the classroom to obtain the RFID data.

3.2. Instant Seat-Mapping Method

Therefore, we propose a flexible, stable, and efficient method for daily use in a classroom. In this method, a teacher does not manage the pen-student-position mapping statically; the mapping is constructed in cooperation with the student’s note-taking.

To perform “instant seat-mapping,” the teacher prepares special paper sheets mapping each column of seats in the classroom (Fig. 8 above). At the beginning of the lecture, the teacher distributes the sheets to the students who sit in the front rows of each column. Then, each student is asked to write his/her name on the table cell of the paper corresponding to his/her seat position, and pass the paper to the student behind. ATN handles the signatures on the paper as “mapping data of pen ID and seat position.” The drawings of each student name (signature) are collected and displayed on an ATN seat-map controller (Fig. 8). The seat-map controller works similarly to the conventional seat map (Fig. 6). When the teacher clicks a name area, the corresponding student notes are enlarged to show the details. Therefore, the teacher simply specifies the student note without considering the pen IDs.

In this method, the necessary preparation for the teacher merely consists of printing the mapping sheet. The teacher does not need to undertake the seat-student-pen mapping by editing a configuration file. The mapping sheet can be static because the numbers of rows/columns are the same, assuming the desk setup stays the same. Using this method, the pens can be randomly distributed to the students and the teacher can adopt any distribution strategy. No
problems occur when a student uses another’s pen. Moreover, in case of unexpected pen troubles, the teacher can provide another pen to the student. When the student writes his/her name with the newly assigned pen, the updated configuration of the mapping is finished. This random distribution has the advantage of improving the anonymity of notes. In the former ATN session, the teacher had often assigned the pens in sequential ID order. The serial ID enables the students to infer the authors of notes. We do not recommend anonymous sessions, but some teachers may consider hiding the student name to protect anonymity. Using the instant seat-mapping method, the teacher can easily hold an anonymous session by the random distribution of the pens.

3.3. Experimental Lecture

To validate the instant seat-mapping method, we conducted an experimental lecture session at an elementary school in January 2009. We purposely chose younger school children (second-year, seven- to eight-year-olds) for the experimental lecture. Because the mapping method owes cooperation to the participants, we wanted to know whether the younger school children can perform the mapping tasks.

The class consisted of 33 students. The seats were arranged in a grid layout of six rows and six columns ($6 \times 6$). The size of a table cell printed on the mapping sheet (A4) was 30 mm in width by 25 mm in height. The seats and participants in the class are shown in Fig. 9. The teacher first instructed all students to pick up a pen and then distributed the mapping paper sheets to students in each column of seats. The instruction message was both stated by the teacher and written on the sheets: “Sign your first name on the table cell corresponding to your seat, send a note, and pass the sheet to the person behind you.” All participants had experienced the pen lecture several previous times so they knew the function of the pen and the method to send a note. Moreover, they were accustomed to fetching their own pens from the cradle box. However, not all of the students had written their names on the sheet.

During the experimental lecture, the mapping took approximately five minutes to complete. We consider it can be reduced to approximately three minutes: 1 minute for sheet distribution by teacher, 20 seconds to write a name for each student, and six students in a sheet column. Figs. 10 and 11 show the result of mapping with the seat-map controller. Since the mapping succeeded, and it did not include errors, we confirmed that the instant seat-mapping method is applicable for elementary schools.

One reason why the mapping error was eliminated was that the task of writing their own names under the previous student’s name was simple. Note that there were no absentees in the class. If students were absent, the error could be eliminated by the teacher’s marking the position of the absentee in advance.

The teacher explained that the students should write their “given name,” but some students asked...
what to do in the case of duplicate given names. Based on the teacher’s suggestion, several students wrote an initial of the family name with the given name (Fig. 11).

Incidentally, the ATN system can keep notes from time periods before the mapping begins. Thus, the teacher can start the lecture before finishing the mapping operation. The notes written on the special mapping area are also stored with the other notes on the regular sheet. When the teacher wants to review lecture notes after the lecture ends, the notes in the area are also displayed, and the seat-map controller is reconstructed. Therefore, the teacher can also utilize the seat-map controller for reference and review. The button layout of the seat-map controller can be modified by rotating 90, 180, and 270 degrees.

3.4. Possible Issues

While some issues might arise, they can be easily resolved. For example, a student might mistakenly write his/her name in a wrong place. In such a case, the mapping can be fixed when the student writes the name again in a correct place. If multiple names are written in the same place, the ATN system shows the pen IDs on the seat-map controller button (Fig. 8). When the teacher puts a mouse cursor on the pen ID, the notes written by the pen are highlighted. The teacher can delete the mapping through menu selection on the pen ID. If the teacher accepts the multiple pen IDs (in case of pen trouble), the teacher selects the “integrate” menu item. The function can also gather the notes written with multiple pens. Such functions can reduce the difficulties of the teacher, especially in the case of pen trouble.

In larger classrooms with many seats, the area of each seat on the seat-map will be decreased. To solve this issue, the seat-map table can be divided and printed on multiple sheets. The divided mapping sheet is also advantageous to reducing the time to construct the seat-map.

Some students might intentionally write notes in an incorrect place. This method cannot work properly in the case of such a “false statement.” The possibility of a false statement will increase in the larger classes, but can be diminished by authentication of the notes. However, we consider that such a strict operation is unsuitable for the educational perspective; the teacher should prevent this irregularity by developing a relationship of mutual trust.

4. SUMMARY

In this paper, we described improvements to a digital pen learning system for use in daily lectures in a regular classroom. Anoto pens can make the system usage simple and provide stable notes, unlike ultrasonic pens. We confirmed that the system’s simplicity and stability of the notes did not disturb the active participation of lower-performing students, and also relieved the anxiety of higher-performing students regarding the note checking by the system. Also, we confirmed the validity of the instant seat-mapping method which solves the difficulties with seat-student-pen mapping correlations.

The wireless digital pen can gather a detailed status of learners better than a response analyzer such as EduClick can (Huang et al., 2001). The response analyzer can collect superficial statuses through answers to posed problems via student remotes, whereas the wireless pen is suitable to capture continuous thinking activities from notes with a timestamp. The real-time feedback function can provide a summarized view for not only the teachers but also the students. The timestamp data can be useful for playing note writing games similar to Explanogram (Pears and Erickson, 2003). The note playing can be realized and practiced through the use of stimulated-recall procedures (Yoshizaki and Watanabe, 1992) that are recorded on video. ATN can make the reflective activities casual during daily lectures. We believe that the improvements to the daily operation of ATN are important for advanced interactive learning. We continue to construct an effective learning environment and to investigate the effects through practice.

ACKNOWLEDGEMENTS

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NOTES

1) We consider that the reduced position error relieves the anxiety to show an unintentional answer. We also consider that the calibration-free interface diminished the anxiety for position error.

2) We think the no correlation is better than positive/negative correlations, since the anxiety caused by the understanding level can influence the performance of learning.

REFERENCES


