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Analysis of Behavior Sequences of Students by Using Learning Logs of Digital Books

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Abstract: Recently, many studies have analyzed digital textbook reading data by treating all events in the data stream as mutually independent of each other. However, there is a potential loss of information if all event indicators are analyzed independent of time or sequence. Therefore, in this study, a sequential analysis method is employed to analyze the sequential behavior of digital textbook reading logs. In order to collect students' learning logs with the same experimental design, we conducted two experiments in the years 2017 and 2018 during an educational technology course for graduate students. We conducted two comparisons of sequential behaviors. First, we compared the different sequential behaviors through different devices. Second, we compared the sequential behaviors of the students of years 2017 and 2018. We found some behavioral patterns that may help digital textbook system developers and instructional designers reach an in-depth understanding of the actual operations and behavioral patterns of learners.

Keywords: Learning behaviors, lag-sequential analysis, learning log, digital textbooks

1. Introduction

Recently, the development of smartphone technologies has made it possible to access the Internet anywhere and anytime. The physical size and weight of a smartphone have been better designed for increasing its portability (Yin et al., 2016; Yin et al., 2017). It is very convenient for students to access digital textbooks through a smartphone. An increasing number of traditional textbooks have been replaced by digital ones (Lee, et al., 2012, Yin et al., 2014; Yin et al., 2017).

In this study, a digital textbook system has been developed to collect textbook reading data such as "turning to next/previous page," "memo," "zoom in/out," "adding marker." The aforementioned reading actions are termed as events in this study. The system is named as digital textbook for improving teaching and learning (DITeL). The DITeL system can be used not only on a personal computer, but also on a smartphone, thereby making it usable anywhere and anytime. Teachers and students can use the DITeL system to read digital textbooks using mobile devices such as smartphones and tablets. The learning logs of the students were collected to analyze their learning behaviors for improving the DITeL system (Yin et al., 2016).

Many researches have analyzed e-books' reading data by treating all events in the data stream mutually independent of each other (Yin et al., 2014; Yin et al., 2015; Yin et al., 2016; Yamada et al., 2015; Mouri & Yin, 2017). However, there is a potential loss of information if all event indicators are analyzed independent of time or sequence (Vista, Care, & Awwa, 2017). Vista, Care, and Awwa (2017) pointed out that a behavior sequence is important and hence more information is gained if we look at sequences of events rather than individual events that we assume to be independent.

In order to analyze the sequence of e-books' reading behaviors, we designed an experiment using the DITeL system to collect the students' learning logs. The experiment was conducted for the graduate students of the educational technology course. The students were assigned to read an academic English journal article during the experiment. After completion of the learning activities,

we applied lag-sequential analysis to analyze and infer their behavioral patterns. The questions that were addressed in this study were as follows:

1) Differences in the behavioral patterns of students for mobile devices versus PCs.
2) Differences and similarities in the behavioral patterns of students in the year 2017 versus 2018.

2. Literature Review

2.1 Previous Studies on Data Collection

Collecting data is the first step of learning analysis (Yin et al., 2013a; 2013b). Yin et al. (2014; 2016; 2017) carried out a review of previous research to survey the categories of data collection. They classified the previous studies on data collection into three categories, namely, questionnaire-based data collection (QDC), manual data collection (MDC), and automatic data collection (ADC).

In QDC, data are collected by using a predesigned questionnaire. In MDC, a manual data collection system is made available to the users who can then employ the system and consciously provide data about their learning behavior. In ADC, the log data of the learning behaviors are automatically recorded while the e-documents are read. For categories QDC and MDC, the data are affected by users' own subjective factors. For category ADC, the data is objectively collected, thereby removing the subjective factors that affect data authenticity (Yin et al., 2014; Yin et al., 2016; Yin et al., 2017). The present work falls under category ADC.

2.2 Behavioral sequential analysis

Behavioral sequential analysis is a statistical analysis method to determine behavioral transitions through a series of sequential analysis matrix calculations (Bakeman & Gottman, 1997; Hou, 2012; Yin et al., 2017). The behavioral sequential analysis method is a one-sided test. The statistical result, if greater than 1.96 (>1.96), indicates that a behavior sequence reaches the level of significance; otherwise, a statistical result less than 1.96 less than or equal to 1.96) indicates that a behavior sequence does not reach the level of significance (Bakeman & Gottman, 1997).

Many researchers have pointed out the benefit of using progressive sequential analyses that using a visualized behavior–transition diagram to explore learners' complex behaviors can help develop a more effective instructional mechanism (Hou, 2012; Hsieh et al., 2016; Hwang et al., 2017; Yin et al., 2017). For example, Hsieh et al. (2016) explored students' engagement patterns by qualitative observation and sequential analysis in order to visualize and better understand their game-based learning process. They found few learning behavioral patterns that can benefit the design of a game-based learning environment.

This study employs a sequential analyses method to explore the differences in the behavioral patterns of students for mobile devices versus PCs when learning using the digital textbook system. This study did not compare tablets because only one student used. This study also explores the differences and similarities in the behavioral patterns of students in the year 2017 versus 2018.

3. Digital textbook system

A web-based digital textbook system using the e-pub format was developed and used in this research (Fig. 1). Fig. 1 shows an interface for students. By using this online digital textbook reading system, we can collect data such as "turning to next/previous page," "memo," "zoom in/out," and "adding marker." All of these actions are stored in the database. These data were used to analyze learning behaviors of the students.

A teacher can register a student in the system by his name and number. The teacher uploads the digital textbook and other relevant materials into the system before a student can login.

Each student has a separate account and, hence, a personal distinct record of the learning course.

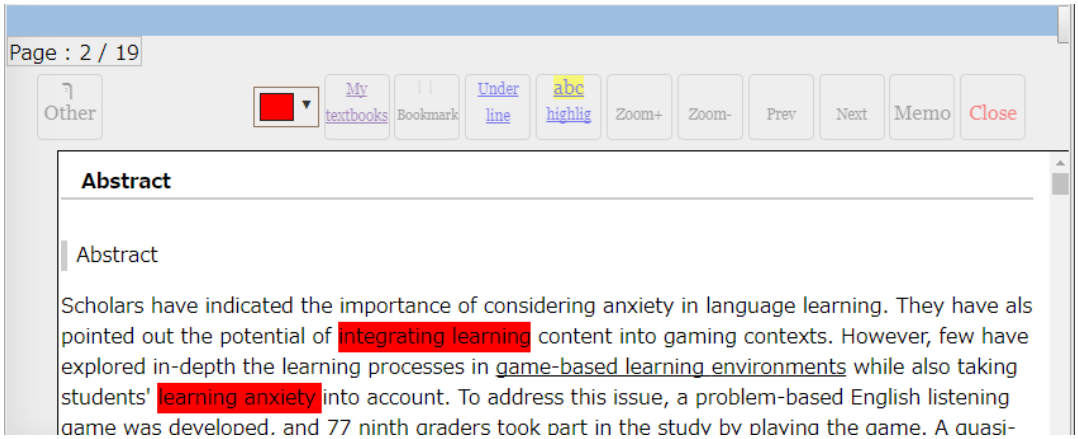

Figure 1. Student interface of DITeL

4. Experimental design

In order to analyze students' sequential behavioral patterns in learning with digital textbooks, we carried out two experiments, which collected students' learning logs by using DITeL system and analyzed the learning behaviors of students reading academic papers. The first time was in May 2017 and the second time in May 2018.

We also explored the common behavior sequences in students' behavioral patterns by comparing the data of these two experiments, and inferred the learning behaviors' features of students when they were reading academic papers.

4.1 Participants

Graduate students participated in the experiment of collecting students' learning logs, by reading academic papers for the duration of about 1.5 h. In May 2017, a total of 21 graduate students participated, of which 17 participants were eligible, whereas in May 2018, a total of 39 graduate students participated, of which 33 participants were eligible.

The experiments were conducted following the ethics criteria suggested by an authorized ethics committee in Japan in order to protect the participants. Further, the personal information of the participants was hidden.

4.2 Coding scheme

A progressive sequential analysis usually requires a coding process (Hou, 2012; Hsieh et al., 2016; Hwang et al., 2017). However, our experiments used the DITel system that can automatically record students' learning logs, and hence, no coding process was needed in our experiments.

5. Analysis and comparison of the learning behavioral patterns

In total, 1,370 records were collected in 2017, and 3,698 records in 2018.

5.1 Devices (PC, Mobile)

Table 1 lists the number of devices that the students used in the experiment. In the experiment, 29 students used personal computers (PC), and 11 used smartphones to access the DITel system. The number of students who simultaneously used the PC and smartphone were 7.

Table 1

Number of devices used by the students

Devices	Number of the students	Number of logs
PC	29	3239
Smart phone	11	388

5.2 Analysis of the frequency of behavioral patterns based on devices

Table 2 shows the frequency and percentage of individual coded behaviors of the students when using a PC or smartphone. The data in Table 2 indicates that the ranking of frequencies of behaviors is almost the same. This is explained in detail in the following paragraphs.

Table 2

Frequency and percentage of data of the students' behaviors collected from a PC and smartphone

Category	Frequency		Percentage (%)	
	PC	**smartphone**	**PC**	**smartphone**
NEXT (NX)	1440	189	44	49
PREV (PR)	1134	133	35	34
HIGHLIGHT(HL)	399	29	12	7
UNDERLINE (UL)	118	11	4	3
BOOKMARKER(BM)	41	15	1	4
DEL HIGHLIGHT(DH)	47	0	1	0
DEL BOOKMARKER(DB)	27	11	1	3
MEMO(MO)	2	0	0	0

First, we found that "go to next page" (NEXT) and "go to previous page" (PREV) were the most frequent and common behaviors.

Second, we found that "make highlight" (HIGHLIGHT) and "make underline" (UNDERLINE) were also used frequently. The percentage of usage of "make highlight" was more than "make underline." This means that the students are more likely to use the highlight function than underline function to make marking, irrespective of using a PC or smartphone.

Third, we found that "make bookmaker" (BOOKMARKER) and "delete bookmaker" (DEL BOOKMARKER) were also used frequently by smartphone users; the percentage of usage of "make bookmaker" was more than "make underline." This means that the students who used a smartphone are more likely to use the bookmaker function than underline; however, its usage is less than the highlight function.

5.3 Comparison of learning behavior-sequence patterns based on devices

Tables 3 and 4 show the results of sequential analyses of the data collected from a PC and smartphone, respectively. The rows represent the starting behaviors, and the columns represent subsequent behaviors.

Table 3

Sequential analyses table (n = 29) of a PC

Z-value	PR	NX	UL	DU	MO	HL	DH	BM	DB
PR	**27.45**	-15.18	-4.94	-2.6	0.44	-10.2	-4.15	-2.93	-1.81
NX	-15.57	**23.66**	-3.2	-1.36	0.16	-7.16	-4.09	-3.99	-3.49
UL	-4.12	-4.37	**12.43**	**9.51**	-0.28	**2.14**	0.22	1.36	0.02
DU	-2.21	-3.92	**10.47**	1.29	-0.14	0.09	**5.33**	**2.67**	-0.52
MO	-1.04	0.16	-0.28	-0.14	-0.04	-0.53	-0.17	**6.3**	-0.13
HL	-10.28	-7.36	1.02	-0.45	-0.53	**23.92**	**5.9**	-0.4	-1.37
DH	-4.13	-2.34	0.22	0.82	-0.17	**4.09**	**13.84**	0.58	-0.64
BM	-2.41	-2.92	1.26	0.97	-0.16	-0.99	-0.79	0.72	**28.67**

DB	-2.2	-3.12	1.05	-0.52	-0.13	-1.96	-0.64	**29.41**	-0.48

Table 4

Sequential analyses table (n = 11) of a smartphone

Z-value	PR	NX	UL	DU	MO	HL	DH	BM	DB
PR	**6.38**	-3.38	-1.81	0.00	0.00	-3.19	0.00	0.65	-1.81
NX	-3.63	**5.92**	-1.43	0.00	0.00	-0.63	0.00	-2.07	-2.66
UL	-1.75	-0.87	**8.51**	0.00	0.00	-0.95	0.00	0.96	-0.58
DU	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MO	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HL	-2.58	-2.13	1.44	0.00	0.00	**9.14**	0.00	-1.06	-0.93
DH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BM	-2.26	-1.27	-0.69	0.00	0.00	-1.12	0.00	0.62	**11.84**
DB	1.11	-2.52	-0.56	0.00	0.00	-0.91	0.00	**4.46**	1.35

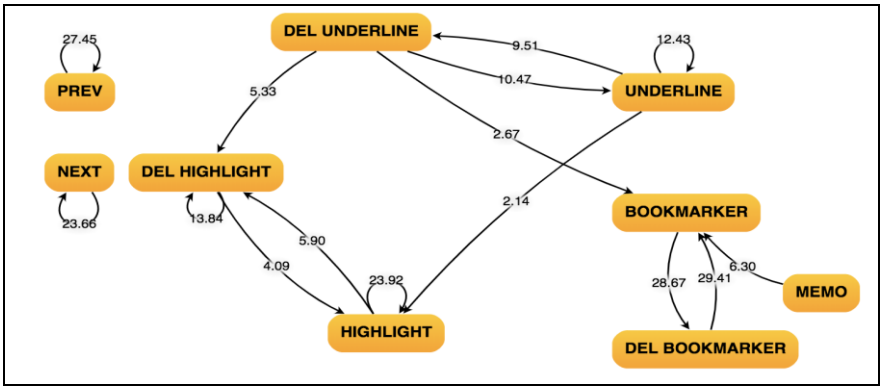

Figure 2. Progressive behavioral patterns of the students for a PC

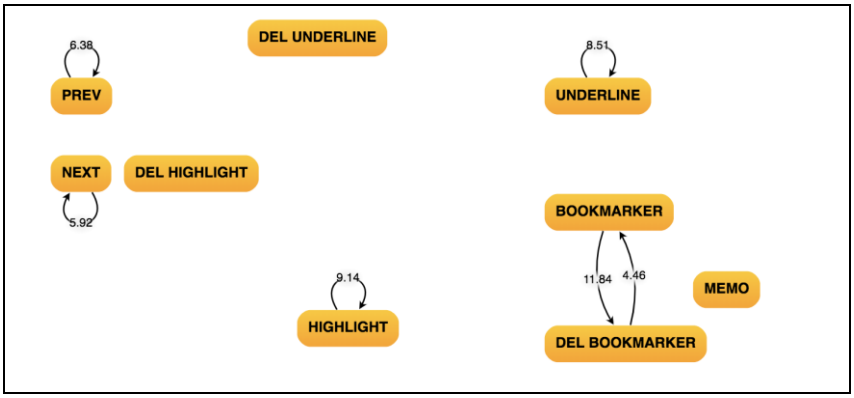

Figure 3. Progressive behavioral patterns of the students for a smartphone

From the table 3 and 4, we found that 15 significant behavior sequences were seen while reading digital textbooks on a PC, and 6 significant behavior sequences while reading digital textbooks on a smartphone. The values above each line in the Figs. 2 and 3 represent the Z-score of the sequence, whereas the direction of the line represents the direction of the behavioral transition.

On comparing the sequences-behavior patterns of the PC and smartphone, we found that the common sequences-behavior patterns namely, PREV and NEXT (Table 5) were that PREV, NEXT have no sequential correlation between other learning behaviors. However, they have sequential correlation with themselves (PREV → PREV; NEXT → NEXT).

Second, the patterns HIGHLIGHT and UNDERLINE have sequential correlation with themselves (HIGHLIGHT→ HIGHLIGHT; UNDERLINE→ UNDERLINE).

Third, the pattern "BOOKMARKER" has sequential correlation with "DEL BOOKMARKER" and vice-versa.

Table 5

Sequence-learning behavioral patterns for a PC and smartphone

No	Learning Behavioral Pattern
LBP1	"PREV" has sequential correlation with itself
LBP2	"NEXT" has sequential correlation with itself
LBP3	"HIGHLIGHT" has sequential correlation with itself
LBP4	"UNDERLINE" has sequential correlation with itself
LBP5	"BOOKMARKER" has sequential correlation with "DEL BOOKMARKER"
LBP6	"DEL BOOKMARKER" has sequential correlation with "BOOKMARKER"

Table 6 shows the differences between a PC and smartphone, and these sequence-learning behaviors are seen in case of a PC but not in a smartphone.

On comparing the sequence-learning behaviors pattern in case of a PC and smartphone, we found that some learning behavioral patterns were always present, whereas some of the patterns appeared in a PC but not in a smartphone.

Table 6

The sequences-learning behaviors occurred in PC but not appear in smartphone

No	Learning Behavioral Pattern
LBP1	"HIGHLIGHT" has sequential correlations with "DEL HIGHLIGHT"
LBP2	"DEL HIGHLIGHT" has sequential correlations with itself and "HIGHLIGHT"
LBP3	"UNDERLINE" has sequential correlations with itself and "DEL UNDERLINE" and "HIGHLIGHT"
LBP4	"DEL UNDERLINE" has sequential correlations with "UNDERLINE" and "DEL HIGHLIGHT" and "BOOKMARKER"
LBP5	"MEMO" has sequential correlations with "BOOKMARKER"

In this research, we focused on the sequence-learning behaviors patterns in case of a PC and smartphone. We found that the behavioral patterns namely, "make highlight," "make underline," "make bookmaker," and "delete bookmaker" were used on a smartphone as well as PC. "HIGHLIGHT," "DEL HIGHLIGHT," "UNDERLINE," and "DEL UNDERLINE" were used only on a PC. The conclusions are given in the following paragraphs.

First, this phenomenon shows that students prefer to use a PC while reading papers on the e-book system. The operations of the e-book system are easier and more convenient on the PC than smartphone.

Second, we also found that students used "HIGHLIGHT," "UNDERLINE," and "BOOKMARKER" repeatedly and frequently in order to mark the content that they thought was important. Especially "BOOKMARKER", This is the difference between the e-book system and traditional reading. It reflects the fact that the e-book system allows students to read and understand papers easily and efficiently.

In future, this e-book system needs to be improved on different devices according to the needs of the students in order to support the learning of students and teaching.

5.4 Analysis of the frequency of behavioral patterns

From the data of Table 7, we found that ranking of frequencies of behaviors is almost same. The details are as follows:

Table 7

Frequency and percentage of coded behaviors of students

Category	Frequency		Percentage (%)	
	2017	**2018**	**2017**	**2018**

NEXT (NX)	537	1651	39	44
PREV (PR)	390	1280	28	34
HIGHLIGHT(HL)	301	461	22	13
UNDERLINE (UL)	79	131	6	4
BOOKMARKER(BM)	8	57	1	2
DEL HIGHLIGHT(DH)	29	48	2	1
DEL BOOKMARKER(DB)	3	38	0	1
MEMO(MO)	8	2	1	0.1

5.5 Analysis of the learning behavioral patterns

Table 8

Sequential analyses table (n = 33) of 2018

Z-value	PR	NX	UL	DU	MO	HL	DH	BM	DB
PR	**38.42**	-20.52	-7.40	-4.03	-1.02	-14.46	-4.11	-4.30	-3.78
NX	-19.54	**34.69**	-7.85	-4.93	-1.25	-12.46	-5.56	-4.35	-5.13
UL	-7.28	-7.46	**20.95**	**20.82**	-0.28	**2.90**	-0.60	**2.31**	0.50
DU	-3.68	-3.10	**16.05**	1.38	-0.13	-0.58	**3.97**	-0.68	-0.59
MO	0.46	-1.24	-0.28	-0.13	-0.03	1.54	-0.17	-0.17	-0.15
HL	-15.76	-12.04	**3.42**	-0.06	1.53	**36.45**	**7.56**	-1.56	-2.42
DH	-3.54	-4.67	0.93	**3.97**	-0.17	**4.57**	**17.83**	-0.85	-0.73
BM	-4.97	-5.08	**4.15**	-0.72	**5.38**	-1.39	-0.9	**2.40**	**41.52**
DB	-4.16	-4.46	1.37	-0.59	-0.15	-1.94	-0.73	**39.88**	-0.65

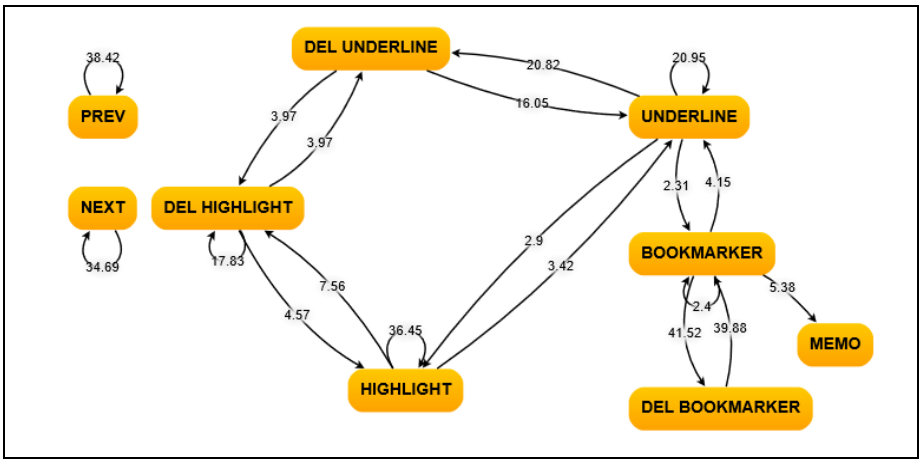

Figure 4. Progressive behavioral patterns of the students in 2018

First, we found that "go to next page" (NEXT) and "go to previous page" (PREV) were the most frequent and common behaviors.

Second, we found that "make highlight" (HIGHLIGHT) and "make underline" (UNDERLINE) were used frequently. The percentage of "make highlight" is more than "make underline." This means that the students are more like to use the highlight function than underline function to mark the content.

From Table 8, we found that 19 significant sequences-behavior occurred while reading the digital textbooks in 2018. The values above each line on the Fig. 4 represent the Z-score for the sequence, while the direction of the line represents the direction of the behavioral transition.

On comparing the sequences-behavior patterns of 2017 and 2018, we found that some behavior sequences occurred in 2017 as well as 2018 (Table 9). For instance, that PREV and NEXT behaviors have no sequential correlation with other learning behaviors. However, they have sequential correlation with themselves (PREV → PREV; NEXT → NEXT). And "after adding HIGHLIGHT, the students deleted the HIGHLIGHT," "after deleting HIGHLIGHT, the students added HIGHLIGHT".

Table 9

Sequence-learning behavioral patterns occurred in 2017 and 2018

No	Learning Behavioral Pattern
LBP1	"PREV" has sequential correlations with itself
LBP2	"NEXT" has sequential correlations with itself
LBP3	"HIGHLIGHT" has sequential correlations with itself and "DEL HIGHLIGHT"
LBP4	"DEL HIGHLIGHT" has sequential correlations with "HIGHLIGHT"
LBP5	"DEL UNDERLINE" has sequential correlations with "UNDERLINE"
LBP6	"UNDERLINE" has sequential correlations with itself and "DEL UNDERLINE"
LBP7	"BOOKMARKER" has sequential correlations with "DEL BOOKMARKER"
LBP8	"DEL BOOKMARKER" has sequential correlations with "BOOKMARKER"

On the other hand, we found the differences between 2017 and 2018 (Table 10). For instance, some sequence-learning behaviors occurred in 2017 but not in 2018 namely, "DEL HIGHLIGHT" has sequential correlations with "DEL BOOKMARKER," "BOOKMARKER" has sequential correlations with "DEL HIGHLIGHT" and "DEL UNDERLINE", and so on.

Some sequence-learning behaviors occurred in 2018 but not in 2017 namely, "HIGHLIGHT" has a sequential correlation with "UNDERLINE," "DEL HIGHLIGHT" has sequential correlations with itself and "DEL UNDERLINE", and so on.

Table 10

Different points of learning behavioral patterns of 2017 and 2018

Year	No	Learning Behavioral Pattern
2017	**LBP1**	"DEL HIGHLIGHT" has sequential correlations with "DEL BOOKMARK"
	LBP2	"BOOKMARKER" has sequential correlations with "DEL HIGHLIGHT" and "DEL UNDERLINE"
	LBP3	"DEL UNDERLINE" has sequential correlations with itself
	LBP4	"UNDERLINE" has sequential correlations with "DEL BOOKMARKER"
2018	**LBP1**	"HIGHLIGHT" has sequential correlations with "UNDERLINE"
	LBP2	"DEL HIGHLIGHT" has sequential correlations with itself and "DEL UNDERLINE"
	LBP3	"DEL UNDERLINE" has sequential correlations with "DEL HIGHLIGHT"
	LBP4	"UNDERLINE" has sequential correlations with "HIGHLIGHT" and "BOOKMARKER"
	LBP5	"BOOKMARKER" has sequential correlations with itself and "UNDERLINE" and "MEMO"

5.6 Analysis of the questionnaire about the learning behavioral patterns

According to the sequence-learning behaviors patterns which occurred in both years 2017 and 2018, we had the students fill out a questionnaire asking the reason for their actions.

5.6.1 Question 1

It was found that: After adding HIGHLIGHT, the students deleted the same, or after deleting HIGHLIGHT, they added the same. Some of the students who had these learning behavioral patterns stated their perceptions as follows:

1. *I highlighted it because I thought that it was the most important content of the paragraph during the first reading; however, after a second reading, I realized that some other content was more important than the previously highlighted content, and hence I deleted it.*
2. *In order to deepen my understanding about the article.*
3. *As I read the sentences, I found a part more suitable for the question.*

It was found from the questionnaire that students often changed important keywords while reading the textbook, and it was difficult for them to identify which words were important. It is suggested that it would be appropriate to mark important places on the teaching materials before students read the contents.

5.6.2 Question 2

It was found that: After adding UNDERLINE, the students deleted the same, or after deleting UNDERLINE, they added the same. Some students who had this learning behavioral pattern stated their perceptions as follows:

1. *I wanted to distinguish the degree of importance of the contents. I realized after a second reading that some content was more important than the content which had been previously underlined.*
2. *After understanding the contents which I had underlined earlier, I usually delete them.*
3. *As I read the sentences, I found a part more suitable for the question.*

It was found from the questionnaire that in order to understand the main idea of a paper, students often read the article repeatedly, and they were often confused about which words were important. It is suggested that it would be appropriate to mark important keywords on the teaching materials before students read the contents.

5.6.3 Question 3

It was found that: After adding BOOKMARKER, the students deleted the same, or after deleting BOOKMARKER, they added the same. Or after adding BOOKMARKER, they add MEMO. Some of the students who had this learning behavioral pattern stated their perceptions as follows:

1. *It was especially important that I would be able to review some content later. After the review, I deleted* BOOKMARKER if I was able to understand the contents well.
2. *After adding* BOOKMARKER, I usually wrote down my thoughts about the paper by adding a MEMO.
3. *After I read the paper repeatedly, I delete the* BOOKMARKER;

From the questionnaire, it was also found that in order to understand the main idea of a paper, students often read the article repeatedly, and were often confused about which contents were important. It is suggested that it would be appropriate to mark the important pages on the teaching materials before students read the contents, and the papers repeatedly.

6. Conclusion

By using a digital textbook system, it is easy to collect textbook reading data, which includes book reading actions. These reading actions are termed as events in this paper. Many researches that have analyzed e-books' reading data treat all events as independent, which leads to a loss of the analysis of sequences of events. In this study, we developed a digital textbook reading system which could be used anywhere and anytime. We collected textbook reading logs to perform learning analysis by using sequential analysis methods.

In order to understand the behavioral patterns of the students while reading digital textbooks, a series of progressive sequential analyses was conducted to compare the differences in students' behavioral patterns in case of mobile devices and PCs. We found that some learning behavioral patterns always appeared, whereas some sequence-learning behaviors patterns were seen in case of a PC but not a smartphone.

On comparing the sequence-learning behaviors patterns of 2017 and 2018, we found that some learning behavioral patterns always appeared. An example of such a pattern is "After adding

HIGHLIGHT, the students deleted the HIGHLIGHT." In order to understand why students take these actions, we had the students fill out a questionnaire.

We found some behavioral patterns through the answers. These may help digital textbook system developers and instructional designers reach an in-depth understanding of the actual operations and behavioral patterns of learners. It also enables them to use a visualized behavior–transition diagram to explore learners' complex behaviors and develop a more effective instructional mechanism for digital textbook systems in the future.

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