Doctoral Dissertation

DEAR: Data-Enhanced Active Reading Using an E-book System

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Abstract

This dissertation proposes active reading (AR) in an e-book environment with learning analytics (LA) data for reading learning. Reading skills are the core of language skills and foundational competencies in any era of learning. Reading literacy instruction has a facilitative effect on other academic outcomes. To improve reading performance and skills, AR strategies have first to be taught and practiced until it is acquired by students. Common AR strategies such as SQ3R (Survey, Question, Read, Recite, and Review) and SQ4R (Survey, Question, Read, Record, Recite, and Review) have been used in language classrooms for many years and studied to verify their effectiveness. However, research on conventional AR strategies has a major issue to be challenged. That is, there is limited exploration of the understanding of the cognitive and behavioral reading process and it limits its potential of supporting learning further. Today, there is a shift from paper-based textbooks to technology-supported classrooms, including e-books and e-learning tools, which offer new opportunities to support teaching and learning. To address the mentioned limit of AR research, the dissertation proposes to develop AR further in a technology-based classroom environment by benefiting from LA data. LA traces and visualizes AR behavior and uses the data to understand the reading process and to inform teaching and learning. Based on the SQ4R AR strategy, a data-enhanced AR framework "DEAR" that supports AR by LA was first developed. DEAR divides AR into three phases: pre-reading, while-reading, and post-reading, and visualizes the AR process and outcomes on the dashboards, aiming to scaffold reading learning by providing feedback to learners and teachers. In this dissertation, we identify three issues in conventional AR strategies and conduct three studies to explore the possibilities of filling the gaps with DEAR. In Study 1, the developed AR dashboard was used in English classes in high school to investigate how data visualization affects reading performance and behavior and how the visualization of the reading process supports reading instruction and learning. Results revealed that the participants of the study improved their vocabulary and reading comprehension after DEAR activities. Moreover, the AR dashboard had a positive effect on the learning behavior of the learners. In Study 2, DEAR was applied in a programming course at an Indian university to investigate the applicability of DEAR to reading comprehension beyond language learning. The results proved that the proposed DEAR strategy could be applied to beginners' programming tasks and positively influenced the out-of-class learning behavior of students in the experimental group. Furthermore, the dashboard helped the teacher to facilitate program comprehension activities in class. Study 3 examined the application of DEAR to students with special needs in inclusive education with the aim to identify AR behaviors of students with reading difficulties. In inclusive education, the difficulties and need for support for learners who struggle with reading are sometimes overlooked. Therefore, it is important to clarify the reading behavior of these students and support them, but there is still a lack of strategies and research on how to support them from the LA perspective. Study 3 shows that learners took different approaches to the same learning task, and log data revealed noticeable behaviors, such as taking longer for writing summaries (output activities), over-concentration, and distraction. This dissertation suggested a data-enhanced conceptualization of AR in the age of emerging technologies and answered the question of how to support reading learning and instruction using log data collected in daily learning environments. Overall, this dissertation revealed that by visualizing reading processes and providing feedback to teachers and learners by dashboards enhanced learners' reading cognition and metacognition and supported teachers in improving their reading instruction. For future work, the AR dashboard will be improved and elaborated, and the AR strategy itself will be revisited to be adapted to the needs of teachers and students that were identified in the study.

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Chapter 1

Introduction

1.1 Research Background

Reading skills are important in any era and are the core of language skills and learning. The OECD 2030 Learning Compass suggests that all learners need the core foundation to move forward autonomously to reach their full potential, and that core knowledge and skills include literacy (OECD, 2019). Also in Japan, "reading" skill is raised as a skill required to survive in the coming era of 2030 presented by Society 5.0 along with the "ability to use information," and "ability to think and communicate on one's own" (MEXT, 2018). Reading skills are the core of language learning and other subjects. Thus, in schools, teachers always search for better ways to improve students' reading skills and performance. Literacy instruction to improve reading comprehension has a facilitative effect on other academic outcomes (Spivey, 1987). Hence, investigating effective and efficient reading strategies and instruction is a target for long-term research as well as for teachers.

Active Reading (AR) strategies, such as Robinson (1946)'s SQ3R (Survey, Question, Read, Recite, and Review) and its extended version SQ4R (Survey, Question, Read, Record, Recite, and Review), are popular reading methods considered suited for textbook reading, helping learners understand unfamiliar information in texts, and providing a structured approach to learning (Basar & Gürbüz, 2017; Khusniyah, 2020; Khusniyah & Lustyantie, 2017; Stahl & Armstrong, 2020). They are systematic and follow step-by-step reading phases to lead learners to understand the written context. The strategies have been primarily used for reading in language learning, such as English. It is also applied to learners with reading difficulties, and its impact has been investigated (Gersten et al., 2001).

The introduction of technology into education has been facilitated, and e-learning tools and e-books are now used as textbooks in classes. Along with this, research on AR using those digital systems is also progressing (CHEN et al., 2020; C.-M. Chen & Chen, 2014; Mulcahy-Ernt & Caverly, 2018; Wang et al., 2017).

Learning analytics (LA) research, which quantitatively analyzes and visualizes those accumulated learning logs and uses the data to support teaching and learning, has been attracting attention (Duval, 2011; Siemens & Baker, 2012). LA uses dashboards to visualize analyzed learning logs and use them to support students and teachers. LA dashboards can be used as a means of such as detecting at-risk students, reflecting on learning, and determining subsequent activities (Dabbebi et al., 2019; Park & Jo, 2015).

1.2 Problem to be Addressed

The effects of AR strategies to date have been verified from past literature. However, a significant challenge remains. That is, reading is a thinking and cognitive process that takes place in the mind, thus it is difficult to understand the processes, such as what the reader is actually thinking and whether he or she understands or does not understand. Therefore, understanding the learner's cognitive and behavioral reading process was lacking in existing research. That brought us the idea that it would be more beneficial for learning to read if we could understand the thinking process in the learner's head during each phase of the reading process. Visualization of the reading process would be expected to contribute to further improvement of reading skills and performance. Some studies have approached AR from LA perspectives to investigate their learning effects (CHEN et al., 2020). However, research contributing to reading learning using LA technology is still limited.

1.3 Our Solutions

In this paper, AR using an e-book and learning log data in the LA learning environment to support reading learning is proposed. This AR strategy was named Data-Enhanced Active Reading, DEAR. DEAR is based on the SQ4R strategy and divided into three reading phases: pre-, while-, and post-reading phases. AR processes and outcomes in each phase are visualized on the dashboard, and feedback is provided to learners and teachers.

In presenting the effects and impact of the proposal, it is necessary to differentiate DEAR from conventional AR strategies. First, there is a limited number of studies investigating how visualizing cognitive processes affects reading performance and behavior; hence it is necessary to demonstrate its effectiveness. In addition, conventional AR strategies have been applied primarily to language learning, such as English, and there are no examples of their application to reading comprehension beyond language learning, such as programming code reading. The third issue is to support students with reading difficulties who learn alongside other students in inclusive education. Little is understood about the use of data to illuminate and support the reading behavior of these students. AR strategies must be the ones for students who struggle with reading can learn to read and improve their reading skills and performance. The primary purpose of this proposal is to provide reading support for those students so that they can gain confidence in their reading. By filling these three gaps, the contribution of DEAR to reading support shall be demonstrated. In order to challenge these three issues, the following research questions are presented:

RQ1: What impacts do LA dashboards provide on reading performance and learning behavior?

RQ2: Can the DEAR strategy be applied to reading learning beyond language learning?

RQ3: How and to what extent can DEAR be adapted to learners with special needs in inclusive educational contexts?

1.4 Structure of the Dissertation

In Chapter 2, we discuss the theory of AR and its research background. Then, LA is introduced as a potentiality that can be applied to reading learning context with the integration of AR strategy, and finally, we explore the current state of AR and LA. In Chapter 3, Data-Enhanced Active Reading (DEAR) is proposed as a framework for AR learning using the LA approach. Chapters 4, 5, and 6 present three study cases to support the proposal of DEAR based on the insights obtained through the demonstration of DEAR respectively. Chapter 4 describes the effectiveness of introducing DEAR into

English classes. Chapter 5 pursues the potential of DEAR applying to program code comprehension. Chapter 6 explains the applicability of DEAR to students with different needs in inclusive education. In Chapter 7 as a discussion, a summary of the three studies and two other case studies as variations of the approach in different language learning contexts are presented. Finally, Chapter 8 concludes the paper with the contributions, limitations, and future works. A schematic diagram of this dissertation is presented in the figure 1.1.

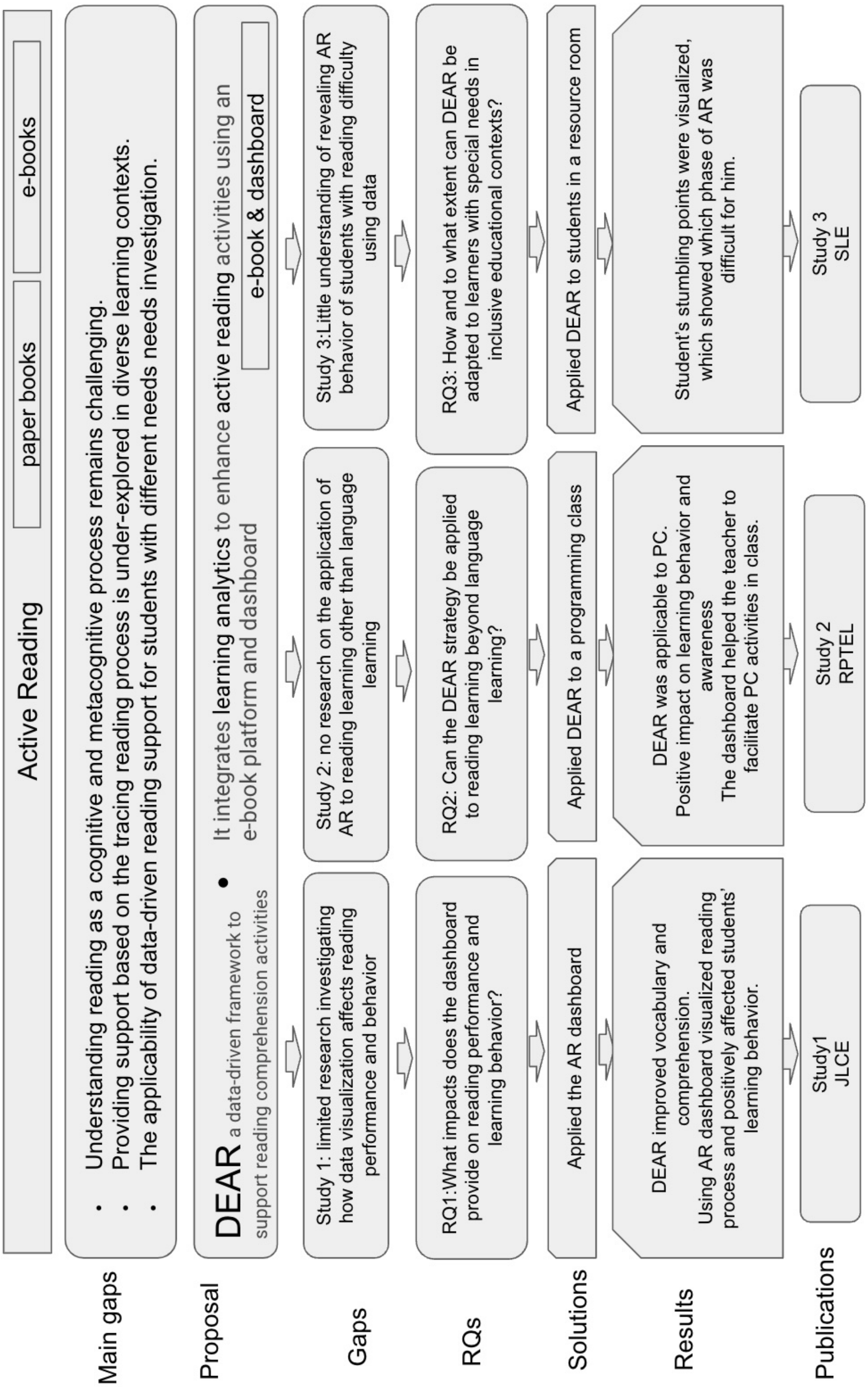

Figure 1.1: Overview of this dissertation

Chapter 2

Literature Review

2.1 Theoretical Background and Strategies of Active Reading

Reading can be broadly classified into two categories. One is passive reading (PR) and the other is active reading (AR). PR is a reading style in which readers read the text without having a purpose or intention, do not criticize or evaluate the content, and do not engage in reading deeply, whereas AR is a style in which readers engage in reading deeply with questions in mind, evaluate and criticize what is written in the text (T.-T. Sun, 2020). Spivey (1987) views constructivism as a framework of knowledge about reading. Reading is defined as the constructive process of meaning, in which readers actively construct mental representations by connecting previously acquired knowledge to new information. AR is based on the theory of constructivism. It is a strategy that activates knowledge and experience gained in the past and associates these with new information to facilitate the understanding of the written text (Ogle, 1986; Spivey, 1987). Additionally, it is a student-centered active learning approach, in which learners actively participate in the cognitive structure of existing knowledge (schema), explore keys in the text, and learn by absorbing and adapting new knowledge to old information (Cheek, 1992; Fosnot & Perry, 1996; Spivey, 1987; Yager & Lutz, 1994). According to Pulver (2020), AR is "the practice and skill of making meaning through deep engagement with a text or other composition, using the basic techniques of re-reading, annotating, responding, and sharing." Spivey (1987) suggests that reading instruction includes both comprehension (reading) and composition (writing).

Robinson (1946)'s SQ3R is for learners to understand unfamiliar information in texts.

The strategy requires reading methods such as skimming and scanning, to identify an overview of the text that is about to be read, creating self-generated questions, reflecting on what they have read, and reviewing reading performance to confirm and retain understanding (Aziz, 2020; Biringkanae, 2018). Through this strategy, learners read to achieve their cognitive goals of understanding and deepening comprehension of the content. SQ4R is an advanced version of SQ3R. The "Record" phase was added as the 4th phase, which encourages learners to keep reading records by taking notes and/or using markers (Khusniyah & Lustyantie, 2017). It is important to understand and master cognitive reading strategies or basic reading methods, such as activating background information, skimming and scanning, inferring from context, taking notes, highlighting, and summarizing, which improve reading comprehension (Ahmadi et al., 2013; Ali & Razali, 2019; Marzuki et al., 2018). Furthermore, mastering metacognitive reading strategies, which involve higher-order behaviors of planning, monitoring, arranging, and evaluating learners' own learning, is also crucial (Israel, 2007). AR strategies provide a strategic method and a practical place for learners, which promotes both cognitive reading and metacognitive reading comprehension (Livingston, 2003). AR is primarily used in English language learning but also has been applied in other languages such as Arabic and Turkish (Erlina, 2018; Malaquias et al., 2021). Moreover, the strategy is applied to learners with reading difficulties to investigate the impact on their reading performance (Gersten et al., 2001). The advent of mobile e-learning tools such as e-book readers has enabled interactive and effective reading learning based on existing AR strategies (CHEN et al., 2020; Wang et al., 2017). By using E-books for reading, data is accumulated as learning logs. However, no research has attempted to visualize the cognitive processes of AR, which take place in the mind, such as activating existing knowledge, applying it to new knowledge, organizing content, and constructing meaning, and supporting teaching and learning.

2.2 Learning Analytics to Orchestrate and Facilitate Teaching and Learning

Using e-learning tools such as e-books enables us to collect and accumulate learning log data of learning processes and behaviors. LA is research aimed at improving and enhancing teaching and learning by analyzing and visualizing accumulated learning log data and providing feedback based on the visualization through daily learning activities (Bodily

& Verbert, 2017; Duval, 2011; Siemens & Baker, 2012; W. Sun et al., 2021). Its visualization method and system development have received focal attention, and researchers are focusing on designing and developing dashboards deemed suitable for the learner's purpose and needs.

LA dashboards are defined as "a single display that aggregates multiple visualizations of different indicators about learner(s), learning process(es), and/or learning context(s)" (Schwendimann et al., 2016). They provide descriptive and prescriptive feedback to teachers, students, and different stakeholders in education to supplement data-driven decision-making, formative assessment, advising, and communication (L. Chen et al., 2019; Gutiérrez et al., 2020) and interactive and personalized feedback that reflects learners' learning patterns, status, and performance, aiming to adapt to their goals (Sedrakyan et al., 2016). Moreover, instead of just relying on data visualization, LA dashboards can be used as a tool and a valid medium for facilitating interaction and engagement between teachers and students and improving students' academic achievement (Verbert et al., 2013).

Modern educational environments are diverse and complex but require inclusiveness. It is a major challenge for teachers to orchestrate and provide learning support that meets the needs of learners with different needs in inclusive educational contexts, but for its student-centered and personalized feedback, LA has the potential to solve the matter (CHEN et al., 2020). However, LA still faces challenges in supporting learning for learners with diverse needs. First, the current challenge on dashboards in LA research is to understand the diverse needs of users proactively and design meaningful LA indicators and dashboards that adapt tools to suit their needs better (Chatti et al., 2020; Dabbebi et al., 2019). Second, LA research overall lacks examples of effective LA implementations and a need to expand the literature documenting evidence of real impacts on learning (Macfadyen, 2022). Needless to say, to date, only a little LA research has addressed data-driven learning support, especially for students with different needs in inclusive environments (Khalil et al., 2023). One of the contributions of my research to LA is to create an AR learning design within an LA-enhanced learning environment and accumulate examples of AR using LA technology.

2.3 Active Reading Supported by Learning Analytics Technology

Past literature on the use of e-books in EFL education research indicated that reading comprehension, teaching and learning strategies, and engagement in learning are crucial elements of the study (Alice Chen et al., 2023). Up until now, AR using paper textbooks has been widely studied, and there are also recent studies on AR strategies using e-books. Research using paper textbooks on AR includes (Aziz, 2020; Grellet, 1981; Ogle, 1986; Robinson, 1946) and e-books include (Mulcahy-Ernt & Caverly, 2018; Wang et al., 2017) as examples. A search on the Web of Science search engine on LA research on reading learning using e-books from 2011 to 2024 yielded 546 hits, of which 44 papers that only concerned reading learning remained after screening. Sorting them out, the majority of papers were related to reading behavior/pattern/approach (Akçapinar et al., 2018, 2020; Majumdar et al., 2021; Yin et al., 2019), application/system/tool development (M.-R. A. Chen et al., 2022; Hutzler et al., 2014; Klebanov et al., 2019; Luczak-Roesch et al., 2018) and others: monitoring(real-time), eye-tracking, and developing models). Of 23 hits for AR and LA, only five of the papers were concerned with AR; three of them were my papers. The remaining were concerned with issues such as the book club model (VanDeGrift, 2024) and tool development (Temprado-Battad et al., 2019), and were not closely related to AR learning. There is one AR study that was not included in the list of literature from the Web of Science. This is a case study of English learning adapting the SQ3R strategy to an emergent form of reading learning using an LA-enhanced e-book system (CHEN et al., 2020). The results indicated the effectiveness of the learning approach, yet, the use of the dashboard in the class was not confirmed. In summary, in the long history of AR, there have been studies that have implemented AR using e-books or e-learning tools, but none have visualized the AR reading process using LA dashboards and contributed to reading learning. Therefore, this doctoral thesis proposes a new framework for an AR strategy called Data-Enhanced Active Reading (DEAR) in the LA learning environment and supports the proposed strategy with three case studies conducted in different learning contexts.

Chapter 3

Data-Enhanced Active Reading to Scaffold Active Reading

We aim to support reading comprehension, autonomy, and reading motivation for learners, and reading instruction and pedagogical approach for teachers. The LEAF system (Learning and Evidence Analytics Framework) (Ogata et al., 2018) was adopted as the reading learning environment.

3.1 Learning Environment for Data-Enhanced Active Reading (LEAF system)

The LEAF system was designed and developed to support LA and evidence-based education (Ogata et al., 2018). It collects learning logs, analyzes the data scientifically, and identifies the current situation and issues. It aims to improve the learning outcomes of students by providing support in a way that suits teachers' and students' needs, optimizes instruction and learning, improves classes, and reduces the burden on teachers. For this project, the LEAF system has been adapted to support AR activities, collect reading and learning logs, visualize and analyze the data, and provide feedback to students and teachers. All these processes possibly lead to improving reading performance and skills for students and pedagogical approaches and designs for teachers. The LEAF system adopts Learning Tools Interoperability (LTI), an international management system standard for the integration of learning applications. It has interoperability with a learning management system (LMS) that supports LTI and system extensibility, and data linkage with other specifications such as the Experience Application Programming Interface (xAPI). It is a digital learning environment consisting of the following: 1). LMS (Moodle), 2). teaching/learning material distribution system, BookRoll, 3). learning analytics dashboards called LOG PALETTE, and 4). Learning Record Store (LRS) (Ogata et al., 2018). A visualization of the framework of the LEAF system is presented in Figure 3.1.

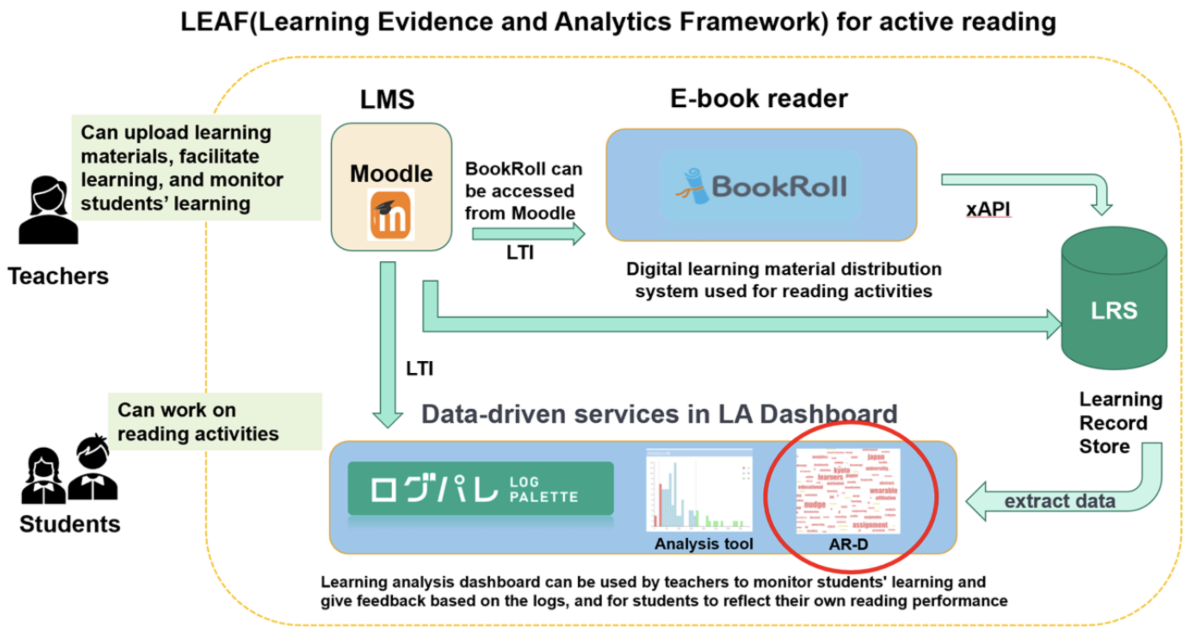

Figure 3.1: A framework of the LEAF system

The system can be accessed from an LMS, such as Moodle through a Web browser like Chrome. Moodle is used to conduct pre-and post-word quizzes, share introductory videos and slides to explain AR activity procedures and the purpose of the class activities, along with submitting reports and manage grades. BookRoll can be accessed from Moodle. It can be used anytime and anywhere from devices such as tablets PCs, and smartphones (Ogata et al., 2015). BookRoll is used as the main platform for AR learning. Learning materials can be registered in the form of PDFs. The main functions of BookRoll include markers, memos, recommendations for quizzes, URL access, and an English/Japanese dictionary. Learning logs using the BookRoll functions contain actions taken by learners, such as markers and memo use, page movements, and time spent on pages. Learning logs are recorded and stored in the LRS, which can be visualized over LOG PALETTE and AR-D to analyze learning performance and behaviors during learning activities with BookRoll. The logs can also be used to make data-driven decisions, identify learners' setbacks, prepare for the next classes, and predict academic performance. In this study, AR dashboard (AR-D) was developed as a part of the learning analytics components in LOG PALETTE (previously called LAViEW). An example of a BookRoll interface is illustrated in Figure 3.2.

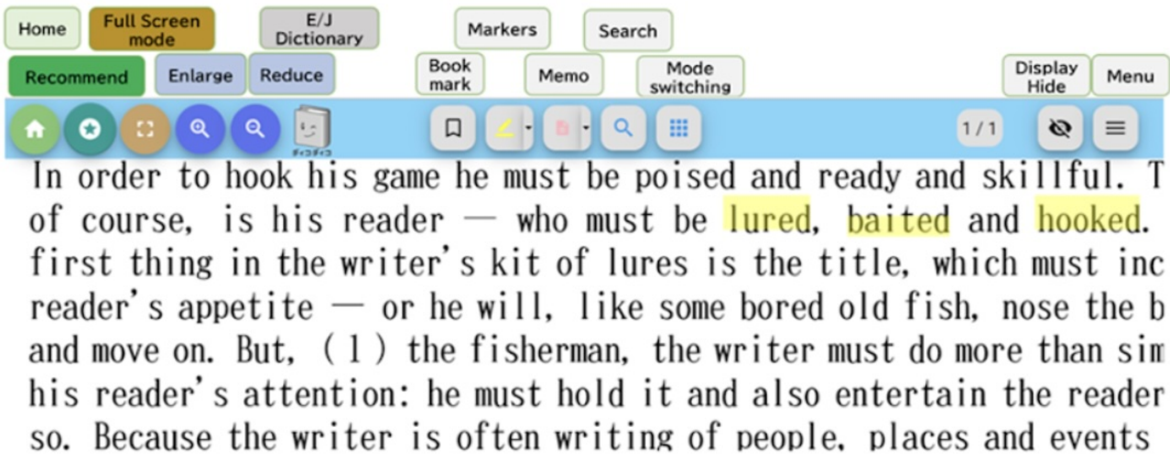

Figure 3.2: Learner interface of BookRoll

3.2 Data-Enhanced Active Reading Strategy for Reading-Learning

We named the AR learning using the LEAF system DEAR (Data-Enhanced Active Reading). DEAR was adapted to the form of AR learning using LEAF based on the SQ3R and SQ4R AR strategies (Aziz, 2020; Khusniyah, 2020; Khusniyah & Lustyantie, 2017; Robinson, 1946). DEAR refers to conducting AR activities with BookRoll using reading facilitating tools and visualizing the reading behaviors and processes on the dashboards. The strategy enables learners to deeply engage in the structure and content of texts and supports them in improving their cognitive reading skills (e.g., reading performance, skills, and strategies) and metacognitive reading skills (reflecting on their own reading learning). The strategy includes AR approaches such as skimming, scanning, predicting summaries, self-questioning, memorizing, summarizing, annotating, and collaborating with others. BookRoll is equipped with memo and marker functions. Hence, the "annotation" and "recording" approach is our primary focus.

Through the structured DEAR strategy, learners follow AR phases to understand the content in the text, reading over and over again until reaching the final goal. SQ3R and SQ4R categorize reading phases into five and six phases, respectively. Pulver (2020) categorized the strategy into four phases: introductory, participatory, analytical, and lateral reading. Taken together, these reading phases are categorized into three simple phases: pre-, while-, and post-reading, which Harida (2016) and Iwai (2011) refer to as the while-reading and during-reading phases. In order to visualize the reading process that is happening in learners' minds while reading in a concise and effective manner, the DEAR process was organized into three phases: "Pre-reading," "While-reading," and "Post-reading". Figure 3.3 summarizes each phase of AR and the AR activities performed using BookRoll's functions.

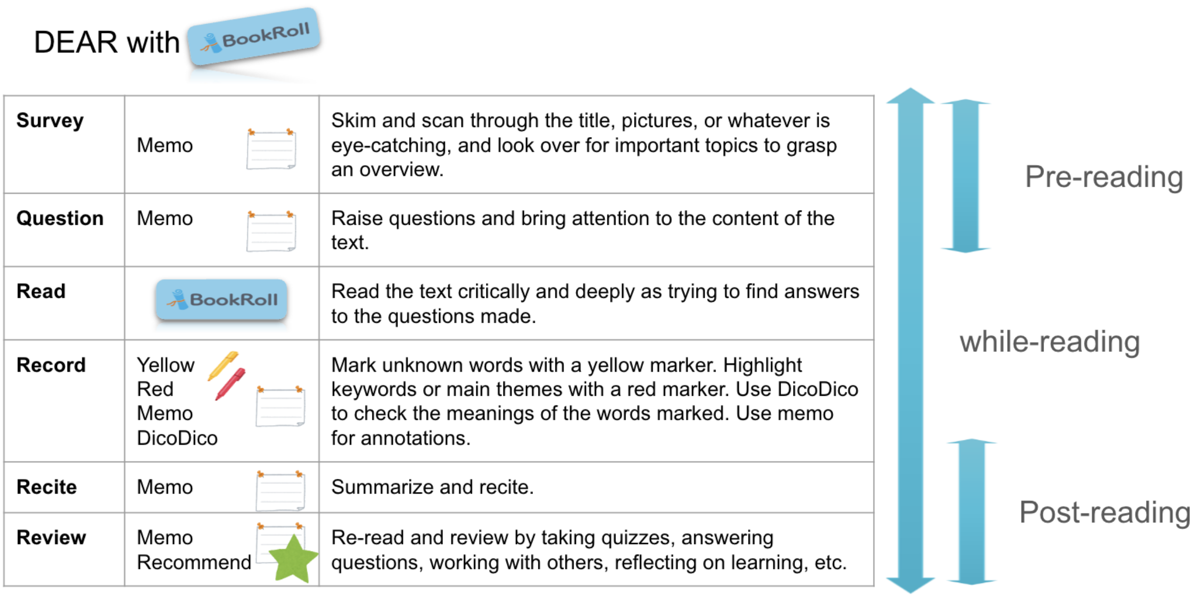

Figure 3.3: AR phases and BookRoll features for AR activities

3.2.1 Pre-reading phase

Foreseeing (or predicting) what to read next is a necessary step for learners to grasp an overview of the reading content. This phase accompanies the SQ stages of SQ3R / SQ4R and is referred to as the planning strategy in the metacognitive reading strategy (Almasi & Fullerton, 2012; Iwai, 2011). In this phase, learners roughly grasp the outline from the information that catches their eyes by looking at the title, subtitles, pictures, or vocabulary. They skim, scan, and connect the information with their own experiences and knowledge to activate their background knowledge and reading motivation. The more difficult the content, the more this foreseeing ability is required (Harida, 2016).

Learners are also asked to make notes or create questions about what they want to know about the content. This concept is comparable to the idea of an advanced organizer (AO). It strengthens readers' cognitive structure, which can be used to prepare for what is about to be learned by providing background information (Herron, 1994). Based on this concept, in the pre-reading phase, learners are asked to type their foreseen overviews (predictions) and self-generated questions in a memo of BookRoll. Another purpose of these activities is to extract, visualize, and understand whether they understand the overview, what they are interested in, and whether they have information or prior knowledge related to the content using the dashboards, and use the information for reflection.

3.2.2 While-reading phase

This is an actual reading phase that corresponds to the Read and Record of SQ4R. Learners critically and carefully read the text such as to find answers to questions they made before reading, identify the author's intention, and critique and evaluate the content. DEAR activities in this phase include using markers and memos for annotations as well as measuring reading speed (WPM: Word Per Minute) and referring to a dictionary in the case of English learning and referring to other reading-related materials.

A timer can be set on the BookRoll screen to measure reading speed and record it as WPM on the AR dashboard. The ability to process information quickly and accurately is one measure of reading comprehension needed in modern society (Arai). WPM makes learners aware of their own reading speed and can be used as a guideline when preparing and taking important English exams such as for school entrance examinations.

The constructivist view points out that readers cannot retain all the information from the text they read; thus, they should follow a selective process in which they make choices using the principle of importance, based on what is given prominently in the text by the author (Spivey, 1987). Based on Spivery's constructivist perspective, we interpreted using markers as actions to make choices, highlight, and have learners reflect. Markers can be used in a variety of ways depending on the instructions. For DEAR, yellow markers are mainly used for unknown words and expressions, and red markers are used for keywords and main themes. Memos can be used to annotate questions, comments, and things learners want to remember for later. Annotations help learners track, reuse, and review the information later.

The recommendation function can be used to post URLs and other e-learning services related to reading activities and to take quizzes. By registering a URL into this feature, teachers can have students directly go to the site they want students to refer to. Moreover, by creating quizzes and having students answer them within this function, teachers and students themselves can check the scores and analysis results on the dashboard.

There are pros and cons to referring to a dictionary in class. One of the reasons is probably because of concerns about wasting time looking up dictionaries in class. There are many meanings listed in a dictionary and it can be a difficult task to find the meaning that matches the content they are reading. However, reading comprehension requires vocabulary. DicoDico in BookRoll allows learners to search for word meanings and select and memorize word meanings depending on the context (Lecailliez et al., 2020). Learners can directly enter the word they want to find out, or they can get the meaning by simply clicking on the word marked with a marker. Teachers can use the list of searched terms on the dashboard for vocabulary quizzes. When they do not need DicoDico during classes or tests, they can hide the icon from students.

3.2.3 Post-reading phase

In this phase, learners review and confirm their understanding and knowledge gained from reading activities to establish it as a memory. The activities include reading aloud, reciting, paraphrasing, and summarizing the contents. They can also take tests and quizzes, answer questions created by them, discuss with others, and give presentations in groups. They may try to apply what they have read to other situations.

Taking summary writing as an example, learners use a memo to write their summaries, and check their own understanding, see others' summaries to deepen their understanding, and confirm their understanding of the content using the dashboard. Teachers can check the summaries written by learners using the dashboard and decide on their next actions, such as considering whether a review or additional explanation is necessary.

3.2.4 Summary of the active reading phases

In summary, in the pre-reading phase, learners predict and leave questions about upcoming content by utilizing information in the text such as titles, pictures, and vocabulary by employing strategies such as metacognitive reading and advanced organizers which activate prior knowledge and motivation. BookRoll's memo feature allows us to record predictions and questions to contemplate and help facilitate understanding and engagement.

During the while-reading phase, learners actively engage with the text using markers, memos, a dictionary, and a timer to increase comprehension and reading speed. Memos and markers are used selectively to highlight important elements to aid memory retention and comprehension. In the post-reading phase, learners reinforce comprehension through activities such as summarizing, reciting, and discussing. While cognitive and metacognitive skills in reading are improved through this series of AR activities, it is further expected that the use of the dashboard will facilitate a cycle of reflection and improvement in which learners and teachers can assess comprehension and adjust interventions accordingly. The next section describes in detail the AR dashboard developed based on these three AR phases.

3.3 Active Reading Dashboard for Active Reading

Various efforts to scaffold improving reading performance and skills have been investigated, yet there have been no efforts to visualize the AR process using logs, verify the effects on learning behavior and performance, and further deepen reading comprehension in a data-driven manner. To this end, an AR dashboard was specifically designed to visualize students' reading behavior such as annotations and artifacts created during AR. The dashboard provides individual feedback, allowing students to reflect on the information from the whole class. Such approaches are difficult when conducting AR with paper-based materials. The following sections present a detailed introduction to the AR dashboard.

3.3.1 Aims of active reading dashboard

Sensemaking of the information presented on a dashboard is crucial for users to make actional decisions. AR dashboard was developed to provide meaningful information for learners and teachers and allow them to observe and confirm the performance and engagement of reading activities during the active reading process.

The student dashboard was designed to help motivate learners to read, learn more, and improve their reading skills and performance by reflecting on their reading process. It also promotes learners' self-awareness of their reading activities by providing a visualization of learning with a comparison of the whole class group and having them reflect on how much and how well they are doing in class. In the same dashboard, the teacher's view was designed to visualize individual learners and the whole class' learning performance and engagement in real-time and offer feedback from what is visualized on the dashboard. Using it, teachers can check where learners are experiencing difficulties or problems, types of problems, and if they are engaging in reading. It can also be used to make decisions on the next steps, such as providing additional explanations about the content, planning the next class, and reflecting on their own teaching method or procedures to the need for improvements.

3.3.2 Active reading dashboard to contextualize active reading

AR dashboard is practically divided into four parts: a histogram of operation logs, text thumbnail, a list and a WordCloud of predictions and questions, and a list and a WordCloud of markers, each of which displays feedback based on data extracted from learning activities at every stage of AR. The description of each component of the AR dashboard is provided in Table 3.1.

Table 3.1: Description of each component of the AR Dashboard and LOG PALETTE

Component	What it presents	Which AR phase is it useful and utility
Histogram of operation logs	Indicates where a particular student is in the distribution of operations and the number of annotations made by different students.	Which AR phase: **pre-, while-, and post-reading** Utility: • for in-class social comparison • for status confirmation • to support learners' metacognitive skills
Annotation overlay on reading content	The contents of each page of the learning material and the yellow and red markers drawn by students and a teacher are displayed.	Which AR phase: **while-reading** Utility: • to confirm learners' understanding

Component	What it presents	Which AR phase is it useful and utility
List of predictions and questions	Students who wrote the predictions and the questions and contents of the predictions and questions are listed in page order.	Which AR phase: **pre- and while-reading** Utility: • to view various ideas and deepen their understanding further • to be used as an introduction
WordCloud of predictions and questions	Displays words written in predictions and questions.	Which AR phase: **pre-reading** Utility: • understand what is in the learners' mind before reading
List of markers	Students who drew the marker and the contents of the marker are displayed in page order.	Which AR phase: **while-, and post-reading** Utility: • to confirm understanding • for reviewing later
WordCloud of markers	Displays words drawn with a yellow and a red marker.	Which AR phase: **while- and post-reading** Utility: • grasp difficult words and important keywords

3.3.3 Active reading modules

AR dashboard can be easily accessed from LOG PALETTE, an analysis tool, or directly from Moodle by setting a custom parameter. Prior to the analysis, users can select the learning material and study period. Individual students can be selected and analyzed by choosing their names. After selecting the material and period, the analysis can begin by pressing the start analysis button. The context selector interface of AR dashboard to start analyzing is illustrated in Figure3.4.

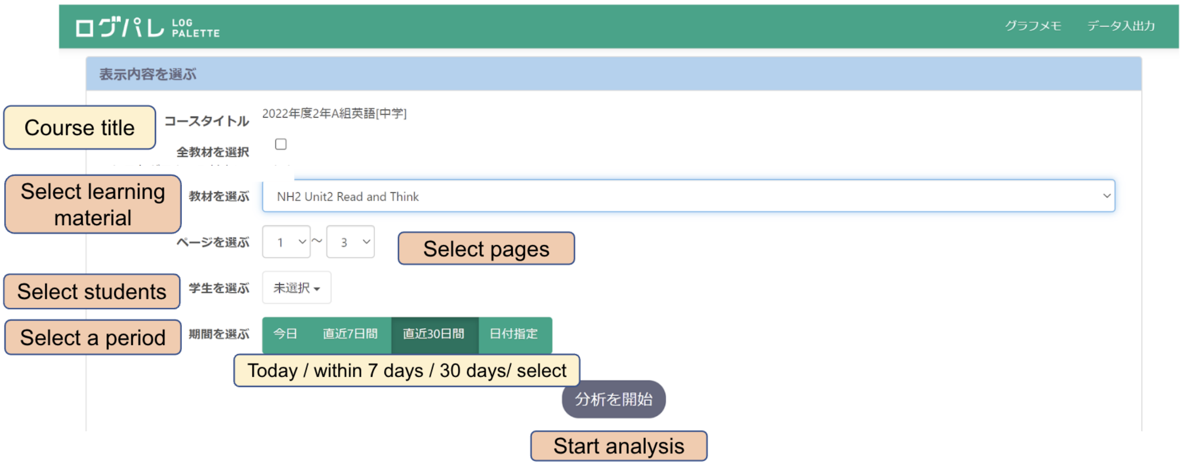

Figure 3.4: Interface of AR dashboard for starting an analysis

Histogram of operation logs

The module of the operation histogram displays quantitative data extracted from marker counts, reading time, memo counts, and word per minute (WPM) are displayed as a bar chart and text message. A bar chart of marker counts with a text message is presented as an example in Figure3.5. The message is to motivate learners to use annotation functions such as markers and memos in BookRoll more in the next class. Values of individual learner's operations are categorized into three groups: the triangle group (△) in red, the circle group (◯) in blue, and the double circle group (◎) which is represented in green, according to the numerical value of the index. The learner's position is indicated by a star (★). This module aimed to have learners check their learning behaviors and status objectively by comparing them with other students in the same class to see how well they are doing in class. It was designed to support learners' metacognitive skills by visualizing log data during the AR process. Teachers can also have an overview of the whole-class approach to activities.

Annotation overlay on reading content

The contents of each page and the yellow and red markers drawn by the learners are displayed on a text thumbnail. The more markers, the darker the colors appear on the panel. By moving a cursor over a marked position, a popup displays the name of the

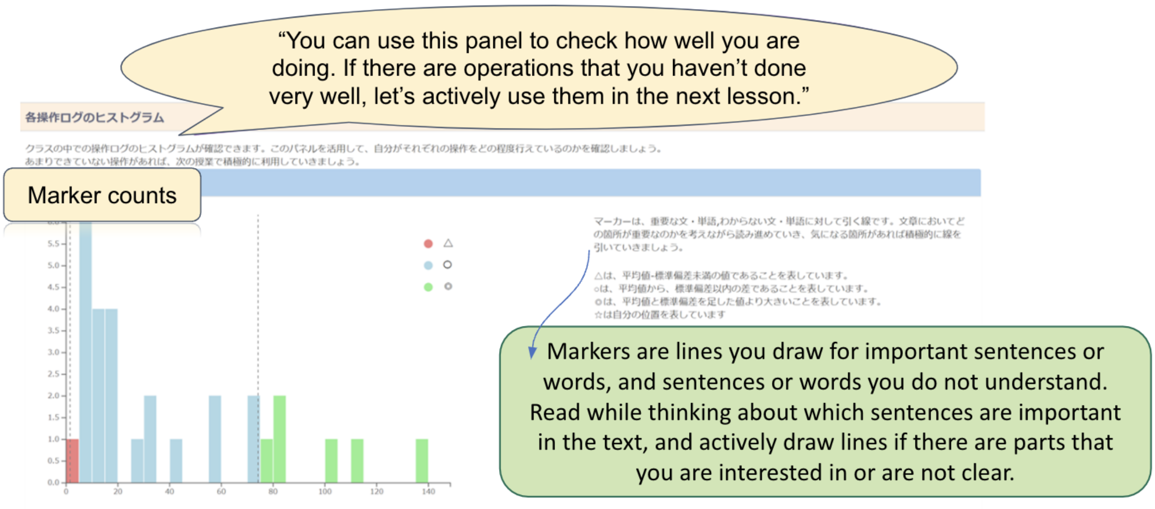

Figure 3.5: Operation histogram of marker counts

learner who marked it. By selecting a learner, only the markers drawn by that learner are displayed. A yellow marker can be used to mark unknown or difficult words. In this case, by simply looking at the parts marked in yellow, both learners and teachers can immediately see which words and expressions were difficult. This can be used as a basis for determining whether a word review is necessary. A red marker can be used to highlight important ideas or main themes. Red markers drawn by a teacher are displayed in light green, which tells learners the parts the teacher thinks are important, and those drawn by a learner are displayed in light blue. Learners can check if the position of the red markers drawn by their teacher matches the position of those drawn by himself or herself. Teachers can also check whether learners in the class understand the content of the reading by looking at the part marked in red, if not, they may adjust the teaching approach in class. Learners' and teachers' marker use is visualized in the text thumbnail as a marker visualization module, as illustrated in Figure 3.6.

A list and a WordCloud of predictions and questions

The survey and question list allows users to share predictions and questions for individuals and the whole class (displayed anonymously to students), which aims to increase interest in the text content. Word clouds can be used as an introduction to classes, as they allow us to understand the keywords that appeared in a learner's mind before reading. Indicators for the modules are the number of predictions (as foreseen overviews) and questions, the number of characters, and the contents of predictions and questions. The predictions and

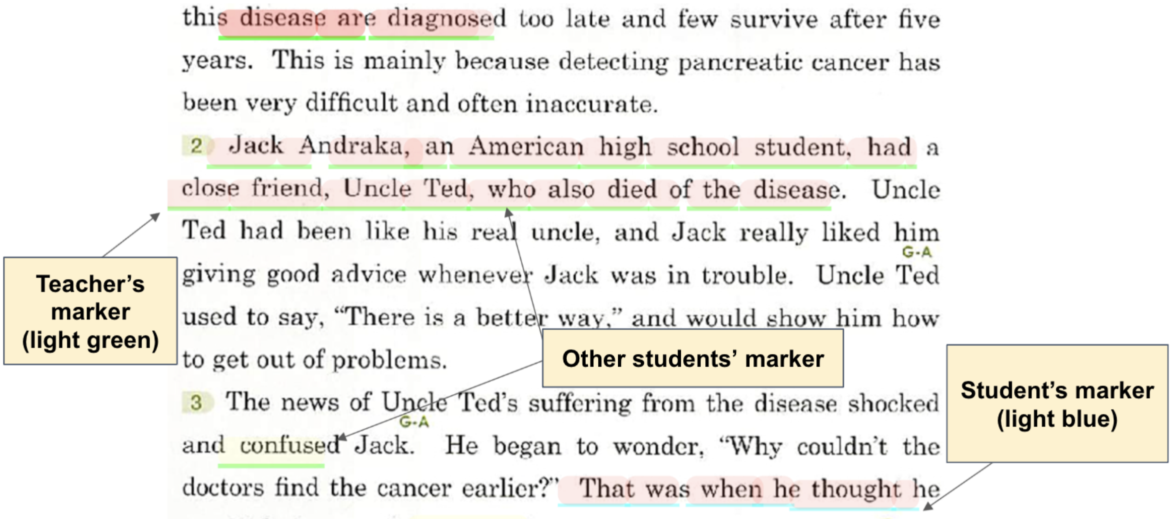

Figure 3.6: Text thumbnail which shows learners' and teachers' marker use

questions made by the student during the pre-reading phase are extracted and listed, and their own as well as other students' predictions and questions can be viewed in the same class. Student names can be displayed anonymously in case a teacher wants to share the logs with a whole class. By observing the outcomes of others, students may accept various ideas and deepen their understanding. The list can be used as an introduction to motivate students to "get into" the world of the story and to check if they have a rough overview of the reading material, what they are interested in, or if they have information and/or prior knowledge related to the content. In addition, students' questions can be shared in each reading phase to provide opportunities to answer their questions and those from others in class to satisfy their metacognitive goals. Words extracted from predictions and questions in memos as a whole class are displayed as a WordCloud in green and light green. Words that appear frequently are displayed in larger sizes and thicker letters. By simply looking at the WordCloud, students and teachers can understand the keywords that came into students' minds before reading. A list and WordCloud of predictions and questions are shown in Figure 3.7.

A list and a WordCloud of markers

Yellow and red markers are used as the main indicators for analyzing activities during the while-reading phase. The marker list indicates who did not understand which words (yellow) and who highlighted which parts as the main theme or important ideas (red)

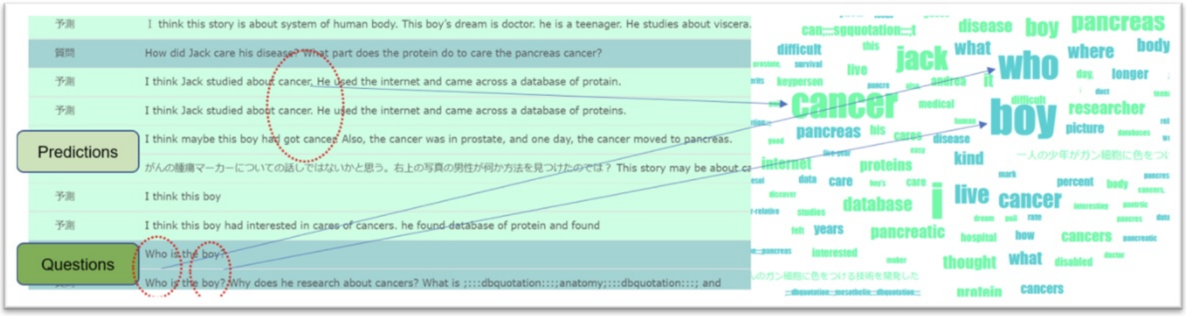

Figure 3.7: Predictions and questions visualized in the list and a WordCloud of the most frequent words in the two categories

while reading. In a WordCloud, red markers highlight the parts that students recognized as important, and yellow markers on vocabulary and expressions that are considered difficult or not clear. One of the purposes of these modules is for students and teachers to be aware of whether they can highlight important words related to the content, and whether it is necessary to review certain words in class. Words listed and visualized in WordCloud can be used when students write a summary in the post-reading phase. An example of a list and WordCloud from marker use are presented in Figure 3.8 and the objectives of the dashboard use in each AR phase are explained in the next section.

Figure 3.8: Listed content marked with yellow (difficult to understand) and red (important) from the reading text and their visualized WordCloud

3.3.4 Active reading dashboard for each phase of active reading

In this section, the objectives and examples of activities in each phase of AR are illustrated with diagrams.

Pre-reading phase

The objective of reflecting learners' predictions and questions in the dashboard is to understand their interests and prior knowledge. The lists can be shared as an introduction at the beginning of the class or teachers can prepare lessons based on the learners' interests and questions. The word cloud can be used in class (or outside class) to grasp keywords students have before reading the text (refer to figure 3.9).

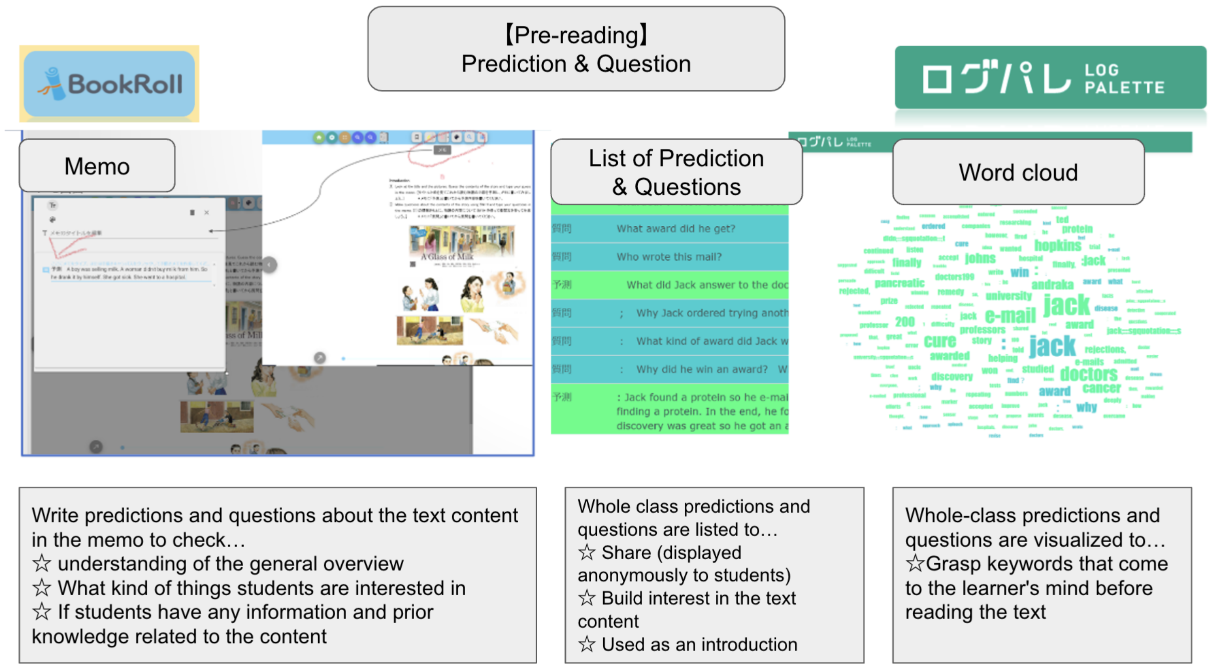

Figure 3.9: Objectives and activities for the pre-reading phase

While-reading phase

During this actual reading phase, learning actions performed using BookRoll functions such as markers, memos, and a timer are visualized on the dashboard. The list of markers can be used by teachers to create tests and quizzes by identifying vocabulary that is highlighted in yellow. The word cloud and text overlay can be shared with the class to encourage students to review vocabulary and confirm key points. Checking vocabulary highlighted in red by them and others in the class on the word cloud and text overlay can help students summarize the content in the post-reading phase. The AR dashboard has been improved by adding an automatic reading speed calculation and its graph. The effectiveness of this module will be investigated in future experiments. The interface of the main dashboard modules used for the studies so far is shown in Figure 3.10.

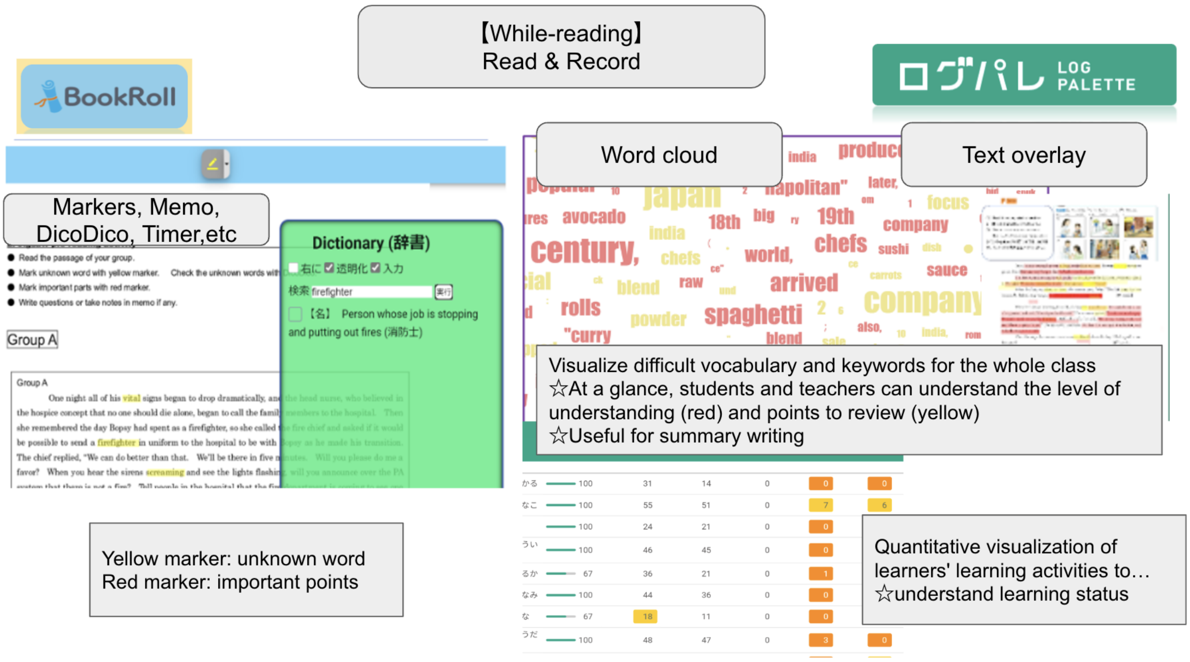

Figure 3.10: An example of activities for the while-reading phase and visualized reading logs

Post-reading phase

The summaries written in the BookRoll memos are visualized in lists and can be used to check students' comprehension. Students can also view summaries written by other students (displayed anonymously); thus they can deepen and expand their understanding by incorporating the opinions of others. Figure3.11 depicts an example of the post-reading phase activity.

3.4 Model and Expected Impact on Teachers and Students

Classes are generally held in the order of "introduction", "learning", and "expansion and conclusion". The three phases of DEAR can be flexibly integrated into the three developments of the class activities. Learners progress reading learning through DEAR by following the three phases and making effective use of learning logs that are visualized and

Figure 3.11: Summary left in a memo and summaries visualized on the dashboard as a list

shared as feedback at appropriate times. By doing so, learners can improve their reading comprehension, skills, and motivation. Once the DEAR strategy is acquired, learners are encouraged to use the strategy outside class by themselves.

Teachers check the logs, grasp what students understand and what they do not understand at the individual and class levels, and intervene and provide feedback, if necessary. In addition, teachers can understand who is stumbling and where they are stumbling at, and decide on a subsequent action, such as adding additional explanations or slowing down the pace of the class. Moreover, by checking students' progress, they can review the class content, plan and prepare for the next activities and class, and reflect on their own teaching methods and approaches. They can proceed with teaching depending on the progress of the class, and flexibly incorporate the strategy into their own pedagogical approaches. Figure 3.12 highlights the cycle of DEAR for students and teachers.

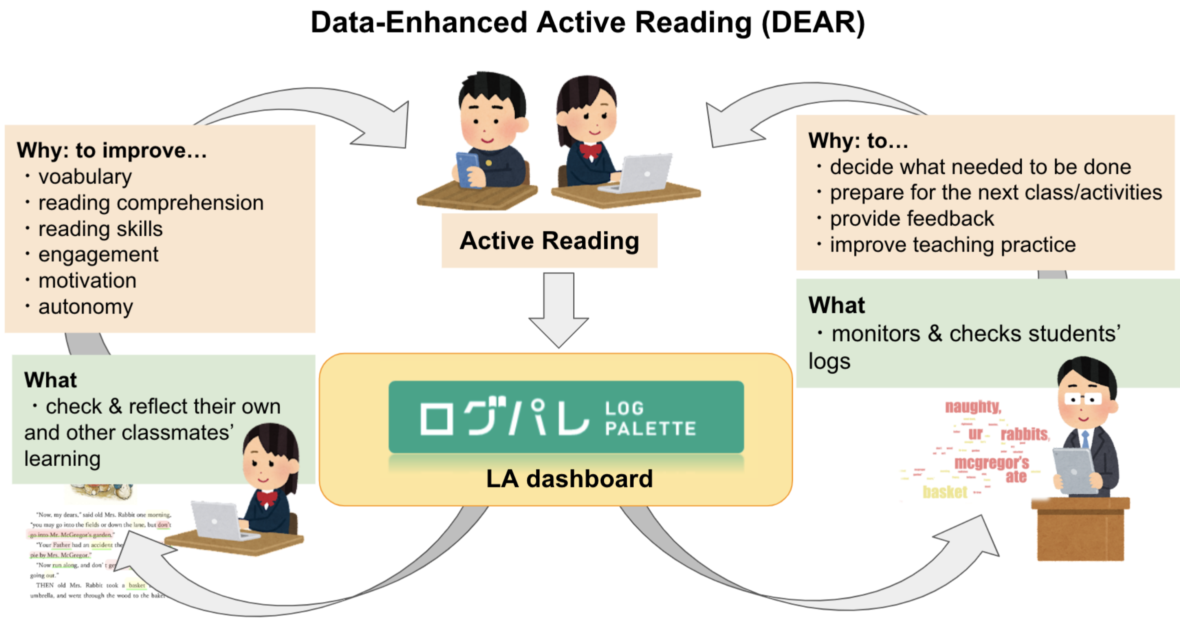

Figure 3.12: The DEAR cycle for students and teachers

3.5 Data-Enhanced Active Reading: Orchestrating Active Reading

In this chapter, we proposed DEAR, an emergent AR learning strategy that integrates an LA-enhanced learning framework. In order to differentiate between existing AR strategies using technology and the research proposal, DEAR, we developed an AR dashboard with aiming to support teaching and learning on reading with visualization of reading processes. The AR dashboard visualizes the cognitive processes of the three AR phases: pre-, while-, and post-reading, and provides feedback to learners and teachers to improve teaching and learning. However, there is still a need to understand how visualization of the cognitive process affects reading comprehension and whether DEAR can be applied in the broader contexts of language and any other types of reading learning. Thus, we present the following three issues and verify that each study fills the gaps:

1. Limited research has investigated how data visualization affects reading performance and behavior from LA perspectives. 2. There is no research on the application of AR to reading learning other than language learning. 3. There is little understanding of revealing AR behavior of students with reading difficulty using data and considering subsequent support.

Two of these studies have been published in international journals, and the remaining one is now conditionally accepted. In the next chapter, I shall present three studies to challenge the three issues.

*Ethical Considerations

We have obtained consent from participants for all studies conducted for this dissertation.

Chapter 4

Research Study1: Data-Enhanced Active Reading for English Reading

4.1 Research Background

In the technology era, various types of e-learning tools such as e-books have been introduced into language learning to support teaching and learning (CHEN et al., 2020). Technology-enhanced learning motivates students to learn, and improves learning performance and skills; moreover, it visualizes the learning process to some degree which was not possible with traditional paper-based learning (L. Chen et al., 2019). English reading classes also benefit from such technology and can be taught more actively. In recent years, teachers make lesson plans by considering how actively and effectively students can improve their reading comprehension by integrating existing reading methods and technology (Yang et al., 2018). However, even though various efforts to scaffold improving reading performance and skills have been investigated, there still lacks the efforts to visualize the reading process, verify the effects on learning behavior and performance, and further support reading learning in a data-driven manner. Hence, an AR dashboard was developed to visualize students' reading behavior such as annotations and artifacts created during AR, and implemented in high school English classes to investigate the impact of the dashboard on reading learning.

Given the need to understand the process of AR to support the development of learners' cognitive and metacognitive reading skills, we posed two specific research questions as follows and designed a quasi-experiment:

RQ1: What are the behavioral differences between the groups of students who were aided with AR dashboard and those who only followed the AR process during in-class English learning activities?

RQ2: Is there a difference in reading performance in terms of vocabulary and reading comprehension between the groups of students aided with AR dashboard and those who only followed the AR process during in-class English learning activities?

The visualized data in the AR dashboard can be a scaffold to decide on the next step toward improvement, which is one of the main objectives of integrating LA in practice. This study discusses how the LA dashboard can be used in a learning environment as an effective means for learners. This study is published in the Journal of Computers in Education (Toyokawa, Majumdar, et al., 2023).

4.2 Methods

4.2.1 Participants and study context

The study was conducted in high school second-year English classes with a total of 61 students, of which, 42 who participated on all days were selected as participants. There are two classes: one class aided with AR dashboard (n=21) as the experimental group and another class following only the AR process without using any dashboard as the control group (n=21). Both classes followed the same AR procedures by using BookRoll. (For the phases of AR, please refer to Section 3) Both groups belonged to the same standard class as per their English ability. Each class session lasted for 50 minutes. One unit was covered in five days. An English story (553 words) was selected from the regular English textbook as the reading content and was divided into two parts. On Days 1 and 2, the first half of the story was covered. On Day 1, the classes started with a pre-reading phase. In the first step, students predicted an overview and created questions related to the first half in memos. Then, in the experimental group, the students' predictions and questions were shared in class using the dashboard. In step 2, they read paragraphs and checked their reading speed using a timer on BookRoll. Students in the experimental group registered their reading speed as WPM in AR-D, whereas those in the control group wrote their WPM in a memo in BookRoll. On Day 2, students conducted step 3 using a yellow marker to mark unknown words while reading the paragraph. In step 4, they used a red marker to highlight the main theme of the first half of the story. Students in the experimental group accessed AR-D to confirm the meanings of the words and key phrases of the story by looking at the list and WordCloud in pairs or in small groups. After checking the main theme using a red marker, students were instructed to complete step 5: write a summary of the first half of the story. Both groups repeated the same cycle for the second half. On Day 5, the students progressed to the post-reading phase and conducted step 6 by writing a summary of the whole story. The procedures for the class activities are presented in Table 4.1. The steps followed by the AR dashboard group are in order and bold.

The procedure of the experiment is displayed in Figure 4.1. At the beginning of the experiment on Day 1, a questionnaire-based pre-survey was conducted to investigate students' perceptions of their AR before the AR activities. Students then answered the pre-vocabulary quiz, followed by an introduction to the AR strategy. On Day 5, after the AR activities were completed, students answered the post-vocabulary quiz and a questionnaire-based post-survey was administered to assess the transition of their perception of the AR strategy.

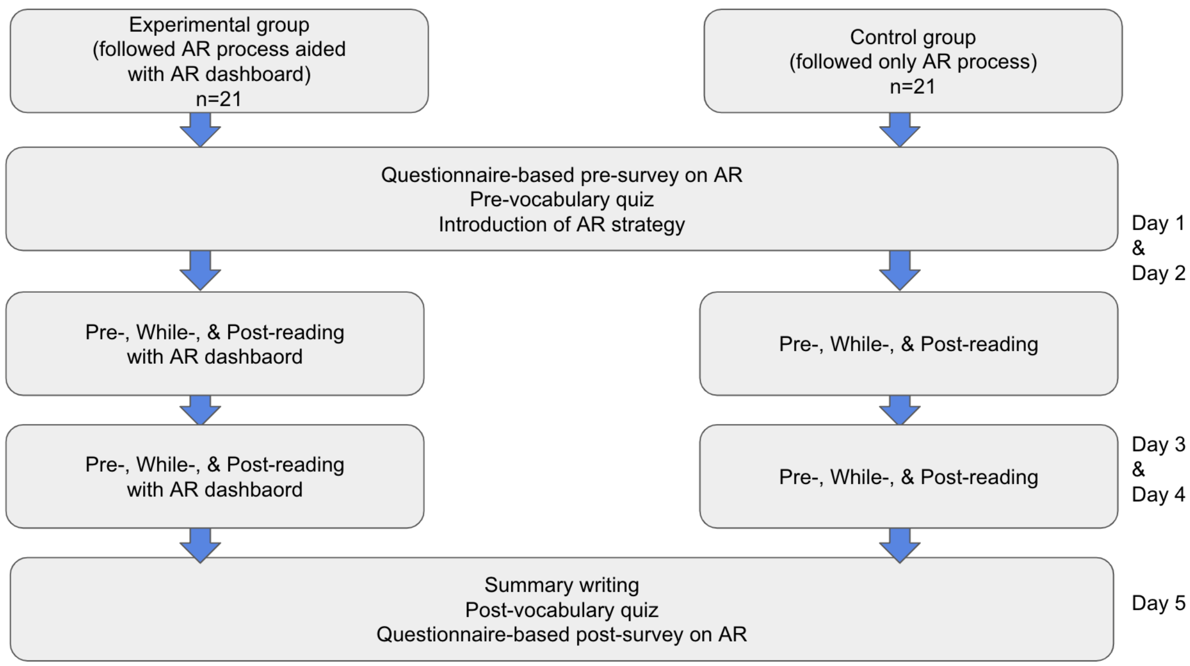

Figure 4.1: Experimental procedure

Table 4.1: Active Reading class procedures and explanation of class activities

Days	**AR phase**	**Steps during class activities**	**LEAF tool used**	**Expected duration**
Day 1	Rre-Reading While-Reading	1) Write a prediction and questions **Share predictions and questions** 2) Read and check WPM **Register and check WPM**	BR memo **AR-D** BR timer **AR-D**	15 mins. 2 3 mins. 5 10 mins. 2 3 mins.
Day 2	While-Reading Post-Reading	3) Mark unknown words with a yellow marker 4)Mark important ideas or main themes with a red marker **Share parts marked by markers** 5)Write a summary of the first half of the story	BR yellow marker BR red marker **AR-D** BR memo	5 10 mins. 10 15 mins. 3 5 mins. 10 15 mins.
Day 3	Pre-Reading While-Reading	1)Write a prediction and questions **Share predictions and questions** 2) Read and check WPM **Register and check WPM**	BR memo **AR-D** BR timer **AR-D**	15 mins. 2 3 mins. 5 10 mins. 2 3 mins.
Day 4	While-Reading Post-Reading	3) Mark unknown words with a yellow marker 4)Mark important ideas or main themes with a red marker **Share parts marked by markers** 5)Write a summary of the second half of the story	BR yellow marker BR red marker **AR-D** BR memo	5 10 mins. 10 15 mins. 3 5 mins. 10 15 mins.
Day 5	Post-Reading	6) Write a summary of the entire story	BR memo	20 30 mins.

4.2.2 Instruments and data collected

Behavioral data related to AR were collected as learning logs in the BookRoll. It included operation, yellow and red markers, and memo counts. The operation count shows the number of all operations performed on the BookRoll, including typical operations such as page navigation, yellow and red markers created, and memo use. Frequency counts of English words used in memos were also measured. The number of predictions and questions written in English, Japanese, or both English and Japanese was counted to examine behavioral differences in language use. Along with behavior logs, pre- and post-surveys related to students' perception of AR behaviors were also collected from the experimental and control groups. Pre-survey was conducted to assess students' awareness of each task of AR methods before introducing the AR strategy in the class, and a post-survey was conducted to reflect on how they did AR during the sessions. The questionnaires were developed based on the "Study Skill Inventory" proposed by Congos (2011). Items that had acceptable reliability scores as measured by Cronbach's alpha were selected and applied in three phases: pre-, while-, and post-reading. Survey questions covered each AR technique, such as "Before reading, I survey headlines, bold print, italics, questions, summaries, and so on," "I formulate questions before, during, and after reading," "I take notes as I read my textbook," and "I convert text material into my own words." A 5-point Likert-type scale was adopted to measure students' perception of each task of the AR phases ranging from 5 "agree," 4 "somewhat agree," 3 "neutral," 2 "somewhat disagree," and 1 "disagree." Students in the experimental and control groups responded to 20 and 12 items from the pre-survey and post-survey, respectively. From there, items with low reliability were excluded and only reliable ones were selected: two items each for the pre- and while-reading phases, and three items for the post-reading phase. The Cronbach's alpha values were calculated: pre-reading (0.761 and 0.736 for pre- and post-survey, respectively), while-reading (0.607 and 0.710 for pre– and post-survey, respectively), and post-reading (0.728 and 0.754 for pre- and post-survey, respectively). These values imply acceptable reliability of the scale except for while-reading for the pre-survey (0.607), which is relatively low reliability of the scales.

As a performance indicator, pre- and post-vocabulary quiz scores were measured to analyze vocabulary acquisition. The pre-vocabulary quiz measured participants' prior English vocabulary knowledge. The post-vocabulary quiz measured participants' lexical achievement after the AR activity. Both quizzes consist of the same 30 multiple-choice vocabulary questions. The selected quiz was created by a subject matter expert with 15 years of experience of teaching English. This was further verified and approved by the English teacher who taught the classes and the other who taught the same unit but in other classes. The test comprised 30 multiple-choice questions, with a total score of 10 (100). Then students' summaries were scored by an experienced English teacher based on a four-point scoring rubric (Yamanishi et al., 2019). Two dimensions were measured: content dimension as to whether the learner understands the content of the reading and language use dimension to measure vocabulary and grammar use.

4.2.3 Analysis method

To answer RQ1, students' behavioral differences between the experimental and control groups were measured based on operation counts from Day 1 to 4, yellow and red marker counts on Day 2 and Day 4, and memo counts on Day 1 and Day 2 using t-tests. The frequency counts of English use were calculated according to the number of predictions and questions written in memos. Further, students' AR behavior was examined by using a paired t-test based on the results from a pre-and post-survey.

For RQ2 regarding students' reading performance, we examined students' pre- and post-vocabulary scores using ANCOVA and measured their normalized gain (Hake, 1998) to evaluate the differences among individual students in the two groups in terms of their lexical achievement. A t-test was conducted to measure reading comprehension based on the summary writing between the experimental and control groups.

4.3 Results

4.3.1 Students' learning behaviors

Results of t-tests on students' learning behaviors based on the operation, yellow and red marker, and memo counts revealed no significant difference ($p>0.05$) between the experimental and control groups, as reported in Table4.2. However, in terms of operation counts, the number of operations of the experimental group increased over time (M=54.905, 93.190, 94.762, 95.619). This indicates that students who used AR-D in the class studied more actively using the functions in BookRoll. Regarding yellow marker use, the number of markers among the students in the experimental group decreased (M=22.095, 9.000), whereas that of the control group increased (M=15.476, 23.143). The number of red markers increased among those in the experimental (M= 34.810, 132.762) and control groups (M= 81.190, 112.619), and no changes were observed in the number of memos.

Table 4.2: Descriptive statistics of operation, markers, and memo counts

Interaction Behaviors	**Expt. group N=21 M (SD)**	**Control Group N=21 M (SD)**	**Comments**
Operation Count Day 1 Operation Count Day 2 Operation Count Day 3 Operation Count Day 4	54.905 (23.48) **93.190 (54.62)** **94.762 (69.79)** **95.619 (68.27)**	**64.905(32.63)** 80.810 (32.26) 63.286 (48.41) 88.762 (57.75)	Operation counts represent the number of operations in BookRoll, which does not include the number of operations with the AR-D. Students in the experimental group accessed AR-D; however, the operation count on BR increased day by day.
Yellow marker Day 2 Yellow marker Day 4	**22.095 (46.39)** 9.000 (7.43)	15.476 (27.91) **23.143 (64.90)**	The number of yellow markers drawn for unfamiliar words decreased among students in the experimental group while it increased among those in the control group.
Red marker Day 2 Red marker Day 4	**34.810 (89.73)** **132.762 (202.12)**	81.190 (70.96) 112.619 (115.08)	The number of red markers drawn for the important ideas increased among students in both groups, especially among those in the experimental group.
Memo Day 1 Memo Day 2	2.524 (1.32) 2.333 (1.62)	3.333 (1.56) 3.429 (2.73)	No change in the number of memos.

Examining participants' annotation behavior by calculating frequency counts of English use revealed a difference in the rate of using English for annotations, such as writing questions between students who were aided with AR dashboard and those without. Students in the experimental group wrote more questions during the pre-reading phase in

English (N=29; 96%) than those in the control group (N=13; 62%) on Day 1. Moreover, all students in the experimental group wrote their questions in English (N=25; 100%) on Day 3, whereas some in the control group continued writing their questions in Japanese (N=20; 69%). The results imply differences in the proportion of students using English while attempting AR between the two groups. The results of the frequency count to indicate the students' learning behaviors are presented in Figure 4.2.

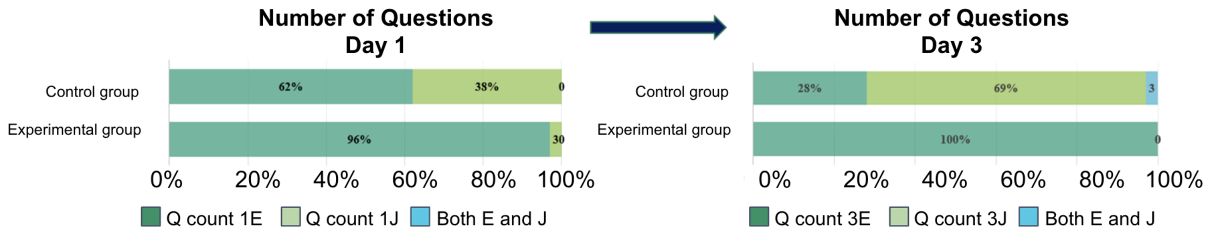

Figure 4.2: Proportion of the desired language use behavior in the pre-reading phase

Furthermore, Table 4.3 reports the results of paired t-tests related to students' perceptions of the different AR phase activities. Perceptions based on the pre-and post-survey indicated a statistically significant difference before and after AR activity on the pre-and post-reading tasks in the experimental group (prediction: t= -2.609, p= 0.017, Cohen's d= -0.569; question: t= -4.806, p= 0.001, Cohen's d= -1.049; summary: t= -2.121, p= 0.047, Cohen's d = -0.463); by contrast, there was a significant difference in question task in pre-reading in the control group (t = -2.142, p= 0.045, Cohen's d = -0.468). This result indicates that the participants' perception of the tasks was affected by the implementation of AR in class, and the introduction of AR dashboard particularly affected the pre- and post-reading phases.

4.3.2 Students' reading performance

One-way ANCOVA was used to compare the two groups' learning performance regarding vocabulary with the post- and pre-test scores as the dependent variable and covariate, respectively. The results indicated no significant difference between the groups (F =3.469; p = 0.07 > 0.05) after adjustment for the effect of pre-test scores. The adjusted mean post-test score of the experimental group (adjusted mean = 8.527 SD = 1.303) was not significantly different from that of the control group (adjusted mean = 9.029; SD = 0.690) (see Table 4.4).

Table 4.3: Paired t-test results of pre-and post-survey questions for behavior toward AR strategies

Perception of task	**Group**	**pre-post**	**M**	**SD**	**t**	**Cohen's d**
Prediction	Expert.	pre	2.905	1.136	-2.609* -0.302	-
	Control	post	3.667	0.966		0.569
		pre	3.429	1.076		-
		post	3.524	0.928		0.066
Question	Expert.	pre	2.429	1.165	**-4.806* -2.142***	-
	Control	post	3.524	0.750		1.049
		pre	2.476	1.030		-
		post	3.143	1.062		0.468
Annotation	Expert.	pre	2.714	1.189	-1.671 -0.719	-
	Control	post	3.286	1.007		0.365
		pre	3.143	1.195		-
		post	3.429	1.121		0.157
Review	Expert.	pre	3.190	0.873	0.449 0.27	0.098
	Control	post	3.048	1.161		0.059
		pre	3.238	1.044		
		post	3.190	1.209		
Evaluation	Expert.	pre	2.381	1.117	-1.793 0.165	-
	Control	post	2.762	1.091		0.391
		pre	2.476	1.123		0.036
		post	2.429	1.076		
Summary	Expert.	pre	3.095	0.831	**-2.121*** -1.599	-
	Control	post	3.524	0.814		0.463
		pre	3.048	1.024		-
		post	3.524	0.873		0.349

The normalized gain (Hake, 1998) for students' lexical achievement indicated that both groups improved their vocabulary quiz scores through AR activities. There was no significant difference between the two groups (p=0.092). The average normalized gain score for the experimental group was 58%, which was in the average range (M=0.586, SD=0.298),

Table 4.4: ANCOVA result of the post vocabulary quiz scores on students' learning performance

Group	N	M	SD	Ajusted mean	M
Experimental group	21	8.524	1.303	8.527	3.469
Control group	21	9.032	0.690	9.029	

and 71% for the control group, which was in the high range (M=0.716, SD=0.174). Although the control group had lower deviation and performed well compared with the experimental group in terms of vocabulary acquisition, both groups improved their vocabulary scores.

Regarding measuring reading comprehension, a t-test to examine the difference between the experimental and control groups indicated that there was no significant difference in the mean of the content (t= -0.306, p>.05) for the experimental (M=2.556, SD=0.922) and control groups (M=2.474, SD = 0.697), and for the language usage (t= -0.583, p>.05) for the experimental (M=2.667, SD = 0.840) and control groups (M=2526, SD = 0.612) (see Table 4.5).

Table 4.5: T-test results of scores in summaries

Dimension	Group	N	M	SD	t
Content	Experimental group	18	2.556	0.922	-0.306
	Control group	19	2.474	0.697	
Language	Experimental group	18	2.667	0.840	-0.583
	Control group	19	2.526	0.612	

4.4 Discussion

Based on our findings, we discuss the impacts of the AR dashboard on reading activities, current limitations, and potential considerations for innovation with data-driven teaching and learning practices.

4.4.1 Impacts of the active reading dashboard on learners' reading behavior and perception

Regarding the introduction of the AR dashboard, the results indicate a positive perceptional change among students who used the AR dashboard in class (refer to Tables 4.2, 4.3, and Fig. 4.2). Based on the results of the statistics of operation, the number of operations of BookRoll functions in the experimental group increased day by day. This indicates that the introduction of the AR dashboard into the classroom led to more active and self-generated use of the BookRoll function by learners. Regarding the use of markers in the experimental group, the number of yellow markers on unknown words decreased, and the number of red markers on important parts increased. This is interpreted as the reflecting on vocabulary and phrases highlighted by markers on the AR dashboard reduced unknown vocabulary and enabled them to identify important parts of the content. Although no statistically significant difference was identified, reflecting on the use of markers in the AR dashboard affected the awareness of trying to understand the meanings of words and the contents of the reading. Additionally, all experimental group students used English to leave memos after the introduction of the AR dashboard. With the AR dashboard, participants had an opportunity to reflect on their reading behaviors, which may result in a positive learning attitude toward writing in the target language. These behavioral changes were observed only among learners who were shown the dashboard. However, there is still a need to understand how visualization of the cognitive process affects reading comprehension. In addition, the pre-and post-survey results indicated that the introduction of the AR dashboard specifically affected the pre- and post-reading phases, whereas it did not affect tasks in the while-reading phase, including annotation behavior. This may have led to the positive recognition that the action of reading includes not only the tasks of reading itself in the while-reading phase but also the tasks in the pre-and post-reading phases. The above-mentioned results support the study on the affordances of LA dashboards and visualization, which indicates that LA dashboards encourage awareness of learning behavior, enhance learning motivation, and nurture connective literacy (Pei-Ling Tan et al., 2017). Hence, we claim that one of the objectives of having learners look at artifacts created by others (e.g., prediction and questions) and comparing their own actions with others (with operation histogram) would help them to objectively reflect on their own active reading process. This result supports previous research suggesting the significance of metacognitive reading strategies which affect factors in promoting reading comprehension in readers (Ahmadi et al., 2013; Anderson, 2002).

4.4.2 The impacts of the active reading dashboard on learners' vocabulary and comprehension performance

While we found that reading behaviors were affected in the group using the AR dashboard, post-test performance did not significantly differ from the group that did not use the AR dashboard. Overall, the AR strategy positively affected participants' reading performance in terms of vocabulary and reading comprehension in both the experimental and control groups. This confirmed the validity of the results of previous AR experiments using BookRoll (CHEN et al., 2020; Toyokawa et al., 2021), and it further interprets that the use of the dashboard influenced the students' metacognition in reading.

To investigate the details of student AR behaviors and the use of the AR dashboard across phases of AR, the differences between two learners (E1 and E2) with contrasting behaviors with varied learning gains while using the AR dashboard were analyzed (see Table 4.6). E1 was a student who continuously participated in AR activities using functions in BookRoll and he achieved a perfect score on the post-vocabulary quiz. By contrast, E-2's completion rate declined across the period of AR activities. E-2 did not actively participate in AR and did not write a summary on Day 5. The vocabulary quiz score did not improve and remained below the class average in the post-test. Their access to components of the AR dashboard that visualized indicators also varied (see the list in Table 1). Both E1 and E2 checked the list and WordCloud of predictions and questions in the pre-reading phase. However, for the while-reading indicators, E1 looked at the WordCloud, whereas E2 checked the list of markers. Furthermore, E-1 also focused on the operation histogram component and compared his own performance with that of others. Such social comparison behaviors were missing for E-2. This difference in access patterns to AR dashboard components may also affect vocabulary and comprehension. However, further studies are required to collect substantial data to confirm this association.

4.4.3 Contributions

LA dashboards can be used as a tool and a valid medium for facilitating interaction and engagement between teachers and students and improving students' academic achievement

Table 4.6: Examples of two experimental groups' students' learning behaviors during AR activities across phases and interactions in AR-D

Items	**Indicators**	**Student E1**	**Student E2**
Learning performance	Pre-test (Class avg: 6.43)	7.67	4.67
	Post-test (Class avg: 8.77)	10	5.33
Learning behaviors (activity outcomes)	Completion % (day 1 to day 4)	86-78-82-100	100-76-36-14
	Words in summary	49	Not written
Learning behaviors (AR pre-reading phase)	prediction list prediction word cloud	Accessed each indicator both days of the activity	Accessed each indicator both days of the activity
Learning behaviors (AR while-reading phase)	page-annotation overlay	Accessed both days of the activity	Accessed both days of the activity
	marker list	Not accessed	Accessed both days of the activity
	marker wordcloud	Accessed once during the activity	Not accessed
Learning behaviors (to check and compare relative engagement)	marker count histogram memo count histogram study time histogram	Accessed each indicator once during the activity	Not accessed

(Verbert et al., 2013). This study observed classroom orchestration of AR dashboard use in actual practice in a language class in a high school context. Sharing questions noted by learners during the pre-reading phase over the AR dashboard and giving them a chance to answer these questions enabled them to engage with the content. In this study, looking at the dashboard was found to be useful as a basis for making decisions for teachers, such as confirming the meaning of vocabulary and whether additional explanations were necessary while orchestrating the activity. The information obtained from the AR dashboard is simple and aligned with the phase of the activity and hence easy to make sense for students and teachers in live classroom sessions.

4.4.4 Limitations and future work

The overall effectiveness of LA dashboards requires consistent and iterative refinements, as well as longitudinal studies in real learning environments (Schwendimann et al., 2016; Verbert et al., 2013). The AR dashboard intervention was conducted in a real class context; however, owing to the constraint of the daily classwork, the phases were extended over a period of time. This may have a learning effect on both groups, affecting the influence on performance at the end of the period. We considered two groups of learners with similar English proficiency levels for the experiment and filtered the data of participants who attended all phases of the AR activity. Although this helped to maintain the equality of the groups, the smaller sample size (N=42) may have affected the results. These limitations require further investigation related to effects on performance and learning behaviors over repeated use of the dashboard in long-term studies as well as for different proficiency levels of the learners.

This initial study provided insights to consider evaluating and visualizing elements related to AR on the dashboard. In our content design, it was also important to divide the pre-while-post phase, which assisted in extracting meaningful information for the dashboard. Currently, we are designing components in the AR dashboard that extract, visualize, and evaluate key vocabularies marked using a red marker as an improved version. It calculates semantic elements from the use of markers to objectively have students reflect on their reading process. Learners will be able to use the indicators to understand important words and phrases to comprehend the content, and teachers will be able to use them to evaluate students' understanding. It will be further improved by providing meaningful feedback to each student for each different goal, as highlighted by (Sedrakyan et al., 2020). There is potential to evaluate how the AR dashboard scaffolds students when they conduct AR by themselves outside class.

4.5 Conclusion

This study described the impact of the AR dashboard on AR learning in an authentic classroom context. Empirical evidence revealed that the AR dashboard had a positive effect on participants' learning behaviors, for example, their willingness to use the target language. Following the AR strategy improved the post-test scores in both groups, yet we could not confirm the significant impact of the AR dashboard on performance. Based on this implementation, we suggest that the DEAR strategy with the LA dashboard be adapted to different grades, subjects, reading activities, and beyond language learning to investigate its effects.

Chapter 5

Research Study 2: Data-Enhanced Active Reading to Programming Language Learning Context

This study focuses on program comprehension (PC) using DEAR. By applying the DEAR strategy to PC, we aim to objectively visualize the code reading behaviors of novice programming learners using learning logs and promote code comprehension. The proposed strategy was applied to novice programming learners in a computer science class at a liberal arts college in India. The results indicate that the DEAR strategy is applicable to PC activities, and the LA dashboard was recognized as an effective means to support PC, while it also suggests the need to elaborate on the way of adopting dashboards and DEAR in code reading tasks. This study is now conditionally accepted by the journal of Research and Practice in Technology Enhanced Learning (RPTEL).

5.1 Research Background

Program comprehension (PC)—a skill and competency requiring many aspects of knowledge, such as critical thinking, communication, and collaboration—is necessary in the 21st century. It has been defined as the process, in which, individuals construct a mental model of a program (Izu et al., 2019). A study that investigated the tasks, in which novice software developers engaged, indicated that reading code and documentation were important and common tasks in the software industry (Begel & Simon, 2008). Just as a prerequisite for writing is being able to read written text, writing and running programs require being able to read and accurately understand written codes. Some past PC studies have approached PC from pedagogical aspects, such as classifying and organizing educational (Lobato & Walters, 2017) and PC tasks (Izu et al., 2019). Many PC tasks include a series of tasks—annotation, modification, and explanation—which are all forms of active learning, based on Vygotsky's social constructivist theory, used in natural language learning (Freeman et al., 2014; Izu et al., 2019). Begel and Simon, 2008 (2008) focused on the socialization—communicating and collaborating with others, and coordinating while reflecting together—that professional novice programmers needed, and suggested incorporating these experiences into their curriculum, to enable them to cope adequately. Given the circumstances, active reading (AR) strategies, which have the same theoretical background as active learning, and value reflecting on learning and collaboration, could be applied to PC learning. Although AR strategies have been applied to natural language texts by past research, to date, no examples exist of its being used for PC. Additionally, many PC studies are primarily based on interviews and surveys (Izu et al., 2019; Nelson et al., 2017; Sentance & Waite, 2017), and no past studies have investigated the feasibility and effectiveness of AR strategies in PC learning contexts, by analyzing and visualizing the logs obtained from learners' learning processes. Therefore, this study has proposed Data Enhanced Active Reading (DEAR), an AR strategy in a learning analytics (LA) environment, and investigated its applicability and feasibility for PC. On the premise, of the necessity of having background knowledge to understand how the proposed DEAR code reading approach could use scaffolding to empower students' code reading performance, a quasi-experimental design was employed to investigate the following research questions (RQs):

RQ1: How feasible and effective is the DEAR strategy in PC learning contexts?

RQ2: How do the students and teachers perceive DEAR in PC?

5.2 Methods

5.2.1 Research context and participants

The datasets were obtained from second-year college students (average age: 20 years). Most of these students had enrolled in a programming course for beginners at a liberal arts college in India, after completing an introductory programming class. This experiment targeted two class sections: one as a control group and the other as an experimental group, comprising 27 and 20 students, respectively, who had consented to participate. Both groups' programming experience and motivation varied with their academic backgrounds. While the control group comprised students majoring in data science (n=11; 40%), computer science (CS) (n=5; 18%), applied maths (n=2; 7%), psychology (n=1; 3%), and other fields (n=8; 9%); the experimental group included students majoring in CS (n=13, 61%), finance (n=2, 9%), psychology (n=1, 4%), business (n=1, 4%), and other fields (n=3, 19%). The same instructor taught both classes, whose PC activities were conducted using LEAF. These classes were conducted face-to-face and held twice a week for 12 weeks from September to December 2023, and this experiment was conducted during the sixth and seventh weeks (two weeks). Before the experiment began, students in each class availed of some trials to get used to operating BookRoll functions.

5.2.2 Program comprehension class activity procedure

Izu et al., 2019 (2019) compiled PC learning activities using the block model, whereas this study applies DEAR to PC activities. The objectives of the experimental tasks were to: quickly and effectively identify the program's target codes and overall goal, while working on DEAR PC tasks, and apply their newly gained information to code composition. The lessons in both classes were planned in consultation with the teacher. During the experiment, the teacher and researchers continually reviewed and revised class activities in each lesson, and exchanged feedback, questions, comments, and evaluations.

The classes were conducted using basic PC tasks, such as tracing, annotating, explaining the codes in their own words, and reflecting on what they had learned during code reading, as indicated in past literature (Izu et al., 2019; Kussmaul, 2012). The experimental group performed these annotation and explanation tasks using memos and markers in BookRoll, and confirmed and reflected, using the dashboard. Figure 5.1 depicts the conformity of the interaction tasks.

As regards the flow in each class, in the pre-reading phase, the teacher first reviewed previous learning and explained the target activity. Students in the experimental group were additionally asked to quickly browse through the code, and answer a question provided in the material to obtain an overview of the code, before actually reading it in a memo. The purpose of making students perform this task was so that by applying their previous knowledge, they would connect it with new information. The teacher responded by checking the students' visualized annotations on the dashboard and providing feedback. During the while-reading phase, the teacher got students to first read the code individually. At this point, a timer was used to measure how much time it took. After

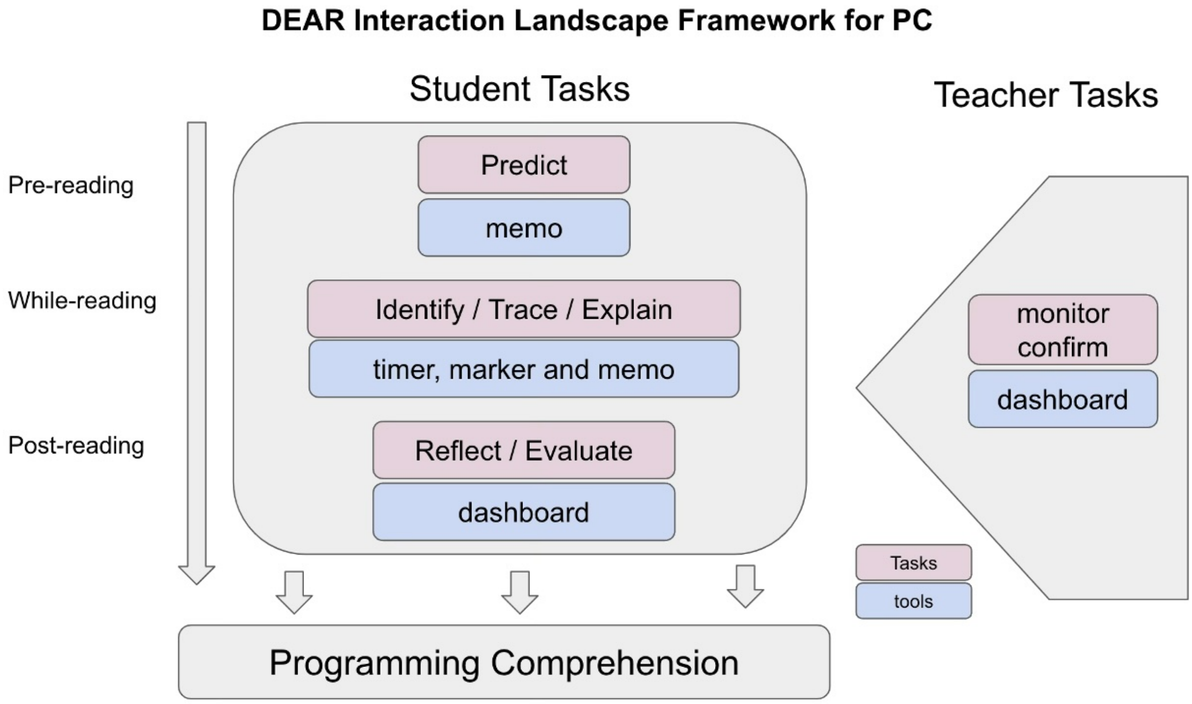

Figure 5.1: DEAR instantiated for PC

students completed their individual reading, they answered questions provided in the material (e.g. if the code could be compiled and run). While working on the task, students in the experimental group were asked to use a marker to highlight any lines that were found to have errors or write the output of the code as a memo. Thereafter, the teacher instructed them to check the answers on their dashboards. Students in the experimental group explained, adjusted, and confirmed their answers to questions, by using their dashboards to visualize their answers. Based on their dashboard visualizations, the teacher highlighted the points that needed explanations, shared them with the entire class, and explained the answers by eliciting answers from students. Figure 5.2 depicts a workflow example of the DEAR PC activities implemented in the experimental group.

The control group students performed their class activities without using a dashboard. After conducting the cycle as a PC activity, the teacher moved on to code composition and the next activity. These students followed the same workflow for class activities, except for prediction in the pre-reading phase, recording in the while-reading phase, and reflection using the dashboard in the post-reading phase. Figure 5.3 shows the experimental procedure used in this study.

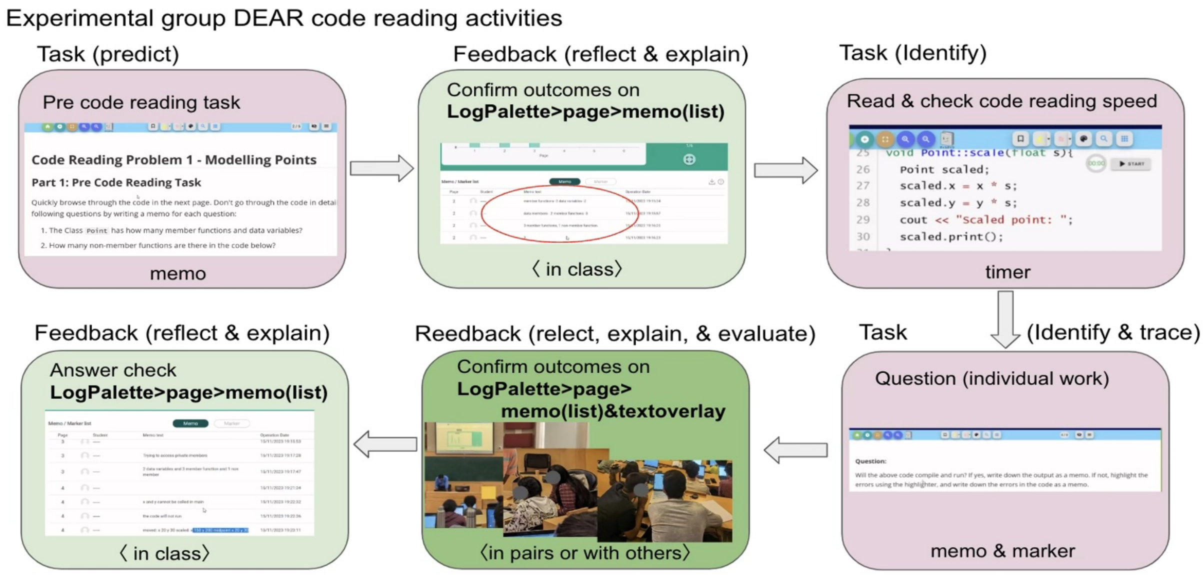

Figure 5.2: An workflow example of DEAR PC activities for the experimental group

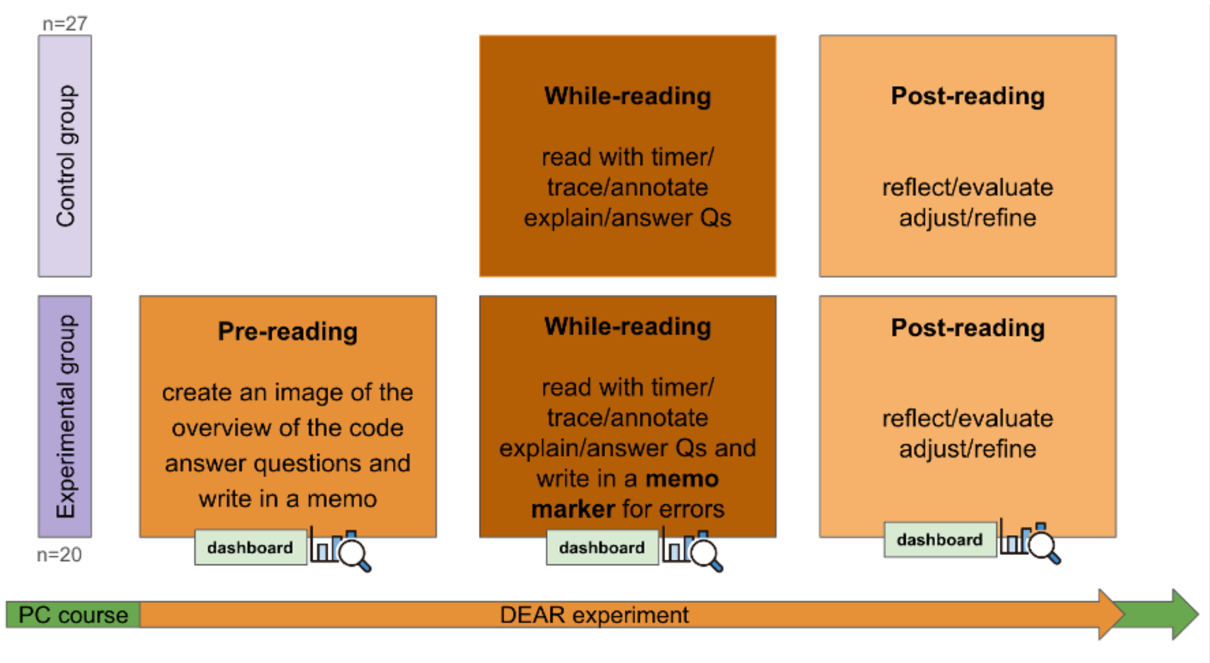

Figure 5.3: Experimental procedure of the PC class for the control and the experimental groups

5.2.3 Data collection and analysis

Interaction logs

The log data of both the experimental and control groups, from the trials before the experiment, during its eight sessions, and out-of-class autonomous attempts during its seventh and eighth weeks using BookRoll, were aggregated in the LRS and analyzed. PC activity-related behavioral data includes reading time, operation counts, operational uses of memo, marker, and timer functions, and access to the dashboard. As indicators of students' learning engagement, this study extracted from LRS, the number and duration of specific learning behaviors as follows: 1) in-class and out-of-class reading time to determine students' reading engagement time; 2) the number of markers for highlighting to identify specific target codes and errors; 3) the number of memos for answering pre-reading questions to predict the program's purpose, and answer its code-reading questions, 4) time logs of timer usage to check reading speed, and 5) number of times the LA dashboard was checked in and outside class to reflect on learning outcomes were automatically recorded. Of the 13606 logs accumulated in the LRS during the classes, learning logs obtained from the participants who consented totaled 6,742 (n=47). Furthermore, data on reading speed were extracted from the TIMER_START, TIMER_PAUSE, and TIMER_STOP time logs, and calculated as the number of words in the material being read, divided by the time taken (in seconds) x 60. To answer RQ 1, the applicability and effects of DEAR to PC were evaluated by examining logs obtained from using the LEAF (see Table 5.1), and analyzed to determine whether the difference was significant between the means of the control and experimental groups.

Survey instruments

A post-survey related to students' perceptions of PC activities was conducted for the experimental group to enable them to reflect on how they performed code reading activities during the experimental session. Students responded to nine post-survey items. Survey questions regarding code comprehension activities were developed based on the 'Study Skill Inventory' proposed by (Congos, 2011), the programming learning scale proposed by (Sáez-López et al., 2016), and recommendations for dashboard development suggested by (Jivet et al., 2018). The initial three survey questions inquired about the dashboard's utility in deepening awareness and reflection on code. The questions were about the dashboard serving as a means to deepen the awareness and reflection on code by allowing

Table 5.1: Summary of indicators and statistical description for this study

Indicators	**n**	**Miss**	**Mean**	**SD**	**Max**	**Min**
In class-	E 20	0	226.880	91.435	332.11	15.58
reading time	C 26	1	200.900	82.064	346.41	16.78
Operation-	E 20	0	137.400	70.696	279	22
counts	C 26	1	47.923	20.016	82	6
Reading speed	E 20	0	133.970	68.517	362.2	10
(rate)	E 23	4	102.133	35.098	168.5	53
Dashboard-	E 17	3	2.471	1.125	6	1
access	C 0					
Out of class-	E 17	3	145.056	121.480	431.05	0.88
reading time	C 14	13	60.326	66.545	214.06	0.75
Out of class-	E 10	10	1.80	1.135	4	1
dashboard access	C 0					

students to review their own memos and those of others, aiding in better comprehension, facilitating communication with others, and sharing knowledge or understanding. The next three questions are about the utility of the overall AR strategy. They asked if the AR strategy fostered a deeper interest in PC, actively had students engage in class activities, and enhanced their understanding of specific aspects of programming through AR exercises. The last three questions pertained to the impact of each phase of DEAR. They inquired about the usefulness of using a timer to measure reading speed to improve PC, the impact of leaving annotations and highlighting, and the significance of pre-reading activities in providing an overview for a better understanding of the PC. These nine questions were combined to ascertain students' perceptions of the DEAR activities. A 5-point Likert-type scale was adopted to measure the students' perceptions, ranging from 5 'strongly agree', 4 'agree', 3 'neutral', 2 'disagree', and 1 'strongly disagree'. Twenty-two participants in the experimental group completed the web form questionnaire after the experiment. Besides the students' survey results, the teachers' comments and observation notes were also considered while answering RQ 2—the students' and teachers' perspectives on DEAR for PC. The Purposes and contents of the post-survey are summarized in Table 5.2.

Table 5.2: Student survey questions

Constructs	**Question Items**
Usefulness of Dashboard (Jivet et al., 2018) (for individual reflection)	Q 1 Using the dashboard to see my own and others' notes enhanced my awareness and reflection of the given code.
Usefulness of Dashboard (Jivet et al., 2018) (for communication purposes)	Q 2 I communicated with others using the dashboard.
Usefulness of Dashboard (Jivet et al., 2018) (for collaboration)	Q 3 Sharing information about code reading with others using the dashboard was helpful for code comprehension.
Overall PC class activities (Sáez-López et al., 2016)	Q 4 After going through BookRoll, I became more interested in programming code reading.
Overall PC class activities (Sáez-López et al., 2016)	Q 5 I participated in the class activities actively.
Overall PC class activities (Sáez-López et al., 2016)	Q 6 I understood the specific aspects of programming through the reading activities.
Usefulness of DEAR (Congos, 2011) (while-reading: reading speed)	Q 7 Using a timer to feel the speed of reading code encouraged me to read the code more efficiently.
Usefulness of DEAR (Congos, 2011) (while-reading: record)	Q 8 Taking notes in a memo and highlighting with markers helped me understand how to program specific aspects of the problem.
Usefulness of DEAR (Congos, 2011) (pre-reading: prediction)	Q 9 The activity of understanding the general outline before reading helped me understand the specific aspects of the code.

5.3 Results

5.3.1 Effects of the interaction process of program comprehension

We first checked the assumption of normality. The results conclude that the data is not normally distributed for operation counts ($p<0.001$), out-of-class reading time ($p=0.001$), and reading speed (p<0.001), while data is normally distributed for in-class reading time (p=0.065). It is clear that there is no difference in the amount of time for in-class reading time since both classes had the same amount of time (90 minutes) for each class. It was also obvious that operation counts were significantly different since the students in the experimental group used more BookRoll functions (such as memos and markers) in class. Thus, in this study, we focused on out-of-class reading time and reading speed, and nonparametric tests were conducted to compare those variables between the experimental and the control groups to answer research question 1 (see Table 5.3). The tests revealed a significant difference between the two groups in terms of out-of-class reading time, W=172, E=17, C=14, p=0.036, with medium effect size, r=0.445, and reading speed, W=311, E=20, C=23, p=0.049, with medium effective size, r=0.352. The results suggest that the students in the experimental group spent significantly more time in reading (or studying) out-of-class than the control group, and showed faster code reading speed compared to those in the control group.

Table 5.3: Nonparametric test results between the experimental and the control group

Parameter	**Group**	**n**	**M**	**SD**	**w**	**p**	**r**	**Cohen's d**
Out-of-class	E	17	145.05	121.48	172	0.036*	0.445	0.865
reading time	C	14	60.32	66.54				
Reading speed	E	20	133.97	68.51	311	0.049*	0.352	0.585
	C	23	102.13	35.09				

*p<.05

5.3.2 Practitioners' perspectives on proposed program comprehension activities

For RQ2, students' perceptions of DEAR in PC were verified by looking at the responses to the survey questions by 22 students, who had anonymously responded to the survey. Questions 1, 2, and 3 were about the dashboard. In response to survey question 1—personal reflections on using the dashboard—by selecting 'strongly agree' and 'agree', 68% said dashboards allowed them to gain more information about code reading by reflecting on their own and others' artifacts, as well as more awareness and reflection on specific codes. In response to questions 2 and 3—sharing information about code reading and communicating with others using the dashboard—approximately 40% to 50% of students gave positive answers, approximately 40% answered neutral, and approximately 10% to 20% disagreed. In response to question 4—PC activities using BookRoll and the dashboard—50% said that they became interested in PC after going through the activities, but 27% disagreed. In response to question 5—actively participated in class—32% chose 'strongly agree' and 54% 'agree' (i.e., totally 86% agreed), while neutral and disagree had low percentages of 9% and 5%, respectively. Survey questions 6 through 9 were about the DEAR strategy's effects. In response to question 6—whether students understood the specific content of programming through PC activities—27% chose 'strongly agree' and 45% 'agree' (i.e., totally 72% agreed), 18% were neutral, and 9% disagreed. In reply to question 7—effectiveness of checking code reading speed while reading the code—32% selected 'strongly agree', 36% 'agree' (i.e., totally 68% agreed), 18% were neutral, and 14% disagreed. Regarding question 8—highlighting with markers and leaving annotations in memos—9% strongly agreed, 45% agreed, 32% were neutral and 14% disagreed); hence, almost half agreed, while the other half said they disagreed or did not care. Regarding question 9—whether the activity of understanding the overview before reading helped them to understand specific aspects of the code—over 80% agreed (strongly agree: 32%; agree: 50%), while none disagreed. The results of the survey responses are illustrated in Figure 5.4.

Additionally, the outcomes of the survey were supported by the teachers' comments and observation memos (reproduced below).

Comments from the teacher:

I had a good time using BookRoll. It was useful in making students read the code. Without this experiment, I would not have been so systematic in giving them code-reading activities. Most of them (students) used the dashboard. It was useful to understand the range of responses students gave to the problems. I got a sense of the different opinions that students had.

From observation and message exchange with the teacher:

In general, the control group was more interactive and chattier, asking questions and interacting. Some students even gave their code reading strategy in class. In the experimental group, some students asked questions in class, but generally, the class was less engaged, unlike students in the control group, who were more interactive.

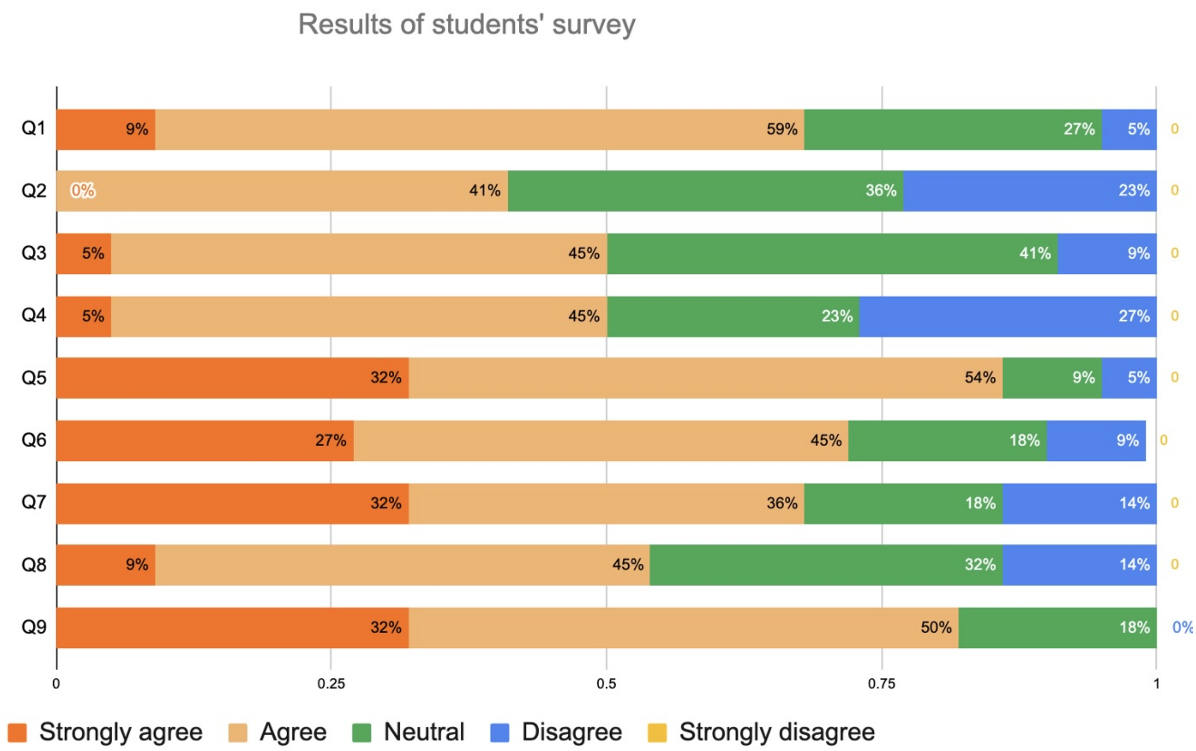

Figure 5.4: Results for each question of the student survey (n=22)

5.4 Discussion

In response to the research questions based on the logs data and survey responses, this section first discusses the overall effects of the DEAR strategy on PC, then the impact of each phase of DEAR activities followed by the limitations and future work of this study.

5.4.1 Effects of Data-Enhanced Active Reading to program comprehension

The results of the nonparametric tests to answer research question 1 showed that the students in the experimental group spent more time working on PC outside of class (E: M=145.05, C: M=60.32). Based on the teacher's comments and observations, it was concluded that the students in the experimental group were more passive than those in the control group. However, several students tried out DEAR using memos and markers autonomously. For example, it was confirmed that students were drawing new markers (ADD_MARKER), erasing markers drawn during class (DELETE_ MARKER), and leaving new annotations (ADD_MEMO). Some students also voluntarily checked the dashboard. Thus, the study confirmed that DEAR engagement in class had a positive impact on PC learning outside class. The results of this study also support the suitableness of the programming code reading pedagogical approaches to PC in previous studies, such as annotating (Freeman et al., 2014; McCartney et al., 2004), analyzing and reflecting (Kussmaul, 2012), processing prediction, observation, and explanation (Furqani et al., 2018), modifying and explaining (Freeman et al., 2014; Furqani et al., 2018; Izu et al., 2019; Murphy et al., 2012), and communicating and collaborating with others (Begel & Simon, 2008). Moreover, as the teacher indicated that the dashboard helped students read the code, enabled him to understand the range of students' responses to the questions, and different opinions of students, the results support past LA studies that suggest learning with a dashboard has a positive impact on learners' cognition and metacognition (Duval, 2011; Schwendimann et al., 2016; Verbert et al., 2013), and teachers in their educational practice (Ahn et al., 2019; Bao et al., 2021). With all these tasks in place, DEAR was proven adaptable to novice learners' PC activity.

The survey results, to answer the second research question, showed that a high percentage of the participants (over 70%) said they understood the specific aspects of the target code through the PC activities and showed high motivation to participate in class. Survey questions 1, 2, and 3 pertained to dashboards. The results indicated that participants found sharing and reflecting comparative data on the dashboard useful in understanding codes. The dashboard can be a tool for novice programming learners to reflect on their learning, particularly for those, who did not have the answers themselves, needed review, and wanted clues from others. The results support the effectiveness of self-reflection with the dashboard (Duval, 2011; Schwendimann et al., 2016; Verbert et al., 2013). Conversely, about 10-20% of the respondents did not agree with the idea of using the dashboard for sharing or communicating with others. The neutral numbers were also high, leading us to conclude that dashboards may be more useful as tools for personal reflection, rather than sharing or communicating. Using the dashboard for communicating with others is an important element of DEAR. Begel and Simon (2008) point out challenges that new graduates working in the software development industry face, such as communicating with others, collaborating, and making adjustments based on reflections, and to adequately address such challenges, recommend that these should be included in the educational curricula. The correlation between using dashboards for personal reflection and interacting with others is noteworthy. Additionally, the collaborative aspects of dashboards that facilitate information sharing and their impact on code comprehension should be further investigated. To verify the impacts of the records, a visualization method using a dashboard that can efficiently allow teachers and learners to confirm the code retrospectively should be considered.

5.4.2 Applicability and impact of Data-Enhanced Active Reading

Pre-reading tasks

Approximately 82% answered that pre-reading activities helped them to understand the general outline and specific aspects of the code. The importance of pre-reading activities has received attention in research on natural language texts, such as the advanced organizer (Ausubel, 1978; Elfeky et al., 2020) and cognitive reading strategies (Gustanti & Ayu, 2021). The result indicates the potential of pre-code reading activities to help students identify specific code elements and grasp an overview of programming.

While-reading tasks: awareness of program comprehension speed

Regarding checking code-reading speed, in this study, the teacher commented, that as he gave his students plenty of time to work on PC code reading, he did not consider code-reading speed as being so important. WPM (Words Per Minute) rate is often measured in natural language text reading; hence, it was considered that this perspective could also be applied to PC. As a result, 68% of participants answered that cognizance of their speed of code reading enabled them to read codes more efficiently. Word-level automaticity—the ability to quickly and easily decode or recognize words both in and out of context—is thought to be important in reading natural language texts (Hudson et al., 2005). Therefore, the reading speed of natural language texts, such as in learning English, is often measured with the intention of improving readers' reading comprehension rate and reading comprehension. (Wagner & Wyrich, 2021) examined the influence of intelligence and certain personality traits on PC, and consequently, identified fluid intelligence, visual perception, and cognitive speed as being influencing factors. The result of the nonparametric test in this study revealed that the reading speed of the experimental students was faster than those in the control group. The experimental group's having a higher reading speed indicates that they read the code faster. It is necessary to anticipate, that actual programming practice would require possessing the ability to quickly read and understand, as well as complete and run codes. Programming codes may be recognized at the token, code, or line levels, rather than at the word level as in natural language text. In the future, this study recommends using reading speed measurement as a means to improve the efficiency of programming code reading, considering calculation methods suitable for code reading, and examining the correlation between code understanding and code reading time, which was presently not considered.

While-reading tasks: record (highlighting and leaving annotations)

In this study, students were asked to use markers to identify and trace the code, and explain what they anticipated or understood in a memo. While approximately half agreed to record tasks, the other half either disagreed, or said that they did not care about highlighting with markers and making annotations in memos. Hence, it can be interpreted that highlighting and annotating that is commonly conducted in natural language text reading, may or may not be useful in code reading. The logs revealed, that two students who studied with BookRoll outside the class used ADD_MEMO and ADD_MARKER, and one used DELETE_MARKER on the markers drawn in class. The reason for keeping records was to later review and reflect on what was understood or not understood; yet, a student did not check the dashboard in class, despite having used memos and markers. In addition, nine students did not check the dashboard after learning outside the class, whereas two students who did not study with BookRoll outside the class, had logs of accessing the dashboard. DEAR includes activities, such as checking remaining records (logs) on the dashboard, and thereafter, deciding on the next course of action. As this study highlights the importance of reflecting by using the dashboard, after leaving annotations, it will consider the purpose of records for PC, how to maintain them using markers and memos, and how to visualize records left as annotations.

Post-reading tasks: dashboard for program comprehension

The DEAR tasks include checking, reflecting, and evaluating PC using a dashboard. Teachers select learning tasks, and provide a series of learning activities tailored to learners' cognition and knowledge levels to help them reach their goals (Lobato & Walters, 2017). In this study, the students' artifacts were visualized on an LA dashboard and used by the teacher as a kind of decision-making tool (e.g. allowing the teacher to check students' understanding levels in class, and provide instant feedback on the spot). Teachers first check and make assumptions about what students initially understand and what they can learn next, and accordingly construct and modify the lesson's goals. Thus, the dashboard served as a scaffolding to smoothly execute the learning trajectory.

This experiment demonstrated that the AR strategy used in natural language can also be applied to PC by visualizing the indicators for each of the DEAR tasks, left in the learning log. Previous research has indicated differences between reading natural language texts and codes (Busjahn et al., 2015), but this study found that the existing AR strategies used for natural language learning are applicable to code reading, at least for novice programming learners in the PC learning context. However, based on the student survey, just as reading approaches are different between them, it was acknowledged that the DEAR strategy also needs to be adjusted to suit PC learning. With this in mind, the next chapter discusses this study's limitations and future work.

5.4.3 Limitations and future work

Reliability of the post-survey responses

First, we must acknowledge the limitation regarding the post-survey on the perception of DEAR among the students in the experimental group. Whether the survey was reliable depends on the length of the questionnaire, the quality of the questions, and their fit to the group being measured (Brown, 1997). In this study, first, the number of participants was small (n = 20). Moreover, even though questions were considered with reference to the existing survey items related to AR and PC, the inference was based on a small number of survey items of 9 questions. These might have affected the reliability and generalizability of the results. The reason for the small number of questions was that we had to limit the number of those to avoid disrupting the class, as we wanted to have the students answer the questions within a limited time during class. Therefore, we carefully selected questions based on reliable questionnaires used in previous literature such as AR activities based on the 'Study Skill Inventory' proposed by Congos (2011), the programming learning scale proposed by Sáez-López et al. (2016), and recommendations for dashboard development suggested by Jivet et al. (2018), to fit this study. We also tried to triangulate based on the observations and understanding of the teacher to address this limitation. The teacher's comments and class observations are considered sufficient supplements to support the reliability of the post-survey.

Equivalency of study groups and participants as limitations

The second limitation pertained to the participants' programming experience. They were beginner course students in programming; yet, almost all of them had completed an introduction course, and some were majors in CS and other fields related to programming. Thus, it can be inferred that some of them already had some code comprehension knowledge, which might have affected their PC learning behaviors and perceptions. The AR strategies used in natural language text reading provide a more systematic reading approach to learners; hence, are suitable for novice readers having less experience in reading, who can learn and acquire a reading strategy and apply it to understand the content. In other words, AR would not be necessary for advanced learners having their own reading strategies. Hence, it is expected that clearer results will emerge in future studies by applying DEAR for PC in K-12 or introductory courses.

The grouping of the experiment also affects the research results. As the experiment was conducted in a real learning context, the experimental and control groups were randomly selected, without controlling for equivalency. As the semester progressed, the teacher recognized that students in the control group were participating more actively in class and understanding better than those in the experimental group. Additionally, it was observed that students in the control group were more interactive and their engagement was stronger, even though more than 60% of students in the experimental group had acknowledged in the survey, that they had actively participated in PC class activities. This study's results indicate a possibility that the contextual factors of the two groups influenced the results. Hence, establishing the equivalency of study groups should be considered in future research.

Devising dashboards for code reading in future studies

Future studies should highlight the need for dashboards, specifically for code reading, visualizing the code-reading process on dashboards, to review and reflect. This study showed that the dashboard served as a means to support the teacher and students, by confirming students' understanding and progress, and using scaffolding for decision-making in class. In this regard, it is suggested that DEAR, which uses AR strategy and LA technology, is effective for code reading. However, the dashboard was created to reflect on AR learning in natural language text, and was not originally meant for code comprehension. In other words, there is a lack of ingenuity in visualizing the code comprehension process in an easy-to-understand manner, and elements geared towards user needs for code comprehension. As previous literature suggests the benefits of designing dashboards for users' specific factors and needs (Ahn et al., 2019), as well as taking into account distinct pedagogical concepts of improving and supporting learning (Jivet et al., 2018), it is necessary to consider designing dashboards for programming learners, that show the correct and necessary choices.

5.5 Conclusion

This is the first study that attempts to apply an AR strategy to PC, and which was introduced as a possible option for PC activities from the LA perspective. Consequently, the approach's effectiveness was shown with a positive impact on the learning behavior of students in the experimental group outside class, and the proposed DEAR strategy was proved to be applicable to PC tasks for novice programming learners. However, this study's limitations regarding the equivalence of study groups and participants as well as the usability of the LA dashboard were acknowledged. Future studies will expand DEAR for PC, so that it is suitable for individual learners based on their needs, motivation, programming experience, and other required aspects, and consider visualization methods of PC logs, that meet their needs.

Chapter 6

Research Study 3: Data-Enhanced Active Reading for Inclusive Education

This study employed DEAR to investigate the challenges and possibilities of applying the strategy to students with reading difficulties in inclusive education. Two students who attended a resource room formed the context. We investigated learning logs in the LEAF system while each student executed a given learning task. We detected specific learning behaviors from the logs and explored the challenges and future potential of AR learning with LA technology. This study is published in the Smart Learning Environments (Toyokawa, Horikoshi, et al., 2023). The following sections present a detailed introduction to this study.

6.1 Research Background

In general, not only in Japan but also in many other countries, students with mild disabilities, such as those with developmental disorders or disabilities (DD), study alongside non-disabled learners in the same learning environment in regular classes in inclusive education. In diverse but constrained learning contexts with different types of learners, teachers have difficulty orchestrating multiple flows of information and tasks (Dillenbourg, 2013). Although there are many different types of educational practices within inclusive education, special education approaches can be used to meet and support the unique learning needs of learners with special needs in a learning environment (Bryant et al., 2019). In regular classes, all learners engage in learning at the same pace, but students with learning difficulties (LD), who are said to be less efficient at processing information, tend to have trouble catching up in class compared with other students (Gersten et al., 2001). For such learners, resource rooms or pullout programs can provide extra support outside regular classes (Bryant et al., 2019). A resource room under inclusive education in Japan is an independent remedial class in which learners with a relatively mild disability, or those who tend to demonstrate some difficulties, leave their regular classes and receive support according to their needs (MEXT, 2020). However, the utilization of emergent technology such as LA for learners with special needs has not been researched extensively in an inclusive Japanese learning environment. Therefore, we propose DEAR to effectively orchestrate reading learning for learners with special needs in inclusive education.

We conducted a case study to explore the current needs, challenges, and opportunities. Case studies have gained considerable acceptance as valid research methods in a wide range of fields. In particular, Yin's case study is said to be reliable for connecting the underlying theory and practice (Zainal, 2007). It enables us to understand behavioral states from the perspective of learners and subjects, which is said to be useful in explaining the complexity of real learning situations in detail (Zainal, 2007). Research on learning in special education is a large field; however, only a limited number of individuals can be selected as research subjects. It is valuable to accumulate data obtained from daily learning in a natural way, and we consider this experiment "a unique way of observing natural phenomena present in a series of data," as defined by Yin's case study (Zainal, 2007). The following research question was addressed to explore the applicability of DEAR on students with special needs in inclusive education:

RQ What are the challenges and opportunities of DEAR for learners with special needs in inclusive education?

6.2 Methods

6.2.1 Participants and study context

The participants were two twelve-year-old boys (boys 1 and 2). Boy 1 attended a resource room for six years to receive social communication training and received special support before entering elementary school. Boy 2 was diagnosed with autism and attended a resource room for six years. He received special support before entering elementary school. Resource rooms are for students with relatively mild difficulties, and many who attend these rooms have not been diagnosed with disabilities. The decision on whether one is to receive special support in a resource room is made by the school principal, following an appropriate understanding of the actual situation and a discussion with the school committee (MEXT, 2020). Therefore, in this study, no details on the particular difficulties that these students face were available. The participants were asked to perform AR at home with their mothers. Written informed consent was obtained from the guardians of the students. First, the flow of learning activities was explained to the students and their mothers. Then, all four AR activities for Boy 1 which lasted about one hour, and three AR activities for Boy 2, which lasted approximately one and a half hours were observed by a researcher. All AR activities (three to four readings) were done on one day. They chose a device to use, either a PC or an iPad, and chose an input method, such as using a keyboard for typing or a stylus pen for handwriting. In Japan, under the Global and Innovation Gateway for All (GIGA) school initiatives, each student is provided with one device. Both students had no problems operating PCs and/or tablets and typing on keyboards at home by themselves. We asked them to work on their reading on their favorite device with the intention of doing it in a stress-free environment as much as possible. We explain the reading-learning activities and AR procedure in the next section.

6.2.2 Active reading learning task

The two boys read the same four reading materials using BookRoll following the AR process. First, in the pre-reading phase, they were asked to have an image of the story they were going to read by looking at the page (title, pictures, etc.) and write their predictions in a memo. They were then asked to formulate questions based on their thoughts. Questions were also asked to be recorded in a memo. Each story contained questions on comprehension. While they read the text, they read the story as they looked for answers while marking the answers to the question with a marker directly on BookRoll. In the post-reading phase, participants reflected on their reading and wrote the content of the story in their own words. One week later, they were asked to recall the story and write about what they had remembered. We additionally communicated the AR learning process to both the resource room teacher of Boy 1 and the mother of Boy 2 with the dashboard, engaging in a reflective discussion and receiving their valuable feedback. The objectives and activities for each phase of the AR activities are explained in Figure 6.1.

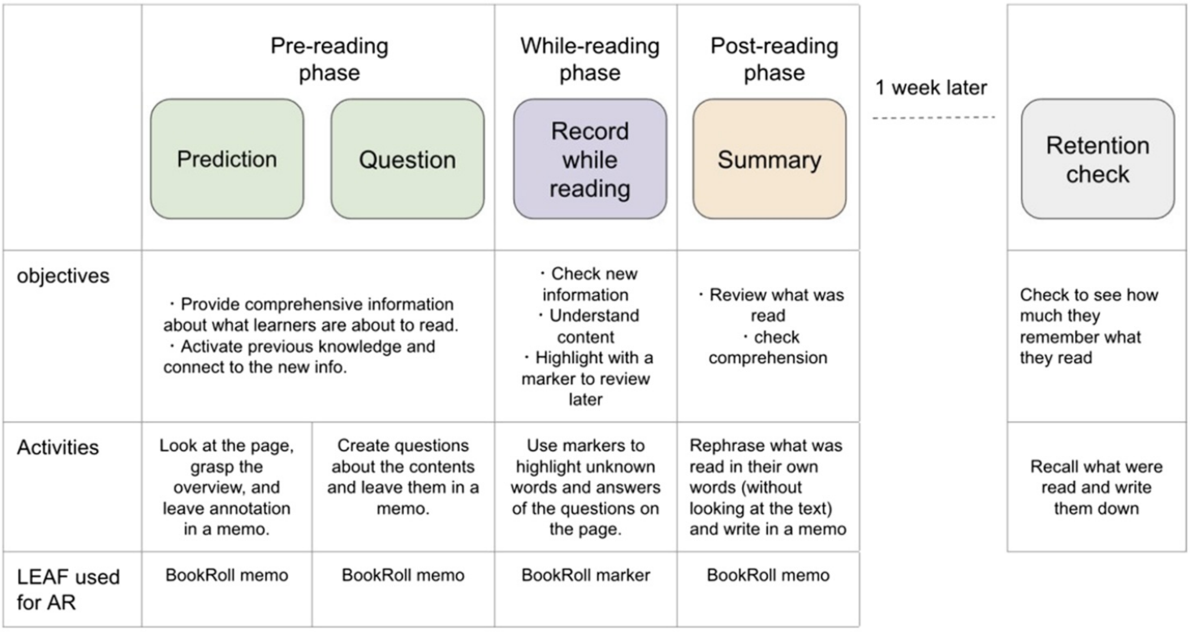

Figure 6.1: The AR objectives and activities conducted using BookRoll

6.2.3 Data collection and analysis

The time spent reading and operation logs were investigated to understand each participant's AR process. First, the time taken for each reading task was extracted from the time logs, including the time taken to complete one AR session, the time taken to make a prediction and questions in the pre-reading phase, the time taken to answer questions while reading, and marking the answers with a marker, and the time taken to write down what was understood in the post-reading phase (Figure 6.2). The objective was to check whether there were any characteristics of reading difficulty, such as taking too long to read, input, and output. Then, behaviors such as frequent page flipping, noticeable writing, erasing, and highlighting actions were visualized as a plot (Figure 6.3) to understand if we could detect any reading difficulties in the logs and at what stage of AR intervention was required. In order to investigate the reading behaviors, logged actions such as OPEN, MEMO, HANDWRITING MEMO, MARKER, NAVIGATION, TIMER, BOOKMARK, and CLOSE were extracted and analyzed, whose descriptions and interpretations of action logs are listed in Table 6.1. After the AR learning, as part of the experiment, we asked the resource room teacher of Boy 1 and the mother of Boy 2 to see each student's AR process and the visualized logs and received their impressions and comments.

		Active Reading 1	Active Reading 2	Active Reading 3	Active Reading 4	Mean
BOY1	All 3 AR phases	11.08	6.06	5.3	10.49	8.22
	1 Prediction&Question	2.09	x	3.35	2.14	2.52
	2 Read&Answer	1.59	1.57	1.55	0.59	1.32
	3 Summary writing	6.44	4	x	7.22	6.28
BOY2	All 3 AR phases	**25.46**	**37.31**	5.43	x	23.13
	1 Prediction&Question	4.54	x	1.16	x	3.25
	2 Read&Answer	1.02	4.53	3.12	x	3.29
	3 Summary writing	**14.57**	**29.37**	x	x	22.37

Figure 6.2: The time spent on active reading activities

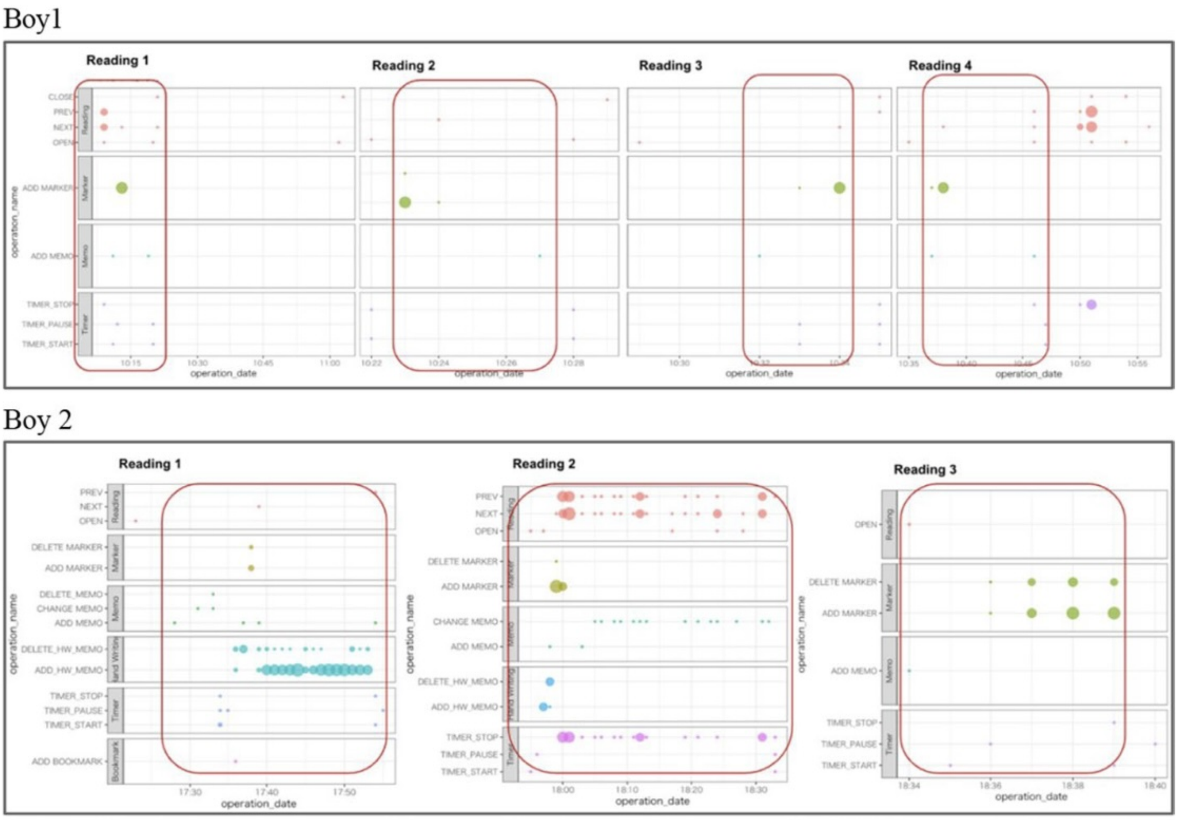

Figure 6.3: Log visualization of the AR behavior among the three students

Table 6.1: Descriptions and Interpretations of Action Logs extracted from BookRoll for Analysis

Behaviors	Logs on the graphs	Description of action	Interpretation for the activity
OPEN	OPEN	The reader opens the content in BookRoll	Open the content to browse and attempt the reading task
	ADD MEMO	The reader adds a text memo to the content	Leave annotation (eg., prediction, questions, and summary) about the reading content
	CHANGE MEMO	The reader opens and changes an existing memo	Update the content of an existing memo on a page
	DELETE MEMO	The reader deletes an existing memo	Delete what was left in a memo
	MEMO JUMP	The reader switches the page by specifying a memo list	Find memo from memo list
HW MEMO	ADD HW MEMO	The reader adds a handwritten memo to the content	Leave annotation (eg., prediction, questions, and summary) about the reading content
	DELETE HW MEMO	The reader deletes an existing handwriting memo	Delete what was left in a memo
MARKER	ADD MARKER	The reader adds a yellow or a red marker in the content	Attempt the learning task by highlighting the answers for the questions and/or unknown expressions on the page
	DELETE MARKER	The reader deletes an existing yellow or red marker	Delete highlighted parts
NAVIGATION	NEXT	The reader goes to the next page	Proceed to the next page or curious what is on the next page
	PREV	The reader goes to the previous page	Refer back to the previous page
TIMER	TIMER STOP	The reader stops the timer	Stop reading or finish the task
	TIMER START	The reader starts the timer	Start reading or a task

Behaviors	Logs on the graphs	Description of action	Interpretation for the activity
	TIMER PAUSE	The reader pauses the timer	Pause a task
BOOKMARK	ADD BOOKMARK	The reader adds a bookmark on a page	Bookmark a page with relevant content to remember and easily navigate to it
CLOSE	CLOSE	The reader closes a content in BookRoll	Close the content or end the task

6.3 Results

In this section, we discuss the findings from the case study, which can serve as evidence for identifying future challenges and possibilities related to the application of DEAR to special education in inclusive education.

6.3.1 Analysis of the participants' time logs

First, we investigated the learning behavioral patterns found in the learning logs regarding the time spent on each AR task. What the two of them have in common is that it took a considerably long time to write a summary (paraphrasing in their own words) after reading. Boy 2 took three times as long as Boy 1 to do the same. The average time spent on summaries for Boy 1 was (m = 6.28 for 3 summaries), which is approximately 76% of the total average AR activity for Boy 1. The average time spent on summaries for Boy 2 was (m = 22.37 for 2 summaries), which is approximately 96% of total AR activity. A summary of the time spent on the AR tasks is presented in Figure 6.2.

6.3.2 Analysis of the participants' operation logs

We then attempted to visualize the AR performance of the two participants from the operation log, which is depicted in the plots in Figure 6.3. Overall, we confirmed that the participants progressed to AR according to the following AR procedure: pre-, while-, and post-reading phases. What we could clearly observe from the plots was that during the first AR activity, Boy 2 with LD noticeably wrote and erased his handwriting, and during the second AR activity, he frequently flipped pages, touched the timer, and wrote and erased his memos. The third AR seemed to proceed smoothly without any extra action; however, the fourth AR was not conducted.

6.3.3 Analysis of the stakeholders' interviews

In general, learners check and reflect on their own learning processes, but this time, we asked the resource room teacher and the mother of Boy 2 to observe the data, reflect on the learning, and give us their comments. Their comments were as follows:

The teacher told us that all learning with paper is stored in a file and shared with the parents during the interviews, which are conducted twice a year. Students' data are always collected and reported to schools. She said that it would be nice if they could accumulate and share what they had learned using (electronic) tools. She also mentioned that parents need to (and want to) know what their children are doing in school. Boy 2's mother said that her son cannot get rid of his obsession with things he cannot do. Due to this, he cannot move on to the next task, and as a result, he cannot complete the task. She told us that she made posters so that her son could visually check the tasks, but he now makes his own to-do list daily and keeps it in his school bag. She said that being able to see what he is doing through his learning logs helps her understand and accept how he is doing in school.

A week after the AR, the mothers of the two boys sent us what the boys remembered about each story. Boy 1 wrote concise summaries that covered the main points of each story. Boy 2 also wrote detailed summaries of three stories. The mother of Boy 2 added the message saying that she was surprised that her son, who is usually not good at summarizing, was able to summarize them in an easy-to-understand way. A few minutes later, we received another message from her saying that her son said he remembered the stories but he looked them up on a search engine and added the details to his memory for summaries. The summaries were not analyzed this time because they were not credible, but here we could see Boy 2's Perfectionist tendencies.

6.3.4 Erratic learning engagement of students with learning difficulties in different phases of the learning activities and during technology usages

Learners have different time engagements and approaches to the same learning task. In this study on AR activities, Boy 2 required more time than Boy 1 (Figure 6.2). The observations demonstrated that Boy 2 approached each activity carefully. He paid particular attention to the order in which things appeared in the story and the flow of AR itself. He was initially overly focused then lost concentration, gave up on the way, and could not complete the tasks. It was also found from the observations that it took time for him to write his summary with a stylus pen on an iPad for the first AR activity. He appeared unfamiliar with the act of writing directly on the iPad screen with a pen, but enjoyed using a new tool. He did not use handwriting during the second AR session but used the keyboard with which he was already familiar. From the logs and observations, we understood that it might be time-consuming for some learners to perform knowledge output activities, such as writing what they have understood. Regarding technology use (Figure 6.2), Boy 1 had relatively fewer extra actions in the logs besides AR activities, whereas Boy 2 had a greater number of extra actions that demonstrated fixation behavior on ICT features. For example, several operation logs were detected in terms of handwritten memos, such as ADD and DELETE, during the first task. In the second reading task, several additional page movements and timer operations were observed (Figure 6.3). In the third task, it was observed that AR was completed without additional operations on the logs. However, it was observed that he lost concentration and motivation. Consequently, he was unable to start or complete the fourth task. We also found that learners may end up concentrating on things other than learning, such as using e-learning features, such as timers. These pedagogical challenges must be addressed when creating learning designs for students with special needs.

6.3.5 Varied understanding of stakeholders about data-driven learning

In this study, we faced difficulty obtaining the consent of the guardians for the experiments because AR was not the type of learning support that they had originally requested. Some parents did not consent to the collection of their children's learning data. During the interviews, we found that there was still a lack of awareness about data-driven learning, such as how BookRoll is actually used for learning and how logs are used to support learning. However, it was also clear that the teacher and the mother were looking forward to the possibility of employing data-driven learning and sharing learning processes effectively using technology.

6.4 Discussion

In this section, we first discuss the limitations of the current study and then address the possibilities and challenges of applying DEAR for students with special needs in inclusive education.

6.4.1 Limitations and solutions for the sample size

One of the limitations of the current study is its sample size, as there were only two subjects. In resource rooms in Japan, class activities are usually offered by one teacher to either individual students or small groups for a limited time. Therefore, only a limited number of students can receive support each day. In addition, not all schools in Japan have resource rooms. Hence, it was difficult to recruit a large number of participants for this study, even if subjects were collected from multiple schools. Additionally, some parents were not willing to participate in the research and did not consent, making recruiting subjects a major challenge. Thus, it may be difficult to apply and generalize the results of the current study to a broader context. In addition, the small sample size may suggest the possibility of bias in the data analysis. To minimize this possibility, we used log data from the participants' learning process and attempted to visualize the data in plots instead of collecting data from conventional sources such as surveys, tests, and observations. Two researchers performed the confirmation and interpretation of the logs. The results confirmed that differences in the reading process between the two participants, such as differences in how they approached AR and how they used the tools, were interpreted in the same way. Learning evaluations and decision-making regarding whether to provide students with support have often been made based on the evaluation of learners' artifacts, observations, survey results, communication among stakeholders, and subjective measures such as teachers' perceptions or parents' intentions, which may lead to biased judgments or unnecessary support. Although these assessment methods remain essential, by being able to clearly show artifacts and the learning process through log visualization, not only researchers, but also school administrators, teachers, and parents can objectively judge a child's learning progress and make decisions about support provision.

6.4.2 Improving learning design for continuous learning

As mentioned in the existing literature, the majority of research and experiments on reading-based learning typically conclude at the end of the study period, often failing to foster lasting reading habits among learners (Gersten et al., 2001). We must acknowledge that there was a need to repeatedly conduct AR activities over time in this study as well. Additionally, it is difficult for learners who have difficulty concentrating to continue learning if they are not satisfied with their learning activities. Designing learning activities to suit learners' needs and preferences is necessary for learning satisfaction and continuation (Salas-Pilco et al., 2022). The AR procedure employed in this study was segmented into three phases. However, taking learners' attention spans into account, it is also considered to focus on technology (such as LA and AI) applications that offer precise, individualized guidance and feedback for more effective interventions. Emergent technologies such as LA and AI assist learners in learning at their own pace outside the classroom and at school. Learners can then use the dashboard to monitor the learning process and learn to reflect and understand so that they can develop and improve their cognitive and metacognitive skills. Learning activities and pedagogical approaches should be improved so that learners with special needs can continue learning independently even after the experimental period ends.

6.4.3 Usability enhancement of the LEAF platform

Existing dashboards in LEAF have an environment in which general students can reflect. However, current AR-D in LEAF may or may not be suitable for learners with special needs. Therefore, we consider updating and improving the performance and content of the functions and systems regarding the concept of the Universal Design of Learning (UDL) (Rose & Meyer, 2002). This is because system affordances and dashboard designs can significantly impact perception, behavior, and acquisition. Improvements in the usability, accessibility, and reliability of the system are often indicated in past studies (Buzzi et al., 2016; Mejia et al., 2016). Improving the system and developing an LA dashboard based on real data should be considered so that all learners, including students with special needs and their stakeholders, can easily manage their learning and reflect on it, which will help mitigate learners' difficulties.

6.4.4 Log data-driven solutions and potentials of AI for active reading

In this study, we observed variations in the time needed for AR and the approach adopted for the same learning task among different learners. Students with LD have been found to process information inefficiently and not understand appropriate reading strategies, which can lead to unexpected learning failures in comprehension and decoding (Gersten et al., 2001). For such learners, it is essential to present the steps of "what has been achieved" and "what needs to be done" explicitly and offer cues to help them complete the task and progress to the next step (Gersten et al., 2001). In today's data-driven learning environments, such as LEAF, it is possible to notify learners of task completion and reward them to boost their self-esteem and motivation to read and learn. The utilization of log data may lead to more efficient learning. Further, emergent technology such as AI complements learners' previous knowledge and skills. For example, it would be possible to use natural language generation to support reading learning by navigating the contents and the flow of reading activities in an easy-to-understand manner using both text and audio. First, we demonstrate each phase of a potential AI-driven AR approach in the future based on the results of a case study.

Pre-reading phase

Although learners with LD are good at many things, they are said to fall behind other students in reading comprehension because of difficulties like making predictions and having limited imagination and cognitive biases (Randi et al., 2010). However, such students can be instructed to improve their reading comprehension by using pre-reading strategies that activate their attention and prior knowledge (Gersten et al., 2001). AR uses information such as visual and auditory aids to help learners create an image of what they are about to read before (or even while) reading. However, for students who are struggling with reading, AI automatically measures the time required, the length, and the difficulty of a text, integrates it with information from the accumulated learner's data such as their reading speed, weakness, and preferences, and assists them in the reading process. For example, for students who have difficulty imagining textual information, AI generates and provides visual information to make visualization easier. For learners who have difficulty following the order of learning activities, AI can aid learners with audio or textual guides or ask them what they want next to guide their learning. It may also display filters to help students choose what to do next or use past data to calculate the time required for each learner to learn and intervene to complete a task at the appropriate time. In addition, it may activate the learners' existing knowledge by guiding them to vocabulary quizzes and chapters related to the reading content, and provide information relevant to the content they are about to read. In this way, when learners become stuck and cannot predict or create an image of the story during the pre-reading phase, AI may intervene to stimulate their previous knowledge and offer assistance, such as by providing an advanced organizer framework (Idol-Maestas, 1985) to guide them on what to do next.

While-reading phase

There are various types of reading difficulties given as examples, such as difficulty with concentrating on one thing, following procedures, completing tasks through to the end, reading information from a text alone, and inability to empathize with the emotions and viewpoints of the characters, or just simply taking too long to read (Randi et al., 2010; Ryan, 2007). AI can offer cues to help learners maintain focus on their reading objectives and assist them in identifying corrective actions when necessary steps are not completed. When unnecessary actions are detected, AI can redirect learners' attention towards the task at hand. AI may thus enable learners with special needs to work on AR learning alone, which was said to be difficult for them (Gersten et al., 2001). At the current stage, we developed and tested a text recommender in the LEAF system that automatically recommends reading materials based on the logs from markers used for vocabulary during AR. In the future, AI will recommend reading materials that match learners' levels and preferences based on the outcomes from the AR activities, such as different stroke orders, selecting wrong characters, spelling errors, and frequently used words and content stored in memos. AI will assist in making connections with previously read materials and helping students consolidate and develop what they have read by recommending chapters to review and reading materials to work on next. Moreover, AI may act as a reading agent or invite peers and teachers as intermediaries for reciprocal teaching interventions and mutual guidance that improves reading comprehension through communication with others. In this way, AI may provide opportunities for learners to receive feedback and encouragement from others and cultivate independent abilities in connection with others.

Post-reading phase

In this case study, students wrote their understanding of the stories in memos using the keyboard and their handwriting. Currently, the iPad's Speech Recognition function is available for learners who are not good at writing. It is possible for learners to use the voice-to-text function to input what they imagined, understood, and thought about a story into BookRoll memos. This allows for the collection and analysis of data in the LEAF system. Current reading learning does not end with understanding what was read but requires the ability to develop beyond that and apply information that can be used in real life. These application and practical skills may be enforced through interaction with others. In an inclusive learning environment, learners with and without learning difficulties coexist. In particular, encouragement from peers may develop learners' perseverance in the face of challenges and improve their comprehension and learning performance (Gersten et al., 2001). For class activities, data-based group formation can be applied in which groups are created to work together to deepen and develop an understanding of what they read. This is possible with the current LEAF, and group formation parameters such as homogeneous, heterogeneous, random, and jigsaw can be adjusted depending on the learning purpose, learner characteristics, and other considerable factors (Liang et al., 2023). Further, AI will be able to pair learners who need help with learners who have already completed a task, or create peer help groups based on log data. For example, AI would recommend a human learning companion and/or an AI agent, or called a pedagogical agent (Savin-Baden et al., 2019), to read together. Peers can be selected from humans or AI in the future, creating an environment that promotes learning and reading together. This may reduce the burden on the teacher in a busy classroom, provide feedback suitable for the individual with the help of AI and the people around it, and manage and orchestrate the class activity efficiently. Depending on the learner's progress, AI can facilitate a unique inclusive learning experience by potentially involving human intervention and reflection.

6.4.5 AI for facilitating learning reflection and decision-making

Using the LEAF system for AR activities allowed us to capture and visualize participants' reading processes and detect salient behaviors and insights in learners with special needs. Furthermore, the visualized learning process and artifacts were shared between the resource room teacher and the mother. In the LEAF learning environment, learners can use the dashboard to reflect not only on the results but also on the learning process.

Reflection encourages learners' metacognition by allowing them to reflect on their own thinking, and self-reflection provides an opportunity to evaluate their own cognitive processes (Gersten et al., 2001; Silver et al., 2023). Generally, learners reflect on their own learning and deepen their understanding, and teachers review their learning and decide what to do next. However, some learners find it difficult to reflect on their own learning. In the AI-driven inclusive education expected in the future, AI may be used to support reflection on reading learning using both text and audio. Using log data from learners' own learning activities enables more personalized feedback by highlighting interesting and hidden patterns. An AI agent will also play an active role. It will sense "done" or "not done" and provide options for what steps to take while emphasizing what learners can do to increase their self-affirmations. For learners who have difficulty understanding information from graphs and tables, or from texts, audio, and visual images will be automatically selected and added to make it easier for them to understand the information presented on the dashboard to assist in learning comprehension. AI will also automatically explain the data displayed on the dashboard, making it easier to understand not only for learners and teachers but also for parents and other educational supporters. This can improve the efficiency and effectiveness of the decision-making process. For example, learners can decide what to learn next, teachers can choose and plan the next activity, and teachers, school administrators, and parents can decide what kind of support learners will need. AI will further encourage human intervention, making it possible to judge their learning more objectively with the help of stakeholders such as teachers and parents, thus facilitating a unique and comprehensive learning experience.

6.5 Conclusion

To date, no study has investigated the challenges and possibilities of applying AR strategies from the LA perspective in the context of actual inclusive educational settings. Therefore, we undertook a case study to explore how the DEAR approach can be materialized as a supportive reading framework for learners with diverse needs in the context of inclusive education in Japan. In today's data-enhanced learning environment, it is possible to detect and visualize specific learning behaviors using learning logs obtained from daily learning. By integrating emergent technology such as LA into the current learning context, we found that individual learners can be provided with more efficient and appropriate learning and reflections on learning. However, while some teachers and parents, such as our participants, look forward to opportunities to objectively reflect on learning and provide further support using LA technology assistance, we realized that obtaining assent and understanding from teachers and parents along with fostering data literacy remains a challenge for future inclusive education utilizing LA. Our future work includes pursuing the possibilities of an LA- and AI-driven inclusive learning environment in which all learners are expected to receive equal learning opportunities and optimal support with the co-progress of stakeholders. This cannot be achieved without a considerable amount of data. In Japan, the GIGA initiative has created an environment for data utilization on a national level. Although it has been pointed out that data utilization has not fully penetrated Japan compared to other countries (MEXT, 2022c), the country is working to build a large-scale data sphere that supports the use of AI, which has created an environment for the effective use of logs. As the use of educational informatization progresses on a larger scale, the data problems and generalizability concerns found in this study may be resolved. Based on the logs collected from the previous and upcoming implementations, we will derive an algorithm that will realize and aim to create an LA and AI-driven inclusive learning environment that can provide individually optimal learning support to each learner in cooperation with stakeholders. From there, we will pursue evaluating the impacts and understanding the actual situations for inclusive education.

Chapter 7

Discussion

AR is not just about reading, but it is about reading-learning. Its strategy enhances a cognitive and metacognitive process for students and leads them to read and learn better. The primary objective of this dissertation is to support learners' cognitive and metacognitive processes involved in reading to improve their understanding of the written text and thus learning. The idea was to use an e-book reader and its simple tools such as markers and memos to support reading learning, as a way of getting information about the text to organize reading to better understand the text. Moreover, it is to use the dashboard enabling students and teachers to be aware of the student's reading cognitive process. Eventually and expectantly, the students shall get used to the strategy and learn AR strategies.

7.1 Summary from the Three Studies

The findings from the three studies contributed to support the proposal. First, the effectiveness of the DEAR strategy was demonstrated by showing its positive impact on participants' reading performance in terms of vocabulary and reading comprehension in both the experimental and control groups in Study 1. It was also revealed that the AR dashboard visualized the behavior of each phase of the cognitive process in reading and contributed to supporting the metacognitive skills by reflecting on the reading process and outcomes and being conscious of the process. The results of Study 1 indicated the affordances of LA dashboards and visualization, supporting previous research showing that LA dashboards promoted awareness of learning behaviors, increased learning motivation, and promoted literacy (Jonathan et al., 2017). The limitations of Study 1 are first, that DEAR was conducted in a real classroom environment rather than a lab situation, which resulted in phase interruptions and postponements due to daily classroom constraints. This may have affected learning effects and performance in both groups. The daily constraints mentioned here mean that the experiments were postponed due to COVID-19, and they did not proceed as planned because the daily routine of the teacher was prioritized. This is a limitation in terms of examining the effectiveness of DEAR. However, since the teacher flexibly adapted the DEAR to his own teaching and conducted the classes, this indicates that the DEAR can be used in daily classes rather than in experimental settings. Further investigation is considered in actual contexts. Another limitation is regarding the design of the AR dashboard. The AR dashboard enabled the visualization of elements related to AR. However, as Sedrakyan et al., 2020 emphasizes, it is important to provide meaningful feedback to each student for different goals. Therefore, the challenge in the future is to focus on improving the dashboard to extract and visualize meaningful information for each phase of DEAR with consistent and iterative refinements through longitudinal studies in real learning environments as recognized in past studies (Schwendimann et al., 2016; Verbert et al., 2013).

In Study 2, DEAR was applied to PC in a programming course at an Indian university. As a result, the proposed strategy was proved to be applicable to novice programming tasks, and the effectiveness of DEAR was further proven by having a positive impact on the out-of-class learning behavior of students in the experimental group. Moreover, the dashboard helped the teacher to facilitate PC activities in class. Study 2 raised limitations regarding data collection and utilization and highlighted the difficulty of establishing the equivalency of study groups in actual educational settings. Another limitation concerns the usability of the dashboard. The future work is to improve an existing AR dashboard for generality and adapt it to specific purposes considering the benefits of designing dashboards for users' specific factors and needs (Ahn et al., 2019) and clear pedagogical concepts for improving and supporting learning (Jivet et al., 2018).

In Study 3, an investigation was made on the challenges and possibilities of applying AR strategies from an LA perspective to learners with special needs in actual inclusive education settings. As a result, noticeable learning behaviors in AR were visualized, suggesting the possibility of providing more efficient and appropriate learning and reflection on learning to individual learners. On the other hand, it was still a challenge to gain teachers' and parents' consent and understanding and foster their data literacy. The number of consents is proportional to the amount of data that can be collected. This results in the difficulty of collecting learning big data in special needs support settings. The data collection problems and generalizability concerns found in this study are expected to be resolved as the environment for data utilization is improved at the national level. Contributions from the three studies extended the possibility of future technology-enhanced AR support.

Chapter 8

Conclusion

AR strategies, which have been long used in language learning to improve reading skills and performance, have exhibited their effectiveness. However, past studies lacked exploring the understanding of reading as a cognitive and metacognitive process, providing support based on the tracing reading process in technology-enhanced learning environments, and investigating the applicability of data-driven reading support in different contexts needs. To this end, we proposed DEAR, which integrates LA into an AR strategy and supports reading learning using learners' log data. The idea was to use an e-book reader and its simple tools such as markers and memos to support reading learning, as a way of getting information about the text to organize and visualize reading to better understand the text. The dashboard was used to visualize learners' cognitive processes, promote their metacognitive awareness, and provide them with further learning support. However, limitations for further development of research must also be acknowledged.

This research primarily focused on the impact on learners and lacked evidence of the contribution of DEAR to teachers. We examined what teachers did with the student data, how they used it, and how satisfied they were with the DEAR approach. We also understood from the comments from the teachers who participated in this study that the dashboard showed the possibility of providing support tailored to different needs. However, there is still a lack of clear and objective evidence to demonstrate it. For example, there is still room for further research into the extent to which the use of DEAR has improved the efficiency of classroom activities, and how it has changed teachers' workload and approaches to teaching reading classes.

DEAR was applied to learners of different ages and in different instructional situations. However, it was acknowledged that further investigation shall be needed to present the applicability of DEAR to PC, and there is room for improvement in the strategy itself if it is to be effectively adapted to children with reading difficulties. We need more case studies to provide broader and deeper reading support to individual learners and teachers in inclusive but increasingly diverse learning environments.

The findings and current limitations of the studies motivate future developments and research agenda. First, In this study, we developed an AR dashboard based on the proposed DEAR and showed that it contributed to improving teachers' pedagogical approach and students' reading comprehension skills and learning behaviors. In the future, we will consider inclusiveness and work on improving the dashboard according to learners' needs, motivation, and level of understanding. To start with, we will make the dashboard more comprehensible and meaningful so anyone can understand the information on the dashboard by providing clearer feedback on the reading activities of each DEAR phase. To do this, we further investigate the impact of visualizing the AR process and outcomes on the dashboard on the achievement of reading activities during each phase of AR.

Second, the proposed DEAR was applied in this study, primarily in language learning, and verified to have a positive impact on reading performance and behaviors. In addition to the three main studies, DEAR has demonstrated its applicability to various language learning contexts. Examples include jigsaw group activities as collaborative learning in high school English classes, (Toyokawa et al., 2021), flipped online classes at a university, (Toyokawa et al., 2022), and a study in which groups were formed based on marker logs and DEAR was conducted as a group activity (Liang et al., 2023). All of these indicate possible variations of DEAR applications to language learning, conducted based on logs obtained from learning using the LEAF. The potential effect of DEAR on reading learning will continue to be investigated beyond language learning. Further, our future work includes increasing the number of studies targeting students with reading difficulties and younger students, to provide reading support to students with different needs at different cognitive stages in inclusive education. This considers the application of emergent technology including LA and AI, as in Study 3 providing feedback in appropriate ways and using dashboards that meet individual needs.

Finally, our future work suggests improvements in the DEAR strategy. In order to improve learners' reading skills, we also need to engage in making the strategy more flexible enough to be integrated into instruction and easy for teachers to implement in their classrooms. We shall develop our research with teachers having them use DEAR in their instructions, find possibilities of the strategy, and then continuously use it so that all children can develop the core competency that allows them to live confidently and positively in future society.

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