Digital Read-Pair-Share: A Didactic Application for Collaborative Reading and Visual Reading Analytics

I. López García[1], P. Riehmann[2], K. Girgensohn[3], J. Voigt[4] and B. Froehlich[1]

[1] Virtual Reality and Visualization, Bauhaus-Universität Weimar, Germany
[2] Department of Computer Science and Informatics, Jönköping University, Sweden
[3] Center for Teaching and Learning, Europa-Universität Viadrina Frankfurt (Oder), Germany
[4] Kunsthochschule Berlin Weißensee, Germany

Abstract

Reading and discussing complex texts is a recurring challenge in higher education, particularly in seminar-style courses. While the Think–Pair–Share (TPS) method provides a structured approach to collaborative learning, its application to text-based activities is often hindered by media discontinuities and limited support for reflection. We present digital Read-Pair-Share (dRPS), a fully digital implementation of TPS that integrates guided reading, annotation, question answering, peer discussion, and visual reading analytics in a single web-based system. We deployed dRPS in a visualization course to support students in reading a chapter from Munzner's Visualization Analysis and Design. Our initial evaluation shows solid reading comprehension, positive student perceptions, and the emergence of distinctive reading and answering strategies, which were effectively reflected upon using the analytics interface. We conclude that dRPS addresses key limitations of traditional TPS and has the potential to enhance reading engagement and learning outcomes across disciplines.

CCS Concepts

• ***Human-centered computing*** → ***Computer supported cooperative work;*** *Visual analytics;* • ***Applied computing*** → ***Collaborative learning;***

1. Introduction

Think-Pair-Share (TPS) is a well-established instructional strategy in education and pedagogy. It was introduced by Lyman in 1981 [Lym81] and has since been widely used and studied as a cooperative learning technique across educational contexts, including recent work demonstrating its effects on student participation and discussion quality [Pri04, MJ21, GA24]. In TPS, a teaching unit is structured into three potentially recurring stages: students first think individually about a task (*Think*), then discuss their ideas in pairs (*Pair*), and finally share their results with the whole class (*Share*). These phases make TPS particularly well suited for working with texts of limited length in class, as it encourages individual comprehension, peer discussion, and collective reflection on the material. Moreover, it is flexible with regard to the use of media in each phase; analogue formats (books, paper, and pen), digital formats (text editors and online platforms), or hybrid forms can be employed. However, information loss between phases due to media discontinuities or context switches is unavoidable and represents a central weakness of the method.

We therefore designed, implemented, and evaluated **digital Read-Pair-Share (dRPS**, Fig. 2), an enhanced digital version of TPS for academic reading. Our web-based application guides students through five activities designed to support engagement with an academic text. The original *Think* phase is implemented as two reading activities (hence Read–Pair–Share). Students first skim the text using a reduced text representation. They then engage in active reading of the full text to answer a predefined set of guiding questions individually. In the *Pair* phase, students work in teams to discuss and refine the joined set of answers. These results are subsequently presented to the class in the *Share* phase, which is moderated by the instructor. At each step, the application adapts to the activity and provides visual feedback on students' interactions, based on collected user data (provided the user's consent). Our five activities conclude with an analytical activity using the visual reading analytics interface (VRAI), which allows students to reflect on their reading and answering behavior. Instructors additionally have access to an extended version of this interface, enabling them to compare students' strategies and examine aggregated information.

As educators in Information Visualization, we have often found it difficult to motivate students to read selected chapters and articles during the course thoroughly–a challenge that is likely not unique to our setting. In response, dRPS aims to teach students a structured approach to reading by providing guiding activities and questions. As a collaborative method, it motivates students through mutual responsibility for each other's learning [RJ02]. By provid-

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ing visualizations of students' annotation, answering, and reading behavior, we aim to further foster engagement.

We applied dRPS with volunteer students in a visualization course to support reading of the first chapter of Munzner's *Visualization Analysis and Design* [Mun14]. In an initial collaborative reading session, we covered the activities from *Skim* to *Share with the Class*. In a second session, we analyzed participants' reading behavior using the VRAI. Our initial results indicate solid reading comprehension for a voluntary task, positive student perceptions of the overall learning activity, and active use of the reading and annotation interface, which was rated positively in terms of usability. The VRAI revealed four distinct work strategies, which students actively engaged with during the reflection session. Overall, these findings suggest that dRPS has potential to support text-based learning across disciplines.

2. Related Work

The digitization of texts has transformed how we consume them, often promoting faster and shallower reading in detriment to active learning [WB09, Bar21]. However, smart digital media and interactive features can indeed yield better reading performance over static systems [CLSGL23]; for example through intelligent annotations [HBPB12, FKS*23], user-centered navigation [AL08, LCY13], tailored text filtering and presentation [KK19, HF03], and in-paper Q&A capabilities [NSF*23]. These interactions support the user's deliberate engagement with a text through its conscious processing, i.e. *active reading*. Adler and Van Doren's hierarchy of reading levels provides a useful lens for positioning such interventions [AVD72]. At the *elementary* and *inspectional level*, readers focus on basic comprehension and skimming; at the *analytical level*, they engage in deep understanding; at the *syntopical level*, they process the topic across texts and viewpoints. As emphasized in Walny et al.'s work on "Active Reading of Visualizations" [WHP*18], the tight coupling between cognitive processes and interactive tools allows the reader to construct meaning through iterative refinement of interpretations and level progression. Our dRPS system targets the *inspectional*, *analytical* and the transition to *syntopical* level for any text, scaffolding deep comprehension through skimming, guided individual thinking (*Read*), and understanding monitoring (*Pair*), followed by comparative discussion (*Share*). This in-classroom approach aligns with Wilson et al.'s observation that critical reading must be taught and maintained using practical examples and peer discussions for sense-making [WDMHTJ04, Wil16]. Similarly, SERT [McN04], a reading strategy instruction system by McNamara, proposes self-explanation and in-pair practice, but its digital form iSTART [MLB04] relies on predetermined material and solo tasks. In opposition, TPS supports both individual thinking and cooperative work, improving learning motivation and participation [PBP25, GA24], as well as fostering critical thinking in diverse domains [Kad13, KMI14]. Because TPS proposes a faceted work mode, it can be incorporated into reading scaffolding strategies alternating individual pre-reading and reading stages, with post-reading discussions. This coupling has been shown to improve reading comprehension in classrooms ranging from school [Car07] to tertiary level [PBP25].

Figure 1: *Model of the dRPS activities sequence (blue), and the corresponding and adapted TPS phases (gray).*

Digitally-mediated collaborative reading has also proven to be successful. Collaborative annotation platforms like HyLighter and Perusall have shown to yield greater levels of motivation and positive effects on critical thinking [MJ10, MLKM18]. Text-based forums, where students can write their questions and answer their peers' doubts while reading, can increase participation and lead to stronger reading comprehension [ZKAM12, CC14]. While these systems primarily support async collaboration, our approach embeds active reading into a real-time, instructor-guided process, augmented through visual analytics.

In contrast to analogue media, software can provide trace data to test and validate the results of a learning activity [GD12], as well as provide insights to students and teachers on the learning processes [Wis14], including reading behavior and abilities [MFV*17]. For instance, Tan el al. tried WiREAD [PLTKJY17] with high-school students in 30-minute sessions of reading and interacting with peers through forum posts. The students appreciated learning about their own abilities displayed on informative dashboards, but the comparison to other students in normalized metrics could be detrimental to their motivation, specially to those on the lower scores end. Similarly, Wise et al. [WZH14] extracted data from forum-based discussions by students in a graduate seminar and proposed them as prompts for regular reflections. Students showed positive use of this data by setting goals and changing behaviors in the following weeks. While these works focused on the interactions around a text, others have studied reading patterns and their associated effects. Li et al. [LYI*25] analyzed data from a digital learning environment of students reading for essay assignments. Three distinct learning strategies were observed and their responses to different types of scaffolding were studied. Dyson and Haselgrove [DH00] analyzed scrolling patterns while reading at high and normal speed, finding that longer pauses between scrolls tended to result in higher comprehension scores. Studies scrutinizing and visualizing these patterns tend to be set in a lab, for example when analyzing strategies in different media [Oh13] or interfaces [HF03, FKO16]. Unlike these works, our VRAI tool provides detailed visual analysis of reading behavior implemented directly in the classroom, enabling students to actively explore their own and their peers' data, using visual analytics as objects of reflection and discussion.

3. Digital Read-Pair-Share

The sequential phases of dRPS provide a structured path for students and instructor to engage with a text collaboratively. The *Read* phase focuses on guided **individual knowledge acquisition**. In the subsequent *Pair* phase, students **exchange insights** with a partner, explain their individual findings to each other, jointly revisit the relevant text passages, and improve their answers based on consensus. The *Share* phase is flexible and aims to establish a **shared understanding** of the answers and the core messages of the text.

Depending on group size and materials, the instructor can either assign one question to each pair for presentation, or address the questions sequentially, inviting all pairs to present their answers and compare them in discussion. The final *Analyze and Reflect* activity is performed as an additional session where students **analyze their reading data** and reflect on their strategies.

3.1. Learning Objectives

Our motivation is to provide visual and didactic support to foster effective reading and comprehension of academic and scientific texts in tertiary education. The development of the dRPS is thus led by the following *course-agnostic* learning objectives (LO):
LO1: Students should improve their proficiency in academic reading through a structured reading setup with minimal distractions.
LO2: Students should understand the didactic concept of TPS through direct experience and subsequent reflection.
LO3: Students should be able to reflect on their own reading and interaction behavior as well as that of others.

3.2. Design Interventions

For a fully digital and visually augmented implementation of TPS, we propose the following design interventions (DIs):
DI1 Information Management: A standardized information transfer between phases and centralized data management are required, eliminating lost or unreadable notes as well as manual text transfers between different programs or from paper to PC.
DI2 Clear UI and Orientation: The system must provide clear orientation and guidance during and between phases, along with the information necessary to accomplish the activity-specific tasks.
DI3 Visually Augmented Text Display: The display must provide all customary tools for *active reading* [AVD72], such as highlighting, commenting, quoting, and recording students' own thoughts, questions, and answers related to the text. It should offer visual cues about the structure of the text for orientation, but should neither be overwhelming nor distracting [FKO16].
DI4 Visual Collaboration Awareness: To enhance the sense of collaboration and "reading together," visual cues indicating who read, answered, or annotated which parts are provided. These cues offer points of reference that facilitate pair discussions (*Pair* phase) as well as moderation by the instructor (*Share* phase).
DI5 Visual Analytics of Reading: The user interactions with the text should be analyzed with a visual reading analytics interface for exploring reading behavior and text engagement patterns. This would support self-reflection by students [Wis14] and enable visual (meta-)analysis by researchers and educators [GD12].

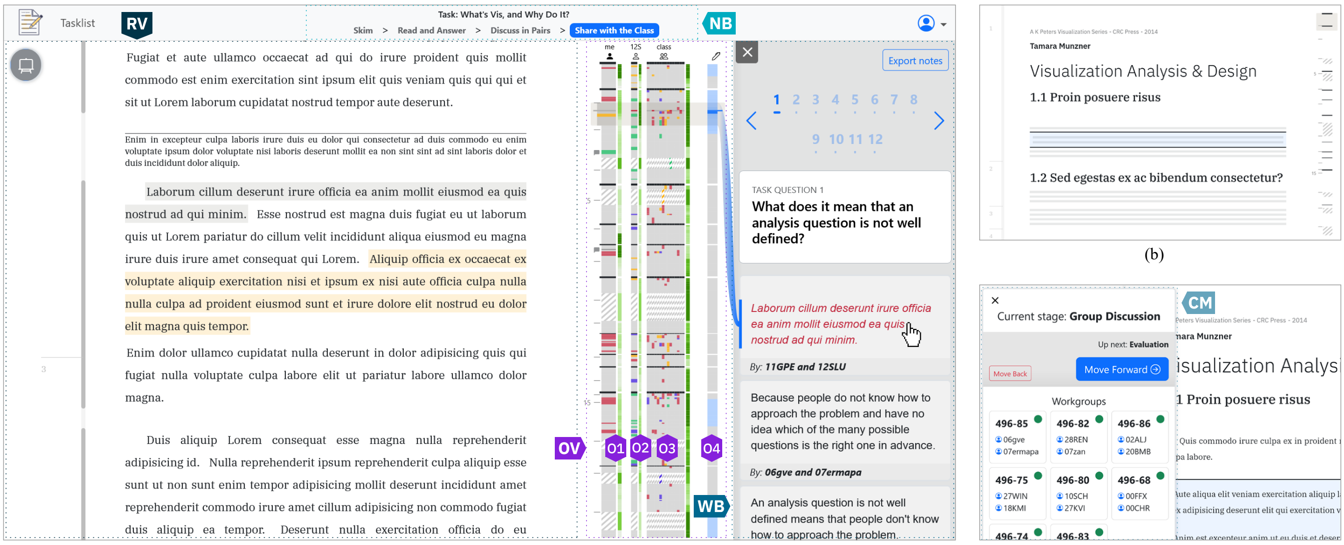
3.3. Application, Activities and Views

Our full-stack web application uses a Django (Python) backend (**DI1**) and a Bootstrap frontend with D3.js and QuillJS components. Its responsive design needs a minimal resolution of 1024x768 pixels, appropriate for students' laptops and tablets. Smaller screens like smartphones are inadequate for the activity and thus present only a reduced-features version. Each activity of dRPS is shown in its own dedicated web view, incrementally building on the visual elements of the previous view. To provide orientation (**DI1**, **DI2**), the sequence of activities (with the current one highlighted) is shown as breadcrumbs in the Navigation Bar (Fig. 2, NB).

Phase *Read:* Skim View. The *Skim* activity provides initial orientation within the text, allows to form preliminary ideas and activates prior knowledge about the subject. This is realized by distant reading techniques using visually emphasized structural elements—title, author, headings, figures, and pages—while body text is only shown as thin gray lines (Fig. 2b). The document *Overview* (OV), vertically aligned on the right of the *Reading View* (RV), locates all displayed elements at their respective positions in the document (see Fig. 2a). The section currently in the viewport is additionally highlighted in the overview and adjusts when scrolling the content in the RV (**DI2**, **DI3**). Using the *Control Menu* (Fig. 2c), the instructor can advance the session to the next phase, automatically transitioning all participating students' applications (**DI1**, **DI2**).

Phase *Read:* Read and Answer View. The subsequent *Read and Answer* activity focuses on the in-depth reading of the text for individual knowledge acquisition. It is guided by a set of questions defined in advance by the instructor, which students answer before the next phase. For active reading, users can annotate sentences and images using comments and highlight colors (**DI3**). This is mirrored in the Overview (OV) using the corresponding colors and with a small comment icon to the left, with the annotation content revealed on hover (see Fig. 2, O1). The Workbook (WB), a collapsible panel on the right, contains the assigned questions with respective text editors for answering. Sentences can be quoted from the RV via context menu, directly into the editor in red italic, while the corresponding text position is highlighted in red in both the RV and OV. By the end of this activity, students should not only have developed an understanding of the text but also have answered their assigned questions sufficiently well to explain the underlying concepts to their partner. The allocated time depends on several factors including topic, text length, complexity, as well as the students' level and prior experience.

Phase *Pair:* Discuss in Pairs View. Before the *Read* phase, student pairs are already formed and the set of questions is divided into two subsets, S1 and S2, each assigned to one partner. In this 20–30 minute *Pair* phase, they exchange their gained insights and refine their joint set of answers for presenting and discussing with their fellow classmates later. Because students worked on different questions, they assume responsibility for their partner's learning, thereby extending their accountability beyond their own individual learning [RJ02]. For this, the WB additionally displays the partner's questions and answers (**DI1**) and unlocks further visualization and interaction features (**DI4**), most notably the partner's annotation overview (Fig. 2, O2). Hovering over an answer reveals a visual link to the OV section visible during writing. Next to each partner's column, an additional heatmap column is displayed, encoding the amount of time each user spent on different parts of the document. This information is approximated from scrolling data collected during the previous phase. It helps align the text sections covered by each partner and identify potential knowledge gaps (**DI4**, **DI5**). These features allow pairs to maintain an overview of their work through distant reading while enabling quick transitions to close reading of passages for further discussion and answer refinement.



(a) (b) (c)

Figure 2: *Different views of the reading interface. **(a)** View of the application during the Share phase, with its components labeled. The Reading View (RV) is were the text is displayed. The Navigation Bar (NB) shows the phases for orientation with the current stage highlighted. The Overview (OV) represents the text in its entirety at viewport height, including structural items for guidance (headings, images, page numbers), as well as the annotations and reading time distribution of the user (O1), selected peers (O2), the whole class (O3), and the related location of answers (O4). The Workbook (WB) allows users to see the questions and answers for the activity. Hovering over the answers reveals their provenance through visual linking to the OV and, in the case of quotes, highlighting in the RV. On Ctrl+Click, the RV scrolls to that point. **(b)** RV and OV during* Skim*; the body of text is only hinted with gray lines. **(c)** The Control Menu (CM) visible only in the teachers' interface. Here they can move between phases and administer student groups, if necessary. In all three images the original text content has been replaced with placeholder text for copyright compliance; bibliographic metadata (title, author, publisher) is retained.*

Phase *Share:* Share with the Class View. This phase aims not only to have students practice oral presentation and reporting skills, but also to ensure a shared understanding of the content across the entire class. The instructor closely guides the discussion by revisiting each question on a shared screen, asking students to present their answers, and comparing them across pairs. To aid the process, the WB lists all questions together with their corresponding answers, to be reviewed and discussed sequentially (**DI1**, **DI4**). Answers remain editable so that students can still refine them. An additional class-level overview shows all students' highlights as thin individual stripes (Fig. 2, O3). This makes it easy to see whether highlights align or are scattered across the text. It is complemented by a class reading heatmap indicating the collective coverage of the document (**DI4**, **DI5**), as well as a dedicated column that visualizes the answer density per text location (Fig. 2, O4). This density is calculated per document sentence as the number of characters written across all answers to a question while that sentence was visible in the RV. Quoted sentences are displayed using a darker scale and are aggregated across all answers. All this allows a rapid identification of patterns and potential misconceptions. When answers are linked to unexpected locations, the instructor can examine these passages and clarify why such interpretations may be inaccurate (**DI1**, **DI5**).

Phase *Share:* Analyze and Reflect View. The *Analyze and Reflect* activity has two main aims: first, to encourage students to explore and reflect on their own text interaction data; and second, to introduce them to visualization interfaces for text-related interaction data and, in Information Visualization courses, to foster critical analysis of the Visual Reading Analytics Interface (VRAI). First, the instructor introduces the VRAI. Students then inspect their individual reading and response patterns on their own devices (Fig. 3, **DI5**), identifying strategies that supported their comprehension as well as obstacles that may have hindered it. A set of questions is provided to guide their analysis. Finally, the instructor anonymously presents visualizations from multiple users and leads a class discussion of the observed patterns.

3.4. Visual Reading Analytics Interface

Data and Metric Computation. The presented data consist of logs of user interactions with the reading interface during the first four activities: saving highlights, comments and quotes, leaving and returning to the tab, saving answers in the WB, and scrolling in the RV. Consecutive window scroll events occurring within two seconds are aggregated into a single event, with corresponding start and end timestamps. The log records the IDs of segments visible at both time points, as well as the viewport height and scroll position in pixels. *Dwell time* per streak segment is measured from the end of a scroll event that brings it into view to the start of one that removes it from view. Streaks are interrupted by forward scrolls larger than the screen size or by backward scrolling. Time intervals during which the tab is hidden or the user is idle are excluded; idle

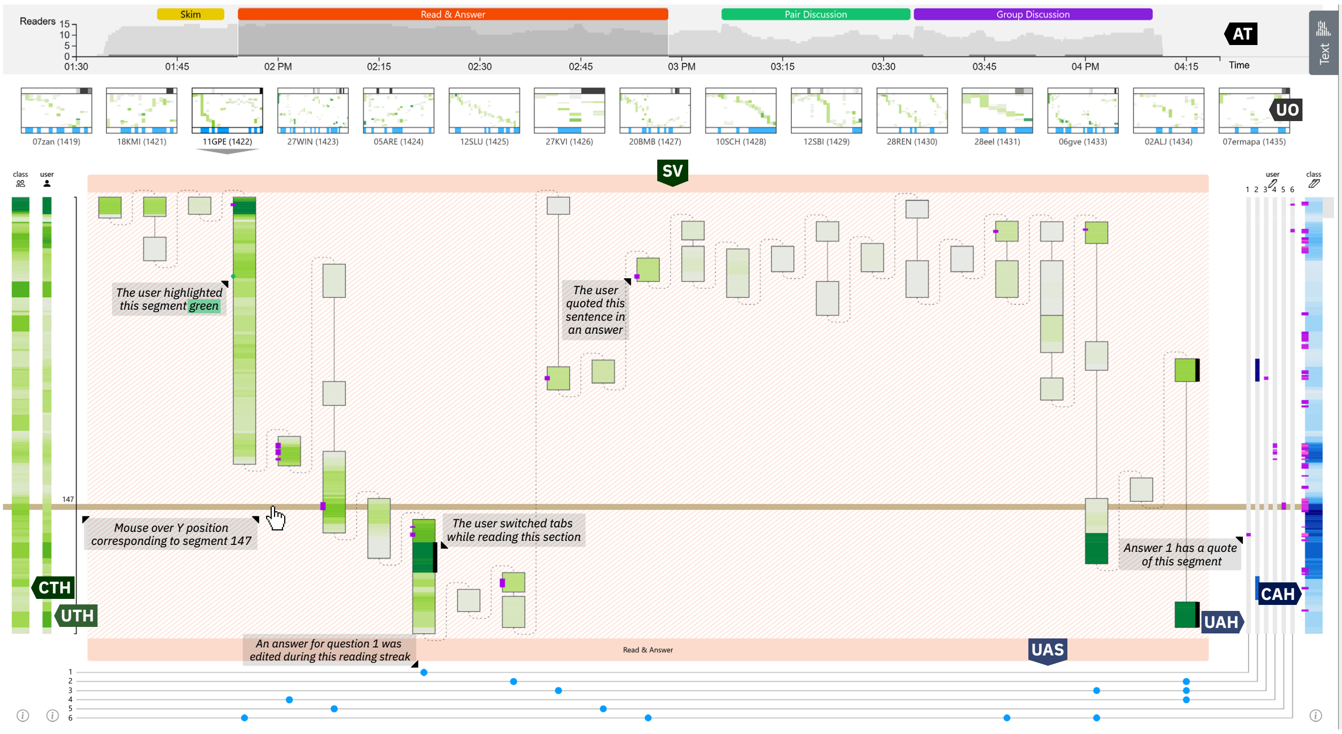


Figure 3: *The Visual Reading Analytics interface (VRAI, instructor's view). The Activity Timeline (AT, top) shows active users across time and phase durations. The Users Overview (UO) displays all users' Sequence Views as small multiples. The Sequence View (SV, center) shows the sequence of scrolling and annotation events of the selected user. Vertical position is the sequential position of each character in sentences, headings and images (size converted to characters) in the document. Each rectangle is a reading streak: a series of short consecutive downwards scrolling events. The segments inside are colored according to dwelling time, from light gray (no time) to dark green (maximum in the view). Markings on the left of the streak indicate annotation events (quotes in purple, highlights in their color); black markings on the right indicate the window was at least partially hidden. On the left, the Class Time Heatmap (CTH) and User Time Heatmap (UTH) show total dwelling time across the text. Farther right, the Class Answer Heatmap (CAH) displays the number of characters written per visible segment (from gray to dark blue). The marking on its left show the segments were quoted; color (purple to magenta) indicates number of times. The User's Answer Heatmaps (UAH) shows the same data per user, overplotting the quote markings over character data. All heatmaps share the SV's Y Axis. On the bottom, the User's Answer Sequence (UAS) locates answering events below their corresponding streaks. In this example, student 11GPE begins with a series of long reading streaks that progress toward the end of the document. Dark green segments coupled with quotes (purple dots) indicate close reading, followed by selective scrolling up and down to complete further answers, until the browser tab was left (black bars). The questionnaire revealed that this is a strategy learned in private tutoring.*

time is defined as five minutes without interaction. Answers written in the WB store the IDs of visible segments and quotes as inline data attributes [Qui26], enabling the computation of *characters per segment* and *number of quotes*.

Views and Layout. The VRAI (Fig. 3) consists of a central *Sequence View* (SV) showing reading behavior as a sequence of reading streaks and interaction events. To the left, the User Time Heatmap (UTH) and the Class Time Heatmap (CTH) provide aggregated dwell time per segment information, while to the right, the User's Answer Heatmaps (UAH) and the Class Answer Heatmap (CAH) show characters written in the WB per visible segment and quotes. Below, the User's Answer Sequence (UAS) shows answer events per answer and streak. Above, the Activity Timeline (AT) shows the number of users active in the task and the dRPS activities over time. The User Overview (UO), only visible to the instructor, shows all students' SV as small multiples. The original text is available on demand in a collapsible panel. To better support the analysis of individual strategies, the layout places the SV at the center and arranges less information-dense views on the sides, sharing the relevant position encodings for maximal space efficiency. This supports the joint analysis of the temporal and text-position dimensions of answering behavior in relation to the text-scrolling sequences.

Encoding. The SV and the four 1D heatmaps share the vertical axis, which encodes the sequential position of characters in sentences, headings, and images (with image size converted to characters) in the text, following a natural mapping. Horizontally, we chose a sequential, event-based encoding to support recognition of streak patterns: consecutive streaks are placed below one another, or in a new column after upward scrolling. The columns expand to fill the available space. Annotation events (highlighting, commenting, quoting) are visualized as dots and rectangles attached to the left of a streak. Periods in which the browser window is hidden are shown as a black stripe on the right side of the streak, and inactive times are indicated by moon icons below it. The SV, UTH, and CTH encode dwell time per segment (and streak) using color, ranging from light gray (no time) to dark green (maximum within the view). The CAH and UAH use a light-gray-to-dark-blue scale to encode the number of characters written per segment. Quotes are shown as overlaid rectangles, with their number encoded in color from purple (one) to magenta (maximum).

Interaction. In the student view, the data shown in the SV, UTH, UAH, and UAS correspond to the current user, whereas the instructor can select users in the UO. The AT supports brushing for time-based filtering, including filtering by activity. A segment hovered in the SV, the heatmaps, or the text view is highlighted in ochre across all views. If the text view is open, clicking on the visualizations scrolls the corresponding sentence into view.

4. Case Study: Lab Classes in a Visualization Course

In the context of an Information Visualization course taught by one of the authors, the dRPS system was evaluated in two voluntary lab sessions: (1) a collaborative reading session consisting of the activities *Skim*, *Read and Answer*, *Discuss in Pairs*, and *Share with the Class*, and (2) a retrospective reading data analysis session centered on the *Analyze and Reflect* activity.

The participants were informed about the experiment and the associated research project. Informed consent for the collection and use of interaction data was obtained during registration in the software. The reading session took place at the beginning of the course and addressed an additional course-specific learning objective, **LO4**: Students should be able to explain what Information Visualization is, understand its practical applications, and develop well-founded expectations regarding its challenges. For this purpose, we selected the first chapter of Munzner's *Visualization Analysis and Design* [Mun14], which was particularly well suited to this objective. The session was planned for 3 hours, with one hour for *Read and Answer*. Two 15-minute breaks were skipped, as the students chose to finish earlier instead. After the session, the students completed a questionnaire comprising five sections. The first section contained 12 multiple-choice comprehension questions: four related—but not identical—to question set S1 from the *Read and Answer* activity, four related to S2, and four covering topics not previously included. The second section consisted of the short version of the USE questionnaire [Lun01]. The third and fourth sections comprised free-text questions about the interface and the learning activity, respectively. The final section collected demographic information and reading habits. The data analysis session took place four weeks later, after students had been introduced to relevant visualization concepts and techniques in the course. Including onboarding, self-reflection, and class discussion, the session lasted one hour. The VRAI included a workbook with guiding questions that prompted reflection on reading and answering patterns. The questionnaires and codebook can be found in the paper's supplementary material.

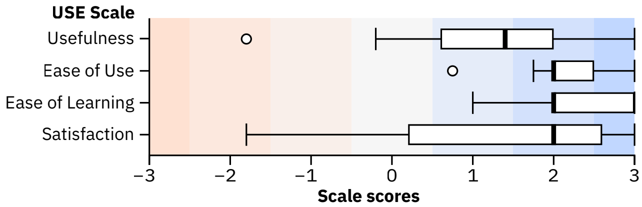


Figure 4: *Box plot of scores per scale in the USE questionnaire.*

4.1. Feedback and Results

Participants. Fifteen volunteers participated in the first session; however, two did not complete the survey. Of the remaining 13 participants, five identified as male and eight as female. The average age was 22.5 years ($Min = 20$, $Max = 34$, $SD = 3.69$). Participants' backgrounds were Southeast Asian ($n = 5$), Eastern European ($n = 3$), Western European ($n = 2$), and from other African and Asian regions ($n = 3$). Of the 15 initial participants, nine took part in the second session, along with two additional students who joined and conducted the analysis with partners.

Reading Comprehension. The 13 participants who filled the survey achieved a mean score of 9.08 out of 12 on the reading comprehension questions ($Min = 4$, $Max = 12$, $SD = 2.14$), indicating a solid comprehension level for a voluntary activity (**LO1**, **LO4**).

Reading Interface. We analyzed the free-text survey responses using open coding. Most participants reported using the highlighting function to mark sentences needed to answer the questions (Answer Count (AC) = 6), to indicate important or interesting points (AC = 6), and to support later recall (AC = 2). Two participants reported not using highlighting at all. The commenting function was used less frequently, primarily for making notes (AC = 4) and, in one case, for writing self-generated questions (AC = 1). Responses regarding the OV were mixed. Some participants found it useful or interesting for viewing peers' heatmaps and the placement of annotations (AC = 6). One participant reported using it to locate their own annotations in the text, while others appreciated the ability to compare their work with that of their peers (AC = 5). However, five participants reported not noticing or using the OV. For the USE questionnaire, we calculated scores as the mean per scale, assigning values from -3 to 3 to the 7-point Likert scale according to valence. Ease of Learning ($M = 2.33$, $SD = 0.71$) and Ease of Use ($M = 2.12$, $SD = 0.60$) received only positive scores, while Usefulness ($M = 1.20$, $SD = 1.36$) and Satisfaction ($M = 1.54$, $SD = 1.64$) showed negative skews (see Fig. 4).

dRPS Method. Most students found the dRPS method and its implementation helpful for understanding the text ($n = 9$), with some specifically naming the questions as useful guidance ($n = 2$). A few students ($n = 3$) described it as "alright" but were taken aback by the length of the text and/or the time required. Two participants reported feeling stressed or pressured by having to read within a fixed time window, given their reading difficulties. When asked about their preferred dRPS phase, responses varied, yet reflected a clear understanding of each phase (**LO2**).

Visual Reading Analytics. Based on both instructor observations and student feedback, we noted active engagement with the VRAI. Students were able to understand the visualization and describe their own actions during the first session, often relating their recollections to elements shown on screen (**LO3**). All respondents reported that the visualization accurately reflected their approach to the task, e.g. one student remarks: *"[...] I used the search function to look for the answers to the questions, finding the sections they could be found in, then scrolling to read those sections, stopping when the section ends, with varying reading times depending on how long I took to understand the text and craft my answer."* Another writes: *"Most of my top spots are figures, so I think I spent time to understand the figures and the explanation that follows the figure."* Notably, some students expressed a desire to view their partner's and the class's data in order to compare their approaches.

Reading Strategies. This comparison became possible when the instructor presented and discussed four reading strategies for the *Read and Answer* activity, identified using the VRAI. The first strategy, **Targeted Reading**, is characterized by large jumps across the text and longer reading periods in selected sections. In the User's Answer Sequence (UAS) (Fig. 3), saving events occurred in the same order as the questions were presented. This pattern suggests that readers used the browser's search function to locate the questions' key terms. This behavior was later confirmed by responses in the reading analytics session's survey. These students (6 of 15) generally required less time to complete the task, with idle periods and tab switches appearing toward the end of the activity. The second strategy, **Focused Reading**, is characterized by long streaks, suggesting that the reader progresses through the text linearly and thoroughly. Only one participant appeared to follow this strategy, first reading most of the text and only then beginning to answer the questions, albeit not in order. For this participant, the available time appeared to be insufficient, as some answers were first entered during the *Pair* phase. The third strategy, **Parallel Reading**, is characterized by simultaneous linear reading and answer writing. These students ($n = 5$) progressed through the text from top to bottom and answered questions as they encountered relevant information, occasionally jumping within the text and revising content. Finally, we also observed a **Mixed Approach**. The remaining three participants showed intertwined periods of targeted and parallel reading. Their answering order did not align with either the order of the questions or the linear structure of the text.

To examine the effect of the four observed strategies on reading comprehension scores, we conducted a Kruskal–Wallis test and a permutation test. Although the *parallel* strategy group had the highest mean score, no significant effects were found (all $p > 0.05$). The small and unbalanced sample, however, limits the statistical power of this analysis.

4.2. Instructor's Perspective, Experience and Observations

The method, the system, and each activity were introduced using slides accompanied by oral explanations outlining the activities, the tasks, and the provided visual support. During the *Read and Answer* activity, some students completed the task quickly and even asked the instructor whether they could do something else after finishing. Others required the full allotted time. During the *Discuss in Pairs* activity, students exchanged insights with one another and collaboratively refined their final answers. The specific strategies they employed (e.g., one partner answering first, alternating by question, or other approaches) could not be reliably ascertained and remain an open research question.

We may have underestimated the time required for the *Share with the Class* activity, as the instructor perceived time pressure. Nevertheless, the shared view displayed in the lab effectively structured the discussion and supported alignment of students' knowledge. As shown in Figure 2, the WB guided revisiting the questions and comparing the answers. The group columns in OV (O3 and O4) made it possible to assess whether students were generally in sync across the document and, through visual linking to the WB, whether answers to the current question originated from similar text locations. When an answer differed from expectations, the instructor could immediately identify where the student was in the text while writing it and discuss that passage with the class, either revealing a mismatch with the question or, in some cases, an additional facet beyond the original intent.

The VRAI in the second session was also introduced with prepared slides and oral explanations. From a visualization perspective, the Sequence View (Fig. 3, SV) initially presents a challenge due to its combination of spatial and temporal encoding along the vertical axis and its non-linear, event-based horizontal axis. However, students grasped the underlying concepts quickly—an observation later confirmed by questionnaire responses—allowing the analytics activities to begin after approximately 10 minutes.

5. Discussion

Supporting Disparate Readers. Part of the motivation for developing dRPS was the perception of declining reading practice in tertiary education, which is reflected in this case study: half of the respondents reported reading one hour or less per week. While this may not be unexpected in an Informatics program, it was lower than we anticipated. We observed that a 60-minute reading period was challenging for some participants, with several reporting fatigue before completing the task. Based on these observations, we recommend starting with shorter passages and session durations that better accommodate diverse reading skills and habits. While this may require a more flexible *Read and Answer* activity, it also highlights the benefits of the *Discuss in Pairs* activity, which enabled students to support one another and share knowledge, resulting in relatively homogeneous reading comprehension scores.

Personal Experience as Data and Motivation. The visual analysis session was met with greater apparent motivation from the class. Based on our observations, this may be attributed to three main factors: (1) the practical nature of the session, which aligned well with the students' regular program assignments; (2) their increased familiarity with the subject matter, resulting in greater confidence with the terms and concepts involved; and (3) the use of their own data as the subject of analysis. Students expressed strong interest in understanding the elements of the visualization, actively asking about visual marks, channels, and interactions during the introduction to the VRAI. In addition, they raised questions about data collection and processing, the design and development of the application, and the long-term research goals underlying the system, topics that typically do not arise during regular lessons.

In the session's workbook, students explored and interpreted their data accurately using the VRAI, and proposed potential improvements or additions, including suggestions for appropriate visual encodings they would like to see. These expressions of interest and motivation raise the question of how such engagement might be fostered for other types of assignments. While the prospect of using the VRAI could serve as an incentive for reading activities, we caution against placing too strong a focus on interaction data during the reading itself. Doing so may increase participants' awareness of being observed and alter natural reading behavior, potentially hindering intrinsic motivation for engaging with the text. In addition to content-focused or conceptual questions, future iterations could encourage readers to relate the material to personal experiences or concrete use cases, thereby providing additional incentives when integrating academic reading into coursework.

Visual Analysis of Strategies. The VRAI introduces a novel approach to visualizing reading behavior by representing sequences of interaction events rather than time series of screen positions, as commonly seen in prior work. Using intensity to encode dwelling time allows for rapid recognition of text passages that received greater attention by the user and the group, while the streaks and annotation markers portray the reader's journey through the text. These streaks revealed linear reading and searching patterns as described in the literature, yet the simultaneous visualization of writing events and locations uncovered detailed strategies for solving the given task. Integrating reading and writing components in one application allowed not only for a seamless combination of tasks, but also comprehensive and synchronized data collection and its visualization along the reading session through the Overview, and in depth later in the analysis session through the VRAI.

The different reading strategies did not significantly affect reading comprehension scores; however, we observed a relationship with students' preferred activities in dRPS. All five students who preferred the discussion-based activities exhibited a *targeted reading* pattern, whereas the four students who preferred the *Read and Answer* activity showed parallel or linear reading behavior. These observations suggest that dRPS not only engages students in discussion around the material, but also supports diverse modes of engagement that align with different learner preferences.

Limitations and Future Work. According to Sedlmair et al.'s design study framework [SMM12], our work represents an initial iteration of a collaborative effort between education and Information Visualization researchers to address current challenges in academic reading comprehension. Although limited by the small number of participants and the use of a single text, the case study provides valuable early in the wild insights into the usability of the approach. Future iterations will be conducted across multiple sessions with different texts and instructional settings; for example, assigning the *Read* phase as homework could better accommodate individual reading speeds and abilities. Repeated application of the method, alongside multidimensional comprehension assessments [MMOM07], will enable analysis of evolving reading behaviors and provide more robust evidence regarding the effectiveness of the approach. As a further step, we aim to use dRPS in other academic communities to gather additional perspectives on reading behavior and to further evaluate the method, with the long-term goal of interdisciplinary comparison and validation. Its use in a Political Science seminar is already scheduled, where the stronger emphasis on academic reading in the humanities may reveal different reading patterns. Likewise, we can expect experiences with the VRAI to differ from those of trained Information Visualization students. Drawing on Plaisant's framework for visualization evaluation [Pla04], we recognize that validating the VRAI as a tool for a broader academic population requires a multi-method approach. Accordingly, future work will combine our ongoing field studies with controlled usability tests to address both task-completion metrics and domain-specific objectives. Finally, we aim to enhance the tool's utility by supporting real-time pedagogical decision-making instead of just retrospective analysis. By providing instructors with a live overview of users' engagement and comprehension bottlenecks, we plan to enable timely interventions, such as reallocating time or directing support to struggling groups, extending the visual analytics into an active instrument for adaptive teaching.

6. Conclusion

In this paper, we presented digital Read–Pair–Share, a web-based system that integrates structured reading activities with fine-grained visual analysis of reading and answering behavior. By visualizing reading as sequences of interaction rather than linear time-series events, the VRAI enables learners and instructors to reflect on reading strategies, engagement, and task progression. Through a case study in an Information Visualization course, we identified distinct reading strategies–targeted, focused, parallel, and mixed–employed by students during the *Read and Answer* activity. These strategies were associated with different preferences for learning activities, while not significantly affecting reading comprehension outcomes. Students actively engaged with both the text and the analytics, and were particularly motivated when exploring their own data. The dRPS system demonstrates how valuable reading and writing interaction data can be collected and analyzed in the wild without costly equipment, and how such data can be used in the classroom to support reflection on and learning of study strategies.

The VRAI contributes a novel visual representation for analyzing reading behavior based on scrolling sequences and text-based dwelling patterns. While such visual analytics tools may pose challenges for students outside informatics and design disciplines, they also offer an opportunity to introduce visualization concepts across fields, leveraging self-discovery and meta-cognitive reflection as motivating factors. To explore this potential more fully, we look forward to engaging with experts in academic reading to better understand and support the knowledge work strategies of today's higher-education students.

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