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Evaluation for Analyzing Self-Regulated Learning Processes using Trace-Data of Learning Log from Digital Textbooks

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Abstract: SRL (Self-Regulated Learning) is currently the subject of much research. In our previous studies, there are systems (STELLA) that can accumulate learners' learning history in digital textbooks and systems (SELFY) that support SRL by providing feedback to learners on their learning history collected by STELLA. However, since the evaluation method is in the form of a questionnaire, the evaluation is inherently subjective and often lacks real-time behavioral insight. Furthermore, existing methods are frequently domain-dependent, making it difficult to generalize findings across different subjects. We had previously proposed this based on trace data from digital textbooks. We compare high and low groups of SRL scores measured by the SRL-SRS scale revealed that the high group tended to exhibit behavioral cycles consistent with theoretical SRL characteristics. These findings suggest the proposed method may be effective for evaluating SRL based on trace data.

Keywords: Self-regulated learning, digital textbook, trace-data

1. Introduction and Related work

In recent years, with the spread of LMS (Learning Management System), it has become possible to collect and store the trace-data of learners and analyze the data. Learning Analytics is one way to analyze this. This made it easier to treat and analyze the learner's detailed learning behavior as a history. Self-regulated learning (SRL) is a process where learners set goals for their learning and then monitor, regulate, and control their cognition, motivation, and behavior, guided and constrained by a plan (Zimmerman, 1989). This is why academic researchers are increasingly looking for ways to measure student SRL behavior and, as a result, provide more effective support to help students engage in more productive SRL (Yizhou, 2022). The method to measure SRL processes is as follows: including self-reported questionnaires, think aloud protocols, and trace-data. Trace-data of learners can be treated as a history of the learner's behavior when using the digital textbook. Ikenna et al (2024) researched how trace-data influence the extracted processes and analysis. However, their study is domain-dependent on performing a specific task (writing an essay). Therefore, action labels and SRL processes are also task-related indicators. Their study did not cover any task or domain except writing essays. Similarly, Ogata et al (2025) utilized BookRoll-based log data and learning analytics dashboards (LADs) to enhance SRL in blended learning environments. However, their analysis focused primarily on coarse-grained metrics such as annotation frequency and reading time, without applying detailed, semantically-rich action labels grounded in SRL theory. In contrast, our study introduces domain-independent and theoretically-informed action labels to capture fine-grained SRL behavior across different subjects and learning contexts. These labels are designed to map directly onto phases of SRL such as planning, performance, and reflection. We proposed STELLA (Storing and Treating the Experience of Learning for Learning Analytics), a system for collecting learning history for digital textbooks. There is also a learner-s' SRL support system called SELFY (SElf-regulated Learning FacilitY) that visualizes STELLA's learning history and provides some feedback to learners. Yamasaki et al (2025) focus on digital textbooks and evaluate whether autonomous

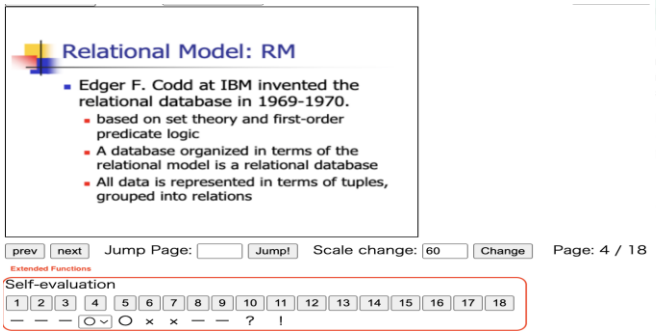
learning occurs based on learner trace data, we proposed action labels independent of specific learning content. However, it was merely a proposal, and no analysis had been conducted. This paper evaluates our proposed method. As an evaluation method, students were divided into those with high and low self-regulated learning indicators based on a concurrently administered questionnaire. We then compared whether there was a correlation between the subjective evaluations from the questionnaire and the objective evaluations from the action labels.

Table 1: Action Labels based Trace-Data (Yamasaki et al 2025)

Action Labels	Action descriptions
GENELRAL_INSTRUCTION	Learners read or re-read general instruction and learning goals
RUBRIC	Learners read or re-read the rubric
RELEVANT_READING	Learners read and learn learning content for the first time
RELEVANT_RE-READING	Learners re-read and review for learning content which they have read before
IRRELEVANT_READING	Learners read the pages which are not relevant to the learning content
IRRELEVANT_RE-READING	Learners re-read the pages which are not relevant to the learning content
NAVIGATION	Learners navigate through pages or scroll at catalogue zone
COPY_PASTE	Learners copy and paste some content from reading materials into the notes
NOTE_EDITING	Learners create, delete, edit or label the notes
NOTE_READING	Learners click to open and read or re-read the notes
HIGHLIGHT_EDITING	Learners create, delete or edit the highlights
HIGHLIGHT_READING	Learners click to open and read or re-read the highlights
HIGHLIGHT_LABELLING	Learners create tags for highlights
SEARCH_CONTENT	Learners use the search tool on the left to search for learning contents
SEARCH_HIGHLIGHT_NOTE	Learners use the search tool search notes or highlights
SRL_RELEVANT_SELF-EVALUATION	Learners click to open and read or re-read the self-evaluation
SRL_IRRELEVANT_SELF-EVALUATION	Learners click to open and read or re-read the irrelevant self-evaluation
SRL_RELEVANT_EVALUATION	Learners click to open and read or re-read the evaluation
SRL_IRRELEVANT_EVALUATION	Learners click to open and read or re-read the irrelevant evaluation

2. STELLA + SELFY

STELLA



SELFY

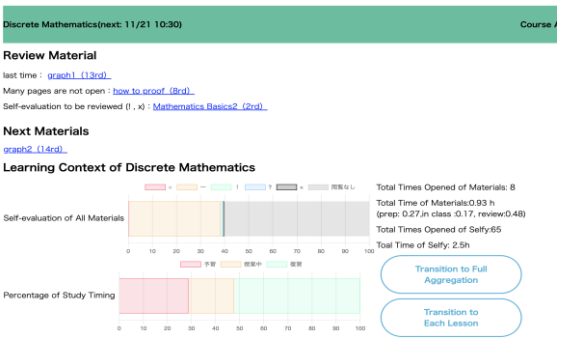


Figure 1: Interface of STELLA and SELFY

STELLA features include PDF viewing, writing on pages, sticky notes, and self-assessment, primarily supporting learning tasks. STELLA functions primarily as a viewer and viewing history can be collected in detail. However, High Cognition (HC: Elaborate by connecting content-related comments and concepts during reading or writing; Organizing of content by creating an overview; write down information point by in notes window; summarizing; adding information generated by oneself; and editing information by rephrasing or integrating information with prior knowledge.) activities such as note-taking are not considered STELLA. Therefore, we added a function to organize them in a note's function and a function to copy and paste keywords from a PDF document into the note's function and keep them as history, and to assign labels from HC activities. SELFY provides learners with a visualization of their learning history collected in STELLA to support SRL. Our prior research suggested that learners' use of SELFY increased motivation and supported SRL.

3. Evaluation

We use SRL-SRS (Tynke, 2012) as a self-regulated learning indicator. The SRL-SRS is a scale developed based on SRL theory, designed to comprehensively measure the entire

sequence of SRL processes: how learners set goals, execute and adjust their learning, and evaluate and reflect on the results during the learning process. We examine the validity of SRL assessment using learning logs by investigating the relationship between questionnaire and action label evaluations and the tendencies of high and low groups in SRL indicators. As a specific verification method, we will have students enrolled in Educational Informatics use STELLA and SELFY and conduct a questionnaire survey on SRL. Based on the questionnaire, we will classify participants into high and low SRL groups and compare their respective learning logs. We use Fuzzy Miner, a process mining technique, for analyzing trace data. Fuzzy Miner abstracts the actual flow of actions from event logs (such as viewing logs and operation logs), enabling visualization and analysis. This enables visualization of learners' learning behaviors and characteristic patterns, allowing for detailed comparison of the behavioral content between high and low groups of SRL indicators based on survey results.

The subjects for the evaluation are third-year students enrolled at our university. Also, out of the 52 students enrolled in Educational Information Engineering, 23 responded to the questionnaire on self-regulated learning was administered. We collected logs from all using STELLA and SELFY for all 16 lectures (two months' worth). We classified students into those with high and low self-regulated learning indicators. Subsequently, we conducted a comparative analysis of the learning records for both groups.

4. Results and Discussion

The questionnaire contained a mix of 4-point and 5-point Likert scales, presenting issues where score distributions and variances differed between items and between subscales. Therefore, standardization was performed by converting each subscale score into a Z-scores. Based on the standardized Z-scores, participants were further categorized into an SRL group (n = 9) and a non-SRL group (n = 14). Specifically, participants were divided into a high-score group (Z > 0) and a low-score group (Z < 0). Mean values were calculated for each category, and the comparative results are presented in Figure 2.

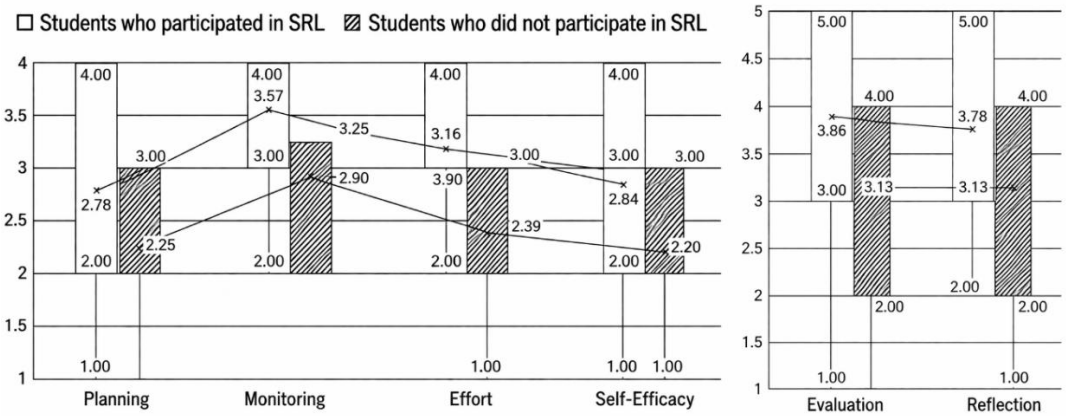


Figure 2 Comparison of questionnaire results based on SRL-SRS

The SRL group exhibited higher scores across all categories. These results suggest that SRL is associated not only with cognitive aspects such as planning and monitoring but also with a strong relationship to learners' motivational orientation toward learning. Next, trace data from both the SRL and non-SRL groups were visualized using Fuzzy Miner (Figure 3).

Students in the SRL group tended to engage in learning through a cyclical process consisting of planning, execution (initial reading and re-reading), and self-evaluation, mediated by SELFY. In contrast, although transitions among planning, execution (initial reading), and self-evaluation were observed in the non-SRL group, no relationship with execution (re-reading) was identified, indicating that the learning processes tended to be more independent and less cyclic. However, this study has several limitations. In this experiment, we assigned action labels on a simple one-to-one basis, and the labeling method is still under consideration. In addition, this experiment was conducted in only one course, and therefore the sample size depended on the number of enrolled students. Not all students used the system, since it was not possible to require participation from all students due to research ethics considerations.

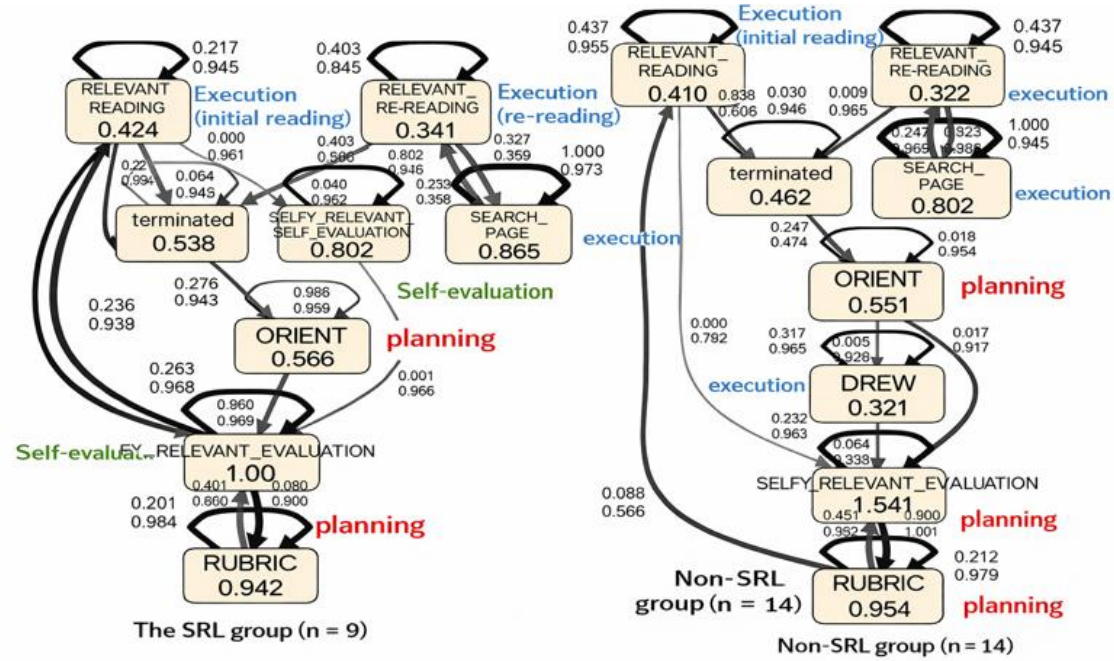


Figure 3 Comparison of the SRL and non-SRL groups using Fuzzy Miner

5. Conclusion

This study verified the validity of the proposed analytical method. As part of the evaluation, we conducted an analysis based on questionnaires and visualized trace data using Fuzzy Miner to verify their correlation. The results suggest that the content-independent action labels proposed in this study for digital textbooks have the potential to evaluate learners' learning processes based on trace data. The results suggest that the action labels proposed in this study for digital textbooks, which are independent of learning content, hold potential for evaluating learners' learning processes from trace data. Future work will apply the proposed method to other courses and examine its effectiveness using a larger dataset.

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