JOIV : Int. J. Inform. Visualization, 9(3) - May 2025 1277-1282

INTERNATIONAL JOURNAL ON INFORMATICS VISUALIZATION

journal homepage : www.joiv.org/index.php/joiv

Exploring Strategies to Improve Digital Literacy Assessment Using Log Data Analysis

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***Abstract*—The purpose of this study is to propose improvement strategies for national digital literacy assessment tools based on the analysis of log data from the first performance-based evaluation conducted in 2023. To achieve this, we analyzed log data from a total of 32,804 primary and middle school students. For the analysis, eleven types of data, including problem domain, problem type, and total number of logs, were utilized for the analysis. Students were assessed on their digital literacy level through 26 items, with primary school students given 40 minutes and middle school students given 45 minutes for the assessment. The key findings indicate that primary school learners generated 1.5 million log entries spanning four modules, whereas middle school participants produced 3.2 million log data points. Both primary and middle school students showed an increasing tendency to skip questions without answering as they progressed through the latter part of the assessment. Additionally, the tendency to skip questions increased when the minimum number of clicks required to solve a problem increased or when the problem length was longer. In the future, it is necessary to clearly define which parts of the log should be recorded in advance so that logs are consistently recorded. To accurately perform analyses such as student response type and pattern analysis, and error type analysis, a design for appropriate log data recording should be prioritized. This will enhance the reliability and validity of the tools and serve as a basis for future digital literacy policy development.**

***Keywords*—National-level measurement; digital literacy; log analysis; annotation analysis.**

Manuscript received 19 Sep. 2024; revised 23 Dec. 2024; accepted 21 Mar. 2025. Date of publication 31 May 2025.

I. INTRODUCTION

Due to COVID-19, the world suddenly experienced remote education on a global scale [1], [2], [3], [4], [5], [6], [7], [8]. In the early stages of transitioning to remote education, both teachers and students faced difficulties due to a lack of digital literacy [9], [10]. It was found that students with higher digital literacy skills showed more positive effects in online classes [11], [12]. In November 2022, OpenAI [13] launched the ChatGPT service. While it has the advantage of being conveniently usable through a conversational interface, since its emergence, side effects have also been revealed, such as students using it in unauthorized ways for exams and assignments [14], and AI-giarism[15] has come to the forefront. Amidst these trends, in Korea, educational programs have been developed to provide a balanced view of AI and understand its technological and social impacts [16], and research has also been conducted on the demand for artificial intelligence education [17].

The importance of digital literacy is being increasingly emphasized. According to previous studies, a quantitative correlation has been reported between AI ethics and digital literacy [18]. Additionally, it has been noted that online risks encountered in digital spaces can be mitigated by cultivating digital literacy [19]. Additionally, it has been reported that digital literacy has a positive effect on self-control [20]. This means that by acquiring digital literacy, one can not only use learning materials ethically and appropriately in an online-based learning environment but also expect high academic achievement when properly using self-control to complete learning.

As previously noted, digital literacy encompasses the skills to critically assess, securely use, and generate information, with its significance in education becoming increasingly pronounced [21]. Digital literacy is crucial for reaping the benefits in a digitalized society [22].

International studies, such as the International Computer and Information Literacy Study (ICILS) and the Program for International Student Assessment (PISA), measure digital literacy through computer-based assessments. Since 2007, the Korea Education and Research Information Service (KERIS), an agency affiliated with the Ministry of Education, has been conducting yearly assessments and analyses of digital literacy proficiency among Korean elementary and middle school students [23]. These efforts offer insights into how Korean students search for, comprehend, and utilize information in digital environments, as well as their problem-solving strategies.

KERIS began incorporating performance-based assessment into its digital literacy measurement items in 2023, shifting from primarily multiple-choice evaluations, and started recording log data [24]. The performance-based assessment aims to evaluate digital literacy at a more practical level by focusing on everyday problems that occur in schools, homes, and communities. The test items are structured as scenario-based modular problem sets. Nevertheless, given that the 2023 performance-based assessment was Korea's inaugural attempt, future iterations require refinements to enhance the test's reliability and practical value.

This study aims to investigate approaches for enhancing performance-based assessment instruments through a comprehensive examination of log data collected from roughly 30,000 students who took part in the 2023 national digital literacy evaluation. This is because online environments require significant efforts to understand learners [25]. By analyzing log data, we aim to identify students' behaviors when solving test items and propose how to improve the test and log recording for a more detailed examination of behavioral patterns. To achieve this objective, Chapter 2 examines key studies on digital literacy, while Chapter 3 outlines the approach used for analyzing log data.

II. Materials and Method

A. Background

Digital literacy can be measured through methods of utilizing digital devices [26], [27]. During the COVID-19 period, when remote learning was implemented, a gap was reported between students who had access to electronic devices and those who did not [28]. This implies a correlation between digital literacy and the possession of digital devices. In Korea, Kwak et al [29] reported that, despite differences across school levels, both teachers and students generally showed a high demand for education in digital device utilization. Furthermore, studies such as those analyzing how components of digital literacy were incorporated into the 'Computer and Information' curriculum in middle and high schools followed by an analysis of lesson examples[30], and research proposing implications for systematic education through analyzing the relationship between the implementation level of information and computing education in elementary and secondary schools and digital awareness/digital attitudes in PISA 2018[31], demonstrate the high interest in digital literacy within the Korean education sector.

The representative study related to national-level digital literacy assessment in Korea is the International Computer and Information Literacy Study (ICILS). Conducted every five years, ICILS [32] measures ICT competency and computational thinking skills of students and teachers worldwide, with the most recent study conducted in 2023. ICILS is comprised of two primary domains: Computer and Information Literacy (CIL), which evaluates proficiency in computer use and information handling, and Computational Thinking (CT), which assesses capabilities in computational reasoning. The CT domain measures students' computing-based problem-solving skills, including programming abilities, and evaluates not only the creation of specific algorithms or codes but also considers 'accuracy' and 'efficiency' aspects based on the overall response data [32]. Although ICILS predominantly employs performance-based evaluation methods, it has not yet published analyses of student activity logs. Nevertheless, it is understood that qualitative data, including students' reflections and responses requiring diverse answer formats, undergo direct analysis and assessment by subject matter experts.

Another platform is the Electronic Assessment Platform (EAP) [33], which analyzes log data in addition to analyzing test results of learners to design appropriate tests and provide feedback. The EAP collects and analyzes comprehensive data on test takers' scores, difficulty and discrimination indices, response times, number of visits to questions, and number of answer changes to identify items that need review. The study aims to gather data on learners' behavioral trends and provide educators with valuable insights. An illustrative finding revealed that problems of higher difficulty attracted more visits and required extended time for final answer selection. By analyzing skipped questions, changes in answers, time spent reviewing questions, and submitted answers, individual learner behavior patterns can be identified.

These investigations predominantly utilize Educational Data Mining (EDM) methodologies within the educational domain. Data mining, a technique employed to enhance understanding of learner-learning management system interactions, is extensively applied in online learning environments [34]. For example, research has been conducted to predict academic achievement by identifying students at risk of dropping out, analyzing learners' log data, or providing appropriate feedback [35]. These studies primarily utilize two categories of data: conventional academic metrics, such as prior semester grades, prerequisite course performance, and initial exam results, alongside engagement indicators, including course and material access frequency, time spent on assignments, quiz and homework scores, and participation in discussions.

B. Subject and Data

The analysis subjects and data were surveyed separately for elementary and middle school students. First, the 2023 digital literacy assessment for elementary school students was administered to grades 4 through 6, involving a total of 15,278 participants. The allocated test duration was 40 minutes, yet the actual average completion time was 19 minutes and 37 seconds. The assessment outcomes for elementary school students revealed the following distribution: 2,068 students (13.5%) at the lowest level 1, 3,750 students (24.5%) at level 2, 4,755 students (31.1%) at level 3, and 4,705 students (30.8%) at the highest level 4.

For middle school students, the assessment involved a total of 17,526 participants. Although the test was allocated 45 minutes, the actual average completion time was 21 minutes and 27 seconds. The middle school assessment results were distributed as follows: 2,718 students (15.5%) at the lowest level 1, 3,963 students (22.6%) at level 2, 6,966 students (39.7%) at level 3, and 3,879 students (22.1%) at the highest level 4. The middle school assessment results were distributed as follows: 2,718 students (15.5%) at the lowest level 1, 3,963 students (22.6%) at level 2, 6,966 students (39.7%) at level 3, and 3,879 students (22.1%) at the highest level 4. This research performs a comprehensive analysis of the log data generated by 15,278 elementary school students and 17,526 middle school students during their assessment period.

C. *Types of Data*

This study analyzes the log data left by students during the examination process, rather than the national-level digital literacy assessment result data, as shown in Table 1. The log data encompasses a range of variables, including problem type, problem domain, correct answer rate, number of student clicks, and frequency of non-responses.

TABLE I
TYPES OF ANNOTATION DATA

Types	Description
Question Type	1. Multiple Choice / 2. Functional / 3. Creative / 4. Algorithmic
Question Domain	Name of digital literacy Main domain
Subdomain	Name of digital literacy Sub-domain
Correct Answer Rate	Number of students who answered correctly (correct answer rate)
Total Number of Logs	Number of logs (clicks) generated by students for each question
Number of non-responses	Number of students who did not respond at all
Number of Clicks to Reach Correct Answer	Minimum number of clicks needed to reach the correct answer
Estimated Time to Solve the Question	Estimated question-solving time by researchers/teachers
Actual Time to Solve the Question(median)	The time students took to respond
Estimated Time to Solve the Module	Estimated module-solving time by researchers/teachers
Actual Time to Solve the Module	The time students took to respond

D. *Analysis Process*

The analysis of performance-based digital literacy annotation data concentrates on examining both the log data captured during the problem-solving process and the submitted correct answer data for elementary and middle school students. To facilitate analysis, data initially recorded in string format is converted into a list format. The data's characteristics are then examined based on this transformed structure. The analysis primarily employs descriptive statistics, including frequency and median calculations. This process is conducted using Python 3.10.4 in the Jupyter Notebook 6.5.4 environment, with Pandas 2.1.4 as the main data manipulation tool.

The analysis process begins with data preprocessing. In this initial stage, the log data, which includes all student activities leading to the correct answer along with corresponding timestamps, is prepared for further examination. Consequently, the complete log dataset is transformed into a Python list format. Subsequently, the student activity data and corresponding timestamp information are merged into a single Pandas DataFrame for further analysis. Second, the processed log data is analyzed to identify the mode, determining the items most frequently chosen by students as answers. Furthermore, an analysis is conducted on the frequency of non-responses, which involves counting the number of students who skipped questions without taking any action. This process determines the quantity of students who failed to submit answers for each question. Thirdly, due to the substantial disparity in response times between the fastest and slowest students, the problem-solving duration for each question was analyzed using the median rather than the mean. Fourthly, the analysis included an examination of the minimum number of clicks required to input the correct answer for each question, as determined by the researchers during the analysis process. Additionally, the total number of logs was computed by summing all clicks made by the students. Fifthly, in identifying outlier data, items with notably fewer or more logs compared to the total required clicks were flagged as outliers. These outlier questions and their corresponding annotation data were then subjected to further detailed analysis.

E. *Item Type Overview*

Multiple-choice questions typically present a problem along with several options (or choices) and ask the respondent to select the correct answer. For elementary school questions, they were structured with only one correct answer, while for middle school, some questions included selecting two correct answers. In the 2023 assessment, logs were not separately recorded for multiple-choice questions.

Functional items are a type that includes the process of students interacting with the user interface (UI) while solving problems, allowing them to solve problems by entering appropriate text for given questions or using functions such as clicking, dragging & dropping. The logs for functional items are generated by assigning numbers to each icon or menu in advance, and sequentially recording these pre-assigned numbers when actions occur. Time is recorded for each log, allowing for the identification of which menu was clicked, when, and in what order.

The logs for constructed-response type items are generated similarly to functional items, where buttons or menus that students can select are pre-assigned numbers internally within the system, recording the numerical form of the selections made by students. Like functional items, constructed-response type items also have time recorded for each log, allowing for the identification of which menu was clicked, when, and in what order.

Algorithmic-type items are questions that require solving given problem situations using computational thinking through algorithms or block programming languages. The logs for algorithmic problems operate in the same way as functional/constructed-response items, with each block and menu pre-assigned numbers, and these numbers are recorded when selected.

III. RESULTS AND DISCUSSION

This chapter covers the results of log data analysis for Module 1 and Module 2 of elementary school, and Module 1 and Module 4 of middle school.

TABLE II
SAMPLE RESULTS OF MODULE1 OF ELEMENTARY SCHOOL

#	QT	QD	SD	CAR	#N	#C	ETSQ	AT	TL
1	Function	Digital Safety and Health	Digital Safety	9,765 (63.9%)	2 (0.01%	1	30s	43s	41,765
2	Function	Digital Safety and Health	Digital Safety	10,792 (70.6%)	5 (0.03%)	1	30s	10s	17,183
3	Functional	Digital Safety and Health	Digital Safety	13,274 (86.9%)	7 (0.04%)	2	60s	19s	84,245
4	Multiple Choice	Digital Safety and Health	Digital Health	13,199 (86.4%)	0 (0%)	1	120s	24s	0
Total Number of Logs of Module						143,193			
Estimated Time to Solve the Module						4m			
Actual Time to Solve the Module (median)						1m 50s			

*QT : Question Type, QD : Question Domain, SD : Subdomain, CAR : Correct Answer Rate, #N : Number of Non-responses, #C: Number of Clicks to Reach Correct Answer, ETSQ : Estimated Time to Solve the Question, AT : Actual time to Solve the Question(median), TL: Total Number of Logs

As shown in Table 2, for Module 1, which corresponds to the first question, it can be confirmed that most students responded. However, it also appears that some students' logs were recorded but they did not submit the correct answers. Specifically, for question 1-1 of Module 1, it is estimated that there were more clicks as a considerable number of logs were generated while students explored the first question. Regarding questions 1-3, the elevated log count is likely attributable to students interacting with various on-screen icons during problem-solving. For questions 1-4, a multiple-choice item, it was verified that the 2023 digital literacy assessment recorded no additional logs beyond the correct answer data for such questions.

TABLE III
SAMPLE RESULTS OF MODULE2 OF ELEMENTARY SCHOOL

#	QT	QD	SD	CAR	#N	#C	ETSQ	AT	TL
1	Multiple Choice	Digital Tools	Understanding digital tools	12,778 (83.6%)	0 (0%)	1	120s	54s	0
2	Functional	Digital Communication and Collaboration.	Digital Communications	13,373 (87.5%)	49 (0.3%)	1	60s	26s	27,292
3	Multiple Choice	Digital Information Data	Information Data Analysis and Evaluation	10,048 (65.8%)	0 (0%)	1	120s	44s	0
4	Algorithmic	Digital Resource Production	Program production through computational thinking	6,857 (44.9%)	0 (0%)	6	120s	56s	39,407
5	Algorithmic	Digital Resource Production	Program production through computational thinking	3,895 (25.5%)	1, 216 (6.9%)	8	180s	132s	519,707
6	Multiple Choice	Digital Safety and Health	Digital Health	9,515 (62.3%)	0 (0%)	1	120s	42s	0
Total Number of Logs of Module						586,406			
Estimated Time to Solve the Module						12m			
Actual Time to Solve the Module (median)						6m 37s			

Table 3 shows that for the fourth question of the second module, detailed log data was unavailable, so the analysis was performed based on the submitted correct answer data. It was a sequential type of algorithmic authoring problems, where students had to select three appropriate items from a drop-down list. However, we can see that the number of responses gradually decreased, and more students moved on to the next question midway. Specifically, 13,893 students selected the first item, 13,158 selected the second item, and 12,356 selected the last item. For the fifth question, which was an algorithmic authoring problem, it was judged that many logs were generated (519,707 cases) during the exploration of where the appropriate blocks were to solve the given problem.

TABLE IV
SAMPLE RESULTS OF MODULE1 OF MIDDLE SCHOOL

#	QT	QD	SD	CAR	#N	#C	ETSQ	AT	TL
1	Function	Digital Communication and Collaboration	Digital Collaboration	9,765 (63.9%)	2 (0.01%)	1	30s	43s	41,765
2	Function	Digital Tools	Utilization of Digital Tools	4,879 (27.8%)	7 (0.04%)	2	30s	30s	83,280
3	Multiple Choice	Digital Communication and Collaboration	Digital Communication	13,893 (79.3%)	122 (0.7%)	1	30s	35s	0
4	Functional	Digital Information Data	Information and Data Search and Collection	15,391 (87.8%)	17 (0.1%)	4	30s	62s	359,473
…Omission…									
Total Number of Logs of Module						853,877			
Estimated Time to Solve the Module						6m			
Actual Time to Solve the Module (median)						6m 4s			

As Table 4 illustrates, question 1 of Module 1, the initial question in the middle school section, recorded relatively few logs despite being the first question. This is likely due to the implementation method, which only records logs for specific elements, such as 'spreadsheet', 'presentation', 'video conference', and 'media player' buttons. For question 1-4, which involves modifying search results from a portal site to match the given scenario, it appears that numerous logs were recorded due to the high number of clicks required for the correct answer. Regarding questions 1-6, although it necessitates fewer clicks than questions 1-4, fewer logs were recorded in comparison. This suggests that the quantity of logs generated is determined not solely by the minimum number of clicks required but also by other factors, such as the intuitiveness of the problem and the nature of the buttons involved (specifically, whether they have the capability to record logs).

TABLE V
SAMPLE RESULTS OF MODULE4 OF MIDDLE SCHOOL

#	QT	QD	SD	CAR	#N	#C	ETSQ	AT	TL
1	Multiple Choice	Digital Information Data	Information Data Analysis and Evaluation	9,742 (55.6%)	1,365 (7.8%)	1	120s	44s	0
2	Algorithmic	Digital Resource Production	Program production through computational thinking	3,264 (18.6%)	1,299 (7.4%)	8	120s	43s	119,431
3	Algorithmic	Digital Resource Production	Program production through computational thinking	5,421 (30.9%)	1,306 (7.5%)	5	120s	55s	293,861
4	Algorithmic	Digital Resource Production	Program production through computational thinking	3,121 (17.8%)	1,337 (7.6%)	5	360s	50s	306,113
Total Number of Logs of Module						719,405			
Estimated Time to Solve the Module						12m			
Actual Time to Solve the Module (median)						3m 37s			

As shown in Table 5, the number of non-respondents in Module 4 was higher than in Module 3. In other words, we can see that the number of non-respondents continued to increase over time. In algorithmic-type questions, such as questions 2 and 4, we can see that numerous logs were generated. However, upon examining the details, it can be confirmed that the majority of logs were generated by clicking on the menu names of block sets presented on the left side of the block programming environment. Question 2 is a sequential programming problem where students must select one item at a time in order from four dropdown lists to match the given problem situation. Unlike other functional or constructed-response type questions, it is estimated that fewer logs were generated compared to the number of clicks due to the lack of buttons or icons to explore. The number of students who selected the first item was 14,686, the second item 14,155, the third item 13,875, and the fourth item 13,658, showing that, like in the elementary school questions, the number of students not selecting items increased towards the end. Questions 3 and 4 are items that require students to perform problem-solving tasks presented in block programming. Although these can be completed with fewer clicks compared to question 2, due to the nature of problems requiring programming, it was confirmed that many logs remained as some students made multiple attempts instead of completing the solution at once, or in some cases, students clicked on the left menu to check the block packages rather than solving the problem.

Drawing from the examination of log data derived from performance-based questions in the 2023 national-level student digital literacy assessment, the key findings and their implications can be summarized as follows:

Firstly, the examination of log data from performance-based questions unveils diverse student patterns that are challenging to identify through conventional descriptive and inferential statistical methods used for level analysis. For instance, in traditional statistics, the pattern of non-responding students typically appears as a single category. However, log data analysis enables a more comprehensive classification of non-responding students into two distinct types. The first type skips to the subsequent question without examining the problem, while the second type engages in various activities but fails to provide the correct answer. This approach enables a more nuanced understanding of students' problem-solving processes, distinguishing between those who lack interest or seriousness in digital literacy problems and those who thoroughly explore the content but fail to provide the answer due to oversight. This information can serve as a fundamental basis for giving feedback on digital literacy education, thereby complementing the assessment outcomes. Moreover, by analyzing students' click order and response time for each question, problem-solving patterns can be investigated, potentially offering an alternative method for analyzing future achievement levels.

Secondly, the analysis of annotation data can offer crucial foundational insights for enhancing assessment tools and systems. It was observed that the number of students who did not respond increased when the minimum number of clicks needed for the correct answer was high or when the problem was lengthy. Additionally, non-responses consistently rose as the test progressed. This highlights the necessity of devising strategies to help students stay focused on questions and suggests that the current method of delivering questions sequentially may need to be reevaluated.

IV. CONCLUSION

Based on the above, we propose the following recommendations for improving national-level digital literacy assessment tools: Firstly, for multiple-choice questions, the current system only records the right answer and response time, but future systems should also record changes in selected options. This will allow tracking of initially chosen options and later changes, enabling analysis of option attractiveness and student response patterns that are difficult to assess using existing methods.

Secondly, for functional, algorithmic, and constructed-response problems, it is necessary to establish a clear and consistent standard for which buttons will produce log records. Currently, only certain buttons in a problem are functional, and only some of these generate logs. The number of logs varies based on the problem's complexity and difficulty, as well as the minimum number of clicks needed for the correct answer. To facilitate objective log analysis, questions should be structured to produce logs consistently across problems with similar formats (such as presentation tasks or programming tasks).

ACKNOWLEDGMENT

This study encompasses a KERIS report (RM 2024-8), which was conducted as part of a public policy research project. Hansung University financially supported this research for independent academic purposes.

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