Study of Evaluation Operation Log Analysis Using 2^3- ERC on Matsue National College of Technology

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Abstract

In response to the demand for educational proposals that address advancements in science and technology in Japanese school education, cross-disciplinary education and STEAM education are receiving increased attention. Given this context, a new unit called "Mathematics and Human Activities" was introduced. However, the need for innovative mathematics teaching materials is necessary. We develop the 2^3 Electric Rubik's Cube (2^3-ERC) with two LEDs for each cube edge for easy tractable operation logging data. By utilizing the operation log data as feedback, we evaluated log data analysis through the experiment on Matsue National Institute of Technology's students. The results from the operation log shows the level of understanding of 2^3-ERC from the number of operations and consideration time.

Keywords: Mathematical education, Rubik's Cube, Unfolded, 2^3-ERC, Logging analysis,IDDFS

1. Introduction

In recent years, the demand for educational methods capable of addressing rapidly advancing science and technology has grown significantly in educational settings. As a result, STEAM (Engineering, Technology, Engineering, Arts, Mathematics) education has garnered considerable attention [1],[2],[3],[4],[5]. In Japan's high school mathematics curriculum, a new unit, Mathematics and Human Activities, has been added [6]. This unit features sections such as Properties of Integers, Properties of Coordinates, and Mathematics in Games and Puzzles.

Against this backdrop, we focused on the widely recognized Rubik's Cube and developed the 2^3-ERC, with each face consisting of 2×2 blocks. The developed 2^3-ERC can be connected to a PC via serial communication to collect operational data. However, there has been insufficient discussion regarding standard methods for analyzing the data obtained from the 2^3-ERC. Thus, the development of methods for evaluating learners' characteristics is required. In this study, we propose a method for analyzing data collected using the 2^3-ERC through the IDDFS (Iterative Deepening Depth First Search) algorithm. IDDFS combines the advantages of depth-first search and breadth-first search, offering high memory efficiency and the ability to explore solutions effectively while minimizing computational overhead. Specifically, IDDFS progressively relaxes the depth limit during its search, making it an effective method for solving Rubik's Cubes, as it guarantees a solution and produces the shortest path to the goal.

This paper presents the results of an experiment conducted with students from Matsue National College of Technology using the 2^3-ERC. The operational logs obtained from the experiment were analyzed using IDDFS, and the findings are discussed herein.

2. 2^3- ERC teaching aid

2.1. About 2^3-ERC

In this study, we propose a new evaluation method for the 2^3- ERC.Fig.1 shows the conceptual diagram of this tool. The 2^3- ERC is equipped with 24 LEDs and 48 operational buttons, along with a function to record the learner's operational data via serial communication with a computer. Fig.2 presents the developed 2^3- ERC. As shown in Fig.2, each face of the tool is embedded with RGB full-color LEDs, and the LED arrangement pattern changes in a manner similar to the rotational movement of a Rubik's Cube when the operational buttons are pressed. By interacting with this tool, learners are expected to develop their spatial and pattern recognition abilities, as well as logical thinking skills.

2.2. *Mathematical models*

As shown in Fig.3, each face of the 2^3- ERC is assigned a face identification index from A to F, and the four RGB full-color LEDs on each face are assigned indices from 1 to 4. For example, on face A, the top-left LED is designated as A_1, and the bottom-right LED as A_4. To handle the color information of these LEDs, we define a vector $\boldsymbol{q_n}$, as shown in Eq. (1), which contains 24 elements. The color information represented in $\boldsymbol{q_n}$ is treated as the index of a color palette corresponding to each color.

$$\boldsymbol{q_n} = (A_1, A_2, A_3, A_4, \cdots, F_1, F_2, F_3, F_4) \in \mathbb{R}^{24} \tag{1}$$

Next, the rotation rule for rotating $\boldsymbol{q_n}$ is given by Eq. (2). Here, Eq. (2) represents a permutation matrix.

$$\boldsymbol{T_X}, \boldsymbol{T_Y}, \boldsymbol{T_Z}, \boldsymbol{T_{X^{-1}}}, \boldsymbol{T_{Y^{-1}}}, \boldsymbol{T_{Z^{-1}}} \in \mathbb{R}^{24\times 24} \tag{2}$$

Here, using a natural number p, Eq. (2) possesses the following fundamental property, as shown in Eq. (3).

$$\begin{aligned} &\boldsymbol{T}_*^{4p} = \boldsymbol{T}_{*^{-1}}^{4p} = \boldsymbol{E}, \quad &\boldsymbol{T}_*^{4p+1} = \boldsymbol{T}_{*^{-1}}^{4p+3} \\ &\boldsymbol{T}_*^{4p+2} = \boldsymbol{T}_{*^{-1}}^{4p+2}, \quad &\boldsymbol{T}_*^{4p+3} = \boldsymbol{T}_{*^{-1}}^{4p+1} \end{aligned} \tag{3}$$

The rotation rules for the 2^3- ERC consist of three types of forward rotations $\boldsymbol{T_X}, \boldsymbol{T_Y}, \boldsymbol{T_Z}$ and their corresponding reverse rotations $\boldsymbol{T_{X^{-1}}}, \boldsymbol{T_{Y^{-1}}}, \boldsymbol{T_{Z^{-1}}}$, for a total of six types. These six types fully represent the motion of the 2^3- ERC. Among these, two rotations are selected to form valid combinations, as shown in Eq. (4). The valid combinations consist of 12 types, and including their reverse rotations, there are 24 types in total.

$$\begin{aligned} &\boldsymbol{T_X T_Y}, \boldsymbol{T_X T_Z}, \boldsymbol{T_X T_{Y^{-1}}}, \boldsymbol{T_X T_{Z^{-1}}} \\ &\boldsymbol{T_Y T_X}, \boldsymbol{T_Y T_Z}, \boldsymbol{T_Y T_{Z^{-1}}}, \boldsymbol{T_Y T_{X^{-1}}} \\ &\boldsymbol{T_Z T_X}, \boldsymbol{T_Z T_Y}, \boldsymbol{T_Z T_{X^{-1}}}, \boldsymbol{T_Z T_{Y^{-1}}} \end{aligned} \tag{4}$$

Hence, if the matrix that rotates each element of the 2^3- ERC is denoted as T, the permutation matrix T from the initial state $\boldsymbol{q_0}$ to $\boldsymbol{q_n}$ can be defined as Eq. (5).

$$\begin{aligned} &\boldsymbol{q_n} = \boldsymbol{T q_0} \in \mathbb{R}^{24} \\ &\boldsymbol{T} \in \prod_{\boldsymbol{i \in S}} \boldsymbol{X_i} \left(\boldsymbol{S} \subseteq \{\boldsymbol{T_X}, \boldsymbol{T_Y}, \boldsymbol{T_Z}, \boldsymbol{T_{X^{-1}}}, \boldsymbol{T_{Y^{-1}}}, \boldsymbol{T_{Z^{-1}}}\}\right) \end{aligned} \tag{5}$$

Here, $|\boldsymbol{S}| > 0$.

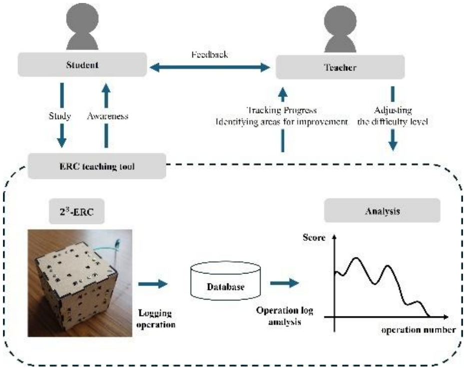

Fig.1 Overview of the 2^3- ERC teaching system.

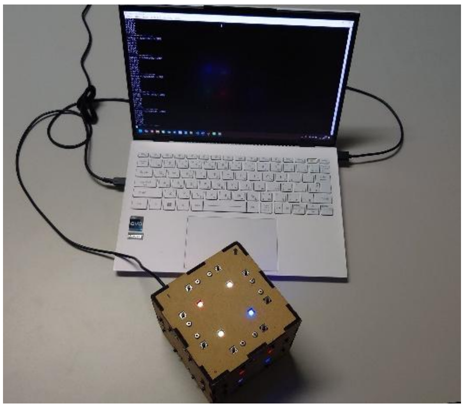

Fig.2 The 2^3- ERC teaching material

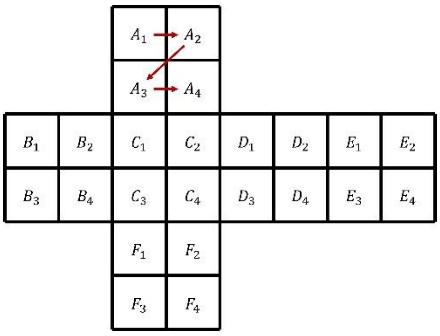

Fig.3 Surface Identification Indices Assigned from A_1 to F_4

3. Solution Search and Evaluation Using IDDFS

The operational data collected from learners using the 2^3- ERC needs to be evaluated with an appropriate method. While various approaches can be considered for evaluating the data obtained from the 2^3- ERC, this paper employs IDDFS and evaluates the results based on the shortest path obtained by this method.

Fig. 4 shows the flowchart of IDDFS. The solution search and evaluation method using IDDFS is outlined in Steps 1 through 4 below:

Step. 1 Initialization

Initialize the solution $\tilde{T}$ obtained by IDDFS as the identity matrix and set the depth limit for the search to 0.

Step. 2 Perform Depth-Limited Depth-First Search

Conduct a depth-first search up to the restricted depth range. If the restricted depth is reached, terminate the search.

Step. 3 Goal State Check

If $T\tilde{T}$ is the goal state, end the search and proceed to Step 4. Otherwise, increment the depth limit by 1 and return to Step 2.

Step.4 Evaluation

The evaluation value L is given by the difference between the total ideal minimum number of rotations for each state operated by the learner and the total number of rotations from the initial state to the ideal state, as shown in Eq. (6). Here, β_i represents the minimum number of rotations required to reach the goal state from the current permutation state $\tilde{\boldsymbol{T}}$ using unit rotations. α denotes the number of moves required to transition from the initial state to the goal state as assigned to the learner, and m represents the total number of operations performed by the learner up to the current point.

$$L = -\frac{\alpha(\alpha+1)}{2} + \sum_{i=1}^{m} \beta_i \qquad (6)$$

4. Experiment

To verify the effectiveness of the proposed method, an experiment was conducted with 9 students from Matsue National College of Technology. In this experiment, the initial state of the $2^3-\mathrm{ERC}$ was set to $\boldsymbol{T}_{Y^{-1}}\boldsymbol{T}_X$, and the time required to return it to the target state $\boldsymbol{E}$ as well as the operation steps were evaluated. The experiment continued until the students either completed the task or decided to discontinue the task and requested to terminate the experiment.

5. Results and Discussion

The experimental results using the $2^3-\mathrm{ERC}$ are presented in Table 1, and the relationship between the number of steps and evaluation values is shown in Fig. 5. In the experiment, all participants successfully achieved the target. Four students completed the task with the shortest number of steps, two succeeded in four steps, and three required more than ten steps. The average number of steps was 6.88, with an average thinking time of 4.48 seconds per step. Additionally, the average task completion time was 33.4 seconds.

Table.1 Results of assigning tasks achievable in two moves to subjects

	Total time	Number of manipulative moves	L	Task achievement
S1	1’13”3	18	56	○
S2	0’02”5	2	0	○
S3	0’12”3	10	18	○
S4	0’50”4	2	0	○
S5	0’17”2	2	0	○
S6	0’19”2	2	0	○
S7	1’29”4	14	36	○
S8	0’15”1	4	5	○
S9	0’12”3	4	5	○

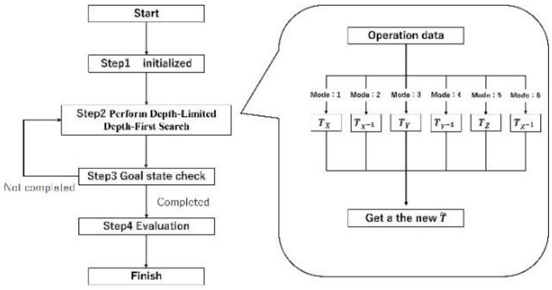

Fig.4 Flowchart of the IDDFS method

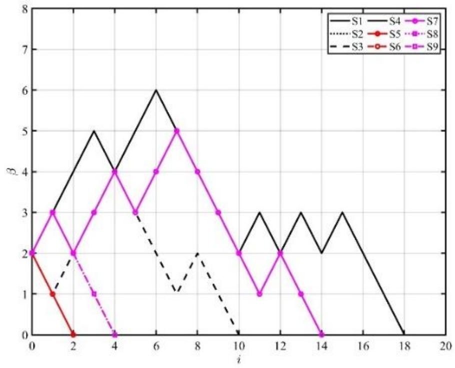

Fig.5 Results of Evaluation Function L Values from IDDFS Method Calculation

Conclusion

In this study, we proposed the evaluation method for the $2^3-\mathrm{ERC}$, and evaluated its effectiveness. Through an experiment involving nine students, the validity of the proposed method was confirmed. All participants successfully completed the task, with an average completion time of 33.4 seconds and an average step count of 6.88. These results suggest that the $2^3-\mathrm{ERC}$ has the potential to enhance logical thinking and problem-solving skills.

Future work will involve conducting experiments with a larger sample size to examine the applicability of the $2^3-\mathrm{ERC}$ in various educational settings. Additionally, incorporating features such as automated feedback and adaptive difficulty adjustments will aim to further enhance the educational value of this tool.

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