Subjective Evaluation on Three Types of Cognitive Load and its Learning Effects

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***Abstract*—Cognitive Load Theory (CLT) distinguishes between three types of cognitive loads: intrinsic, extraneous, and germane. The present study primarily seeks to examine whether participants evaluate cognitive loads correctly when the extraneous and intrinsic cognitive loads are experimentally manipulated. The results showed that the participants evaluated the intrinsic and extraneous cognitive loads correctly, and also evaluated the germane load based on the manipulation of the extraneous load. The study also seeks to identify the type of cognitive load that contributes to learning effects; the results indicate that greater germane and lesser extraneous loads contribute to learning effects. However, the learning effects were not noticeable when far transfer problems were used.**

Keywords - Cognitive Loads; Intrinsic; Extraneous; Germane

I. INTRODUCTION

Cognitive Load Theory (CLT) plays a central role in the process of designing learning environments [1][2]. The theory distinguishes between three types of cognitive loads: intrinsic, extraneous, and germane. Previous studies about CLT have focused on the distinction between intrinsic and extraneous loads [1]. Intrinsic load is the basic cognitive load required to perform a particular task. Conversely, extraneous load is the cognitive load that is unrelated to, and hence wasted in, primary cognitive activities. Therefore, extraneous load may have a negative impact on learning activities. In the mid-1990s, it was found that positive cognitive load increases learning effects. Some studies reported significant learning gains upon the imposition of a large cognitive load on participants assigned to the experimental group [2][3], and this type of cognitive load came to be known as the germane load, which is used for learning [4][5].

Several methods have been proposed for the measurement of the three cognitive loads [6]-[11]. A representative method entails the evaluation of the response time for a secondary task—a longer response time indicates the emergence of high cognitive load in the performance of a primary task. Alternatively, it is also common to use a questionnaire to elicit the participants' subjective evaluation; the questionnaire typically consists of question items related to one of the three types of cognitive loads. However, the reliability of the subjective evaluation method has been called into question as results of multiple evaluations using questionnaires have been inconsistent. Moreover, some studies also imply that it is difficult for naive participants to evaluate each of the three types of cognitive loads individually.

The present study primarily seeks to examine whether participants evaluate cognitive loads correctly when the extraneous and intrinsic cognitive loads are experimentally manipulated. Based on the results of this examination, the relations between extraneous, intrinsic, and germane cognitive loads in the context of subjective estimation are also investigated.

The study also seeks to identify the type of cognitive load that contributes to learning effects. The learning effects are measured based on the increase in the post-test scores, as compared to the pre-test scores. The present study also evaluates the relations between learning gains and the subjective evaluation scores of each of the three cognitive loads measured using a questionnaire developed by the authors.

We explain an experimental design in Section 2, report the experimental results in Section 3, and summarize our conclusions in Section 4.

II. EXPERIMENT

In this section, we will explain the summary of our experiment.

A. Task

The task used in this study involved an 8-by-8, computer-based Reversi game, for which a Reversi-based learning environment was developed by the authors [12][13]. Figure 1 represents the overall configuration of the experimental system. Participants played 8-by-8 Reversi games on a computer against a computerized opponent (i.e., opponent agent) in the experimental environment. Participants were assisted by a partner, also computerized (i.e., partner agent), to selecting winning moves. The opponent agent and the partner agent were both controlled by Edax, a Reversi engine, which suggested the best moves by assessing future states of the game. The partner agent typically recommends candidate moves among valid squares before the participant makes a move.

B. Procedure

In order to determine the baseline for the measurement of learning gains, the participants were involved in a pre-test, which consisted of 12 problems. Following this, the participants took part in the learning (training) phase, which involved

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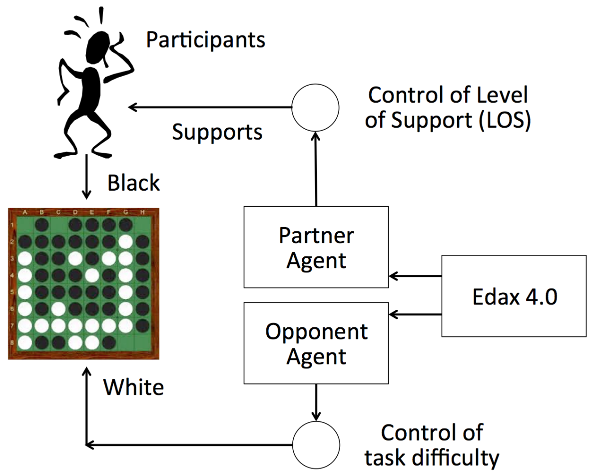


Figure 1. Overall Configuration of the Reversi-based learning environment

16 games. This phase was set up such that the participants had access only to games that were already in progress; as a result, nearly half of the discs were already placed on the board. The learning phase consisted of four blocks, and the participants were required to play four games in each block. A set of winning strategies is proposed; and the training for each block enabled the participants to learn one of the strategies. The discs were arranged in an identical manner for the first three games in each block, whereas the arrangement was altered for the fourth (final) game. The participants were then required to work with the questionnaire designed to evaluate cognitive loads; they were also required to take part in the post-test, which consisted of the same 12 problems as the pre-test.

C. Questionnaire for cognitive load evaluation

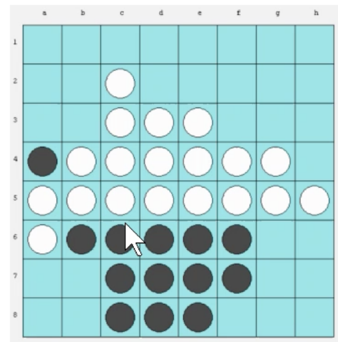
We developed a new questionnaire for cognitive load evaluation by drawing from the questionnaires used in previous studies. The questionnaire used in the present study consists of the following ten items (E, I, and G indicate items related to extraneous, intrinsic, and germane loads respectively). The following examples were translated from Japanese version of the questionnaire that was actually used in the experiment.

- It is difficult to search for possible moves. (I)
- It is difficult to search for the best move. (I)
- It is difficult to look ahead. (I)
- It is difficult to understand the arrangements of the discs on the board. (E)
- The representation of the arrangement of discs is inadequate for learning. (E)
- Great effort is required to perform a task given the inadequate representation. (E)
- I try to find heuristics for winning. (G)
- I try to understand the other party's intention. (G)
- I make great effort to find heuristics for wining. (G)
- I concentrate on my performance in the game. (G)

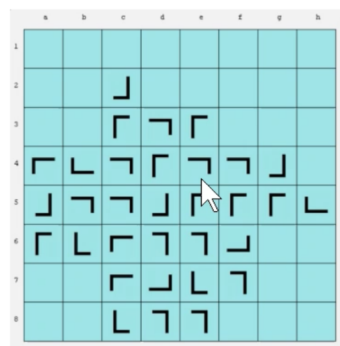
D. Manipulated factors

The following two factors were applied for manipulation: (i) the disc representation factor and (ii) the hint information factor. The first factor was expected to manipulate the extraneous load, whereas the second factor was expected to manipulate the intrinsic load.

1) Disc representation factor: Figure 2 presents a sample disc arrangement typical of the Black and White and the L and rL (reversal L) conditions.



(a) Black and White condition



(b) L and reversal L condition

Figure 2. A screenshot of the game board in the Black and White and L and rL (reversal L) conditions

When the Black and White condition was considered, the Black and White discs were used in the arrangement, whereas when the L and rL condition was considered, the Ls or rotated Ls (black discs) and the mirror reversal Ls or rotated reversal Ls (white discs) were used in the arrangement. In order to perceive the status of the disc arrangement and decide the best move in the L and rL condition, participants had to imagine the rotation of the L or reversal L images during each trial, thus causing a significant extraneous load. As a result, the L and rL condition increased the extraneous load more than the Black and White condition.

2) Hint information factor: For each trial of the game, the main task was to choose the best winning move. In order to do so, the participants had to understand the status of the disc arrangement, search the problem space, and estimate the best move, thus increasing intrinsic load. The computerized partner agent suggested the best moves to the participants in the hint presentation condition (see Figure 3), whereas under

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the no hint condition, no such information was presented. This suggests that the intrinsic load of the participants was lower in the hint presentation condition than in the no hint condition.

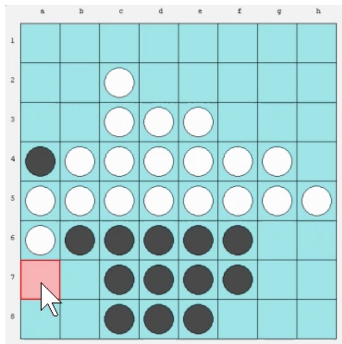

Figure 3. A screenshot of the game board when hint information is presented

E. Learning gains

Pre and post-tests were conducted to evaluate the learning gains, and each test consisted of the same 12 problems. In each problem, the participants were presented with a disc arrangement, after which they were required to determine the best possible move. The 12 problems were grouped into the following three categories, each of which in turn consisted of four problems:

1) Identical problems: This disc arrangements presented here were identical to those used in the training phase.

2) Near transfer problems: For this category, the disc arrangements used for the learning phase were modified. More specifically, they were rotated 90, 180, or 270 degrees from their original position or mirror-reversed from the rotated arrangements.

3) Far transfer problems: New disc arrangements were presented for this category. The participants were able to determine the best possible move based on the strategies they were trained in during the learning phase.

As the number of problems in each category was four, the full score was also determined to be four. In the present study, the difference between the pre-test and post-test scores, more particularly, the increase in the post-test scores, were used as learning gains.

F. Participants

81 undergraduates from Nagoya University participated in this study. Although all the participants had played Reversi prior to their involvement in the study, they were not experts. The participants were divided into three groups: 21 participants were assigned to the no hint and Black and White condition; 19 were assigned to the hint presentation and Black and White condition; 20 were assigned to the no hint and L and rL condition, and 21 participants were assigned to the hint presentation and L and rL condition.

III. RESULTS

First, we examined whether participants evaluate cognitive loads correctly when the extraneous and intrinsic cognitive loads are manipulated. Figure 4 presents the results of the questionnaire used to measure each type of cognitive load.

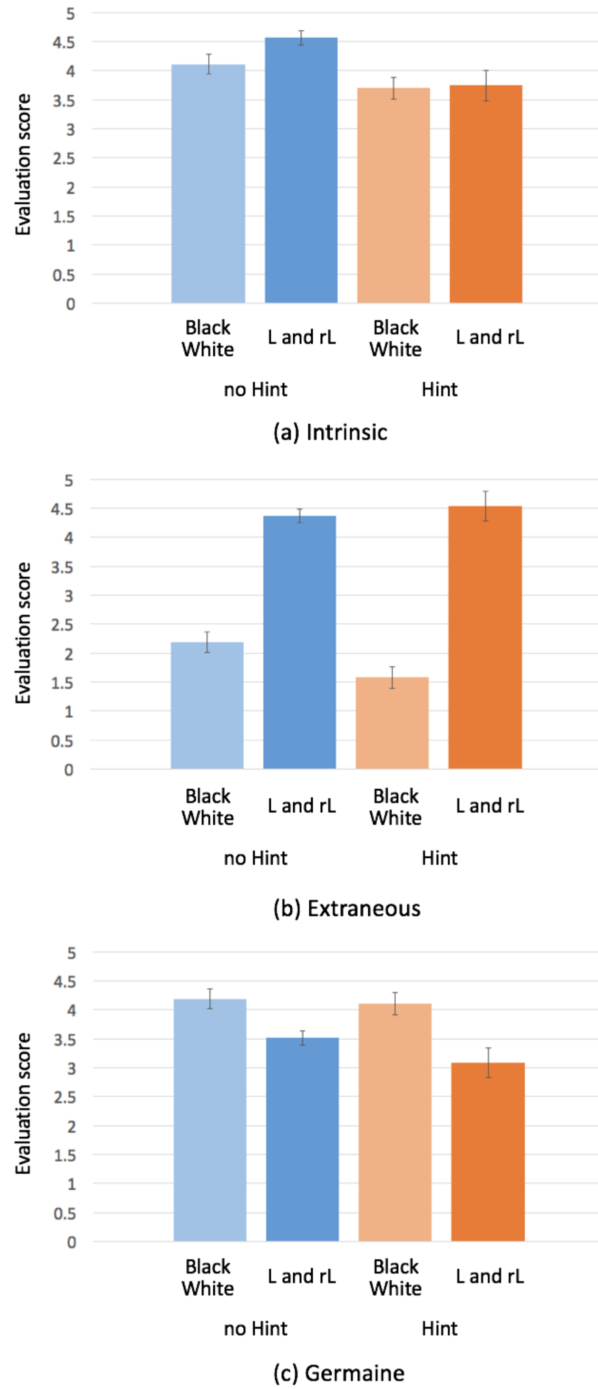

Figure 4. Results of participants' subjective evaluation for the three cognitive loads

In the intrinsic load, a two (hint information: Hint and No hint) × two (disc representation: Black/white and L/rL) ANOVA revealed a significant main effect of the hint information factor ($F(1, 77) = 9.59$, $p < 0.01$), but neither the main effect of the disc representation factor nor the interaction of the two factors reached a significant level ($F(1, 77) = 1.58$, n.s.; $F(1, 77) = 1.07$, n.s.).

In the extraneous load, the same ANOVA revealed a great

TABLE I. CORRELATION OF THE EVALUATION SCORE OF EACH COGNITIVE LOAD AND THE DIFFERENCE BETWEEN THE PRE-TEST AND POST-TEST SCORES

Problem type	Intrinsic	Extraneous	Germane
Identical	n.s.	r=-0.385, $p < 0.01$	r=0.279, $p < 0.05$
Near transfer	n.s.	r=-0.294, $p < 0.01$	n.s.
Far transfer	n.s.	n.s.	n.s.

significant main effect of the disc representation factor (F(1, 77) = 520.43, $p < 0.01$) but the main effect of the hint information factor did not reach a significant level (F(1, 77) = 3.79, n.s.). The interaction of the two factors, however, was found to be significant (F(1, 77) =12.13, $p < 0.01$).

In the germane load, the same ANOVA revealed a significant main effect of the disc representation factor (F(1, 77) =35.13, $p < 0.01$), but neither the main effect of the hint information factor nor the interaction of the two factors reached a significant level (F(1, 77) = 3.21, n.s.; F(1, 77) = 1.43, n.s.).

Second, we sought to identify the type of cognitive load that contributes to learning effects. We analyzed the relations between the evaluation score of each cognitive load in the questionnaire and the increase in the post-test scores as compared to the pre-test scores. Table 1 presents the results of this analysis. We found a positive correlation between germane load and learning gains, but only in the identical problems that were tested. Negative correlations were found between extraneous load and learning gains in the identical and near transfer problems. However, the relations were not noticeable when the far transfer problems were tested.

IV. CONCLUSION

Our first research question involved examining whether participants evaluate cognitive loads correctly when the extraneous and intrinsic cognitive loads are experimentally manipulated. The results indicate that they accurately and consistently evaluated extraneous and intrinsic loads with the experimental manipulation. In the current study, the germane load was estimated based not on intrinsic load manipulation, but on extraneous load manipulation.

The second research question pertained to identifying the type of cognitive load that contributes to learning effects. The results showed that greater germane load contributed to learning effects when identical problems were used in the test phase. This effect, however, was not noticeable when transfer problems were used.

It takes a lot of training and time to acquire skills and expertise to play the games [14]. For the purposes of this experiment, only 16 games were used for training. It is possible that this limitation did not cause learning effects in the transfer problems.

Interestingly, the results also clearly showed that less extraneous load contributed to learning, whereas greater intrinsic load did not. This would depend on the much greater extraneous load caused by the L and rL disc representation. The results highlight the harmful effect of extraneous load on learning activities, which is consistent with the findings of previous studies [2][8][15][16].

The functions of intrinsic load in learning processes still remain unclear; we have, therefore, identified the investigation of its functions as a key objective of our future studies.

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