Effects of Cognitive Load in Acquisition of Assembly Skills

Akira URAO[a], Kazuhisa MIWA[a]
[a]*Graduate School of Information Science, Nagoya University, Japan*
{urao, miwa}@cog.human.nagoya-u.ac.jp

Abstract: Recently, instructional videos are widely being used in educational settings. Many researches have proposed the construction of video-based learning environments that reflect Cognitive Load Theory. In this study, we examined the effects of cognitive load induced by the speed of video playing in an interactive video-based learning environment. The experimental results showed that increasing or decreasing cognitive load affected the learners' selection of problem solving strategies, but did not provide learning effects. The results also indicated that learners showed adaptive behaviors for adjusting cognitive load depending on learning situations.

Keywords: Cognitive Load, Interactivity, Skill Acquisition, Learning Environment

Introduction

Recently instructional videos are widely being used in educational settings due to the development of information technologies such as e-learning and Web-Based Training. It is important to directly impose germane cognitive load relating to learning and reduce unrelated extraneous cognitive load. However, the speed of video playing and the complexity of video contents induce extraneous cognitive load, negatively affecting learners' perception and understanding [1].

To overcome these drawbacks, many studies have proposed an interactive learning environment where learners can control the speed of video playing, pause, replay, review, and so on [2][3]. This attempt is to overcome the drawbacks by controlling such video operations as reviewing the video if learners cannot understand the contents and pausing if they cannot follow it. The effects of such interactivity have been examined by comparing learning systems that have interactive features and those in which learners can only follow a video without controlling the video operations [4][5][6]. As a result, it has been shown that interactive learning systems actually support effective learning better than systems without interactive features. Based on these backgrounds, we examine the effects of cognitive load induced by the speed of video playing in an interactive video-based learning environment.

In this study, we treat an assembly task as a subject matter because this type of learning task has crucial features in interactive video-based learning environments such as “change in time” and “spatial transformation” [2][3]. We use the “LEGO Mindstorms” as a learning material because it is widely used in elementary schools, universities, and companies [7].

In this study, we focus on the speed of video playing as a factor controlling learner cognitive load because it has been indicated that the speed of video playing actually increases or decreases cognitive load while learning video contents.

1. Overview of Experimental System

In this section, we describe an overview of the experimental system used in this study, as shown in Figure 1.

(a) replay screen (b) foot controller

Figure 1: Overview of a learning support system

The system consists of a replay screen and a controller. Users learn assembly skills by actually following the creation process presented on the replay screen. The video contents used in this system were produced by recording an expert creator's process of creating a product by using a portable camera mounted on that person's head. In this system, a mouse and a foot controller are provided as controllers. Users can pause, replay, forward, rewind, and jump to any specific position using the controller. Such features enable interactive learning.

In this study, learner cognitive load is manipulated by controlling the speed of video playing. Control is automatically operated as the system's background process. We assumed that learner cognitive load increases and decreases when the speed of video playing is accelerated and decelerated, respectively. The learners' operations of the controller were recorded automatically.

2. Experiment

We examined the effects of increasing or decreasing cognitive load in an interactive video-based learning environment using the experimental system described above. Figure 2 shows a product created by subjects in the experiment [8].

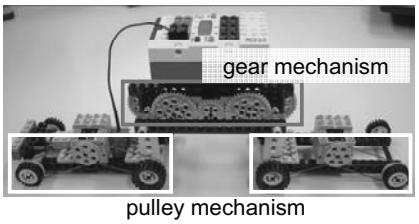


Figure 2: Product created in learning phase

2.1 Participants and Experimental Conditions

Fifty-one undergraduate students participated in the experiment. We set up three experimental conditions: (1) gear condition: accelerating video playing while making the gear mechanism and decelerating while making the pulley mechanism; (2) pulley condition: accelerating video playing while making the pulley mechanism and decelerating while making the gear mechanism; (3) control condition: the speed of video playing is not controlled. Seventeen subjects were randomly assigned to each of the three conditions.

The speed of video playing was adjusted 1.4 times faster when accelerating and 0.7 times slower when decelerating based on a preliminary experiment in which four participants participated.

2.2 Procedure

The experiment consists of four phases: (1) pretest (10 min.), (2) learning (40 min.), (3) posttest (10 min.), and (4) performance test (10 min.). Detailed procedures in each phase are as follows.

2.2.1 Pre and Posttest

The pretest and posttest were conducted to examine to what degree the subjects acquired the basic concepts of the Mindstorms such as knowledge of the individual parts and their combinations. In the

pretest and posttest, subjects were given a photo of a block constructed by a combination of individual parts and required to select items (parts) from the parts list needed to construct each block.

Each test consisted of 16 problems categorized into two types. Each block, as a test item used in the eight problems in one type, related to the local structures of the product's gear mechanism that the learners created in the learning phase. Each block in the other type related to the local structures of the product's pulley mechanism. We performed two types of tests to examine whether controlling cognitive load in the learning phase affected various learning activities.

2.2.2 Learning Phase

In the learning phase, the subjects created the product shown in Figure 2 with a creation process that consists of the following six phases: (1) making structures to reinforce the gear mechanism, (2) making the gear mechanism, (3) making the former part of the car body, (4) making structures to reinforce the pulley mechanism, (5) making the pulley mechanism, and (6) making the latter part of the car body.

We controlled subjects' cognitive load by only manipulating the speed of video playing in phases (2) and (5). The speed of video playing was automatically controlled by the experimental system.

2.2.3 Performance test

A performance test was performed to evaluate subject knowledge and skills for constructing mechanisms to achieve a specific goal. Figure 3 shows an example product that fulfills the requirements of the performance test.

Subjects have to fix two beams on the motor and transmit its power to both ends of the two beams while avoiding obstructions. This task could be solved by adopting one of two local structures of the power transmitting mechanism in the product created in the learning phase. More specifically, the requirements of this test are achieved by adopting the gear mechanism (see the middle of Figure 2) or the pulley mechanism (both sides in Figure 2). This means that subjects can solve this task if they successfully learned the related skills in the learning phase.

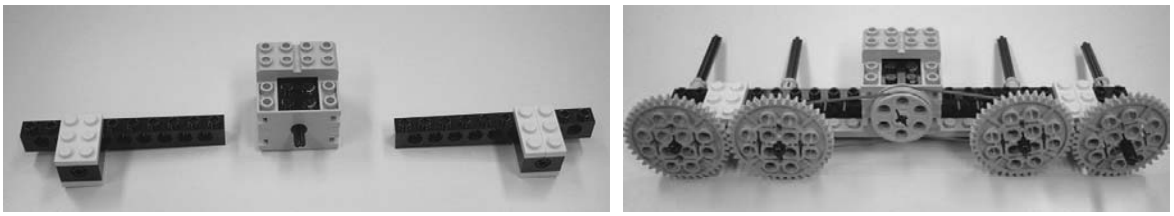


Figure 3: Motor and two beams on which obstruction parts are connected and an example product in performance test

3. Results

The experimental results are as follows. All subjects successfully created the product in the learning phase. In addition, pretest results showed no differences in subjects' prior knowledge of the Mindstorms across the three experimental conditions. The results guaranteed equal subject expertise in this task across the three conditions.

3.1 Results of Interactive Behaviors

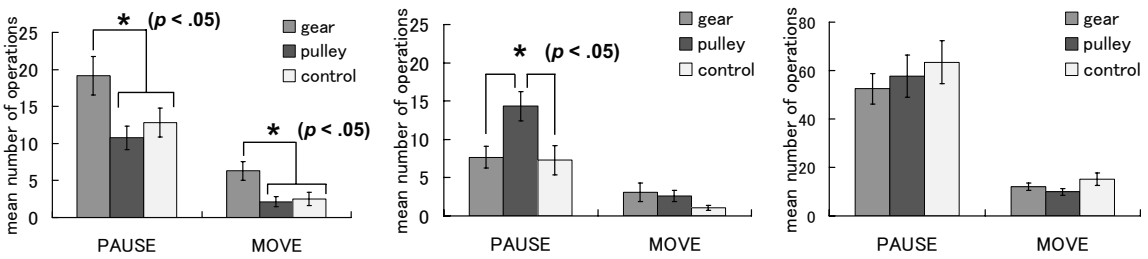
We analyzed subject operations of the controller in the learning phase from the viewpoint of the cognitive load imposed by accelerating or decelerating the video playing. We counted the number of times the video was paused (equivalent to the number of replaying, described as PAUSE) and also the number of times forward, rewind, and jump were used (described as MOVE).

Figure 4(a) shows the results while making the gear mechanism. In both PAUSE and MOVE, a one-way ANOVA showed a main effect of the experimental conditions (PAUSE: F (2, 48) = 4.41, $p < .05$; MOVE: F (2, 48) = 5.48, $p < .01$). A multiple comparison (Tukey's HSD) reached

significance between the gear and the pulley conditions, and between the gear and the control conditions in both PAUSE and MOVE (PAUSE: MS = 74.0, $p < .05$; MOVE: MS = 16.40, $p < .05$). This result confirms that the subjects performed more operations when making the gear mechanism in the gear condition than in the control condition. On the other hand, in the pulley condition, the mean number of operations did not decrease more than in the control condition.

Figure 4(b) shows the result while making the pulley mechanism. A one-way ANOVA showed a main effect of conditions in PAUSE but not in MOVE (PAUSE: F (2, 48) = 4.13, $p < .05$; MOVE: F (2, 48) = 1.62, n.s.). A multiple comparison (Tukey's HSD) reached significance between the gear and the pulley conditions, and between the pulley and the control conditions in PAUSE (PAUSE: MS = 58.74, $p < .05$). This result confirms that the subjects performed more operations when making the pulley mechanism in the pulley condition than in the control condition. On the other hand, in the gear condition, the mean number of operations did not decrease more than in the control condition.

Figure 4(c) shows the result while making other parts of the product (neither gear nor pulley mechanism). In both PAUSE and MOVE, a one-way ANOVA shows no main effect of the conditions (PAUSE: F (2, 48) = 0.46, n.s.; MOVE: F (2, 48) = 1.96, n.s.). This means that the mean number of operations was equivalent across the three conditions while creating other parts.



(a) gear mechanism (b) pulley mechanism (c) others

Figure 4: Mean numbers of operations

3.2 Learning Time

We analyzed the learning time needed to create each mechanism by examining whether increasing or decreasing cognitive load affects the learning time, which was analyzed by comparing the time needed to complete each mechanism with the time at the normal speed of video playing. Completion was determined when the experimenter judged that the subjects had created the same mechanism as that presented in the video. We ignored minor errors such as misalignment or shortage of parts in the decoration when determining the completion.

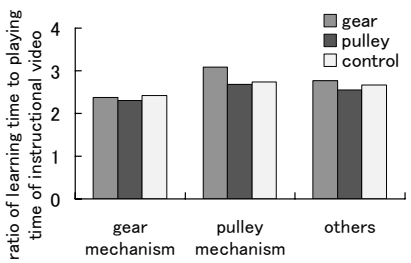
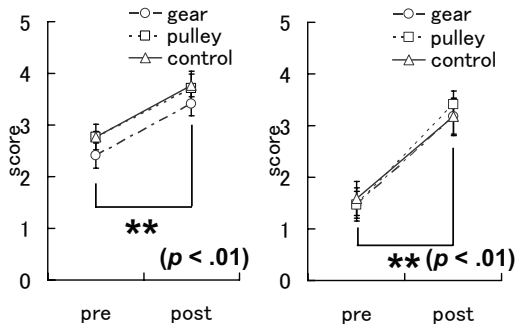


Figure 5: Ratio of learning time to playing time of instructional video

Figure 5 shows the ratio of the learning time in each mechanism to the playing time of the video at the normal speed. The result showed that the subjects consumed 2.4 to 3 more times than the playing time of the instructional video until creating each mechanism in every experimental condition. A one-way ANOVA shows no main effect of the conditions in creating each mechanism (gear mechanism: F (2, 48) = 0.05, n.s.; pulley mechanism: F (2, 48) = 0.21, n.s.; others: F (2, 48) = 1.25, n.s.). This result indicates that across the three conditions learning time was equivalent, and did not depending on the manipulation of cognitive load.

3.3 Pre/Posttests

The pre/posttest was scored by ignoring errors within one segment in the shaft length because it was difficult to identify the difference on the parts list used in the pre/posttests. Figure 6 shows the result of the pre/posttests. The horizontal axis shows the pre/posttest, and the vertical axis shows the number of accurately answered problems among the eight problems in each type of problem (i.e., gear/pulley mechanism tests).



(a) gear mechanism (b) pulley mechanism

Figure 6: Comparisons of pre/posttests

In both gear (Figure 6(a)) and pulley (Figure 6(b)) mechanism tests, a 3 (conditions: gear, pulley, control) x 2 (tests: pre/posttest) ANOVA showed a main effect of the tests, but no main effect of conditions and no interaction. (gear mechanism, condition: F (2, 48) = 1.11, n.s.; pre/posttest: F (1, 48) = 30.58, $p < .01$; interaction: F (2, 48) = 0.01, n.s.; pulley mechanism, condition: F (2, 48) = 0.06, n.s.; pre/posttest: F(1, 48) = 57.98, $p < .01$; interaction: F(2, 48) = 0.20, n.s.). The result indicates that the subjects successfully acquired the basic knowledge of the parts and the combinations of the parts; but the learning effects did not differ across the three conditions.

3.4 Performance test

We analyzed the performance test to examine whether controlling cognitive load affects subject selection of problem solving strategies and learning effects. First, we show analysis of the strategy selection in the performance test. Second, we also show analysis of the learning effects.

3.4.1 Strategy Selection

There are three strategies to solve the performance test: (1) using the gear mechanism, (2) using the pulley mechanism, and (3) using both the gear and pulley mechanisms.

An initial strategy selected at the beginning of the performance test was analyzed. In the analysis, when the subject tried to solve the task using the parts consisting of the gear mechanism or those to reinforce the gear mechanism, it was categorized as selection of the gear mechanism strategy. On the other hand, it was categorized as selection of the pulley mechanism strategy when they solved the task using the parts consisting of the pulley mechanism or those to reinforce the pulley mechanism. No parts are used in both gear and pulley mechanisms. Table 1 shows subject strategy selections in the performance test.

Table 1: Strategy selection in performance test

	gear mechanism	pulley mechanism
gear condition	12	5
pulley condition	5	12
control condition	4	13

A Chi-square test indicated a significant difference ($\chi 2$ (2) = 9.229, $p < .01$). Residual analysis indicated that subjects in the gear condition used the gear mechanism strategy more than in the control condition ($p < .05$), but subjects in the pulley condition did not indicate such a tendency. This result implies that manipulation of subject cognitive load may affect strategy selection.

3.4.2 Learning Effects

For discussing the learning effects, we analyzed the ratio of successful subjects to all subjects. We defined successful subjects as individuals who created a product fulfilling the requirements of the performance test as successful subjects. Table 2 shows the result.

Table 2: Performance test results

	successful	unsuccessful
gear condition	10	7
pulley condition	10	7
control condition	13	4

A Chi-square test did not indicate a significant difference ($\chi 2$ (2) = 1.545, n.s.). The result shows that the percentages of successful subjects did not differ across the three conditions, confirming that no differences in learning effects were caused by the manipulation of subject cognitive load.

3.5 Summary of Experimental Results

The experimental results are summarized as follows.

Analysis of the operations showed that subjects in accelerated video playing situations significantly increased operations more than in normal speed situations. However, subjects in decelerated video playing situations did not decrease the operations more than in normal speed situations.

Analysis of the learning time showed that the time needed to construct each mechanism did not differ regardless of the manipulation of cognitive load.

The performance test showed that subjects in the gear condition used the gear mechanism strategy more than pulley mechanism strategy, but not those in the pulley condition.

The results of the pre/posttests and the rate of successful subjects in performance tests showed no differences in learning effects.

4. Discussion

4.1 Effects of Cognitive Load on Learning

Subjects in the gear condition selected the gear mechanism strategy more in the performance test. This result implies that the increase of cognitive load caused the subjects' active engagements in interaction with the instructional system and affected strategy selection during problem solving. On the other hand, subjects in the pulley condition did not prefer the pulley mechanism strategy, which may be caused by the ceiling effect where many subjects in the control condition also selected the pulley mechanism strategy.

Festinger proposed a “theory of cognitive dissonance” and asserted that humans tend to avoid internal inconsistency (cognitive dissonance) [9]. This theory may explain why subjects tended to use the gear mechanism strategy in the performance test that had been learned with heavy cognitive load; i.e., they avoided cognitive dissonance situations where a learned strategy providing high costs was not used.

Analysis of the pre/posttests and the rate of successful subjects in performance tests showed no effects of increasing or decreasing cognitive load on learning performance. In this study, the subjects learned by actually following an expert's creation process presented by the instructional video. Such learning is considered a kind of example-based learning. Typical studies examining the effectiveness of example-based learning have used “worked-out examples” that consisted of problem formulation, solution steps, and the final solution itself. They are defined as a “model of expert problem-solving [10]”.

The video material used in this study showed the process of an expert creating a product. Therefore, the instructional video in this study shares the features with worked-out examples. Many studies have confirmed that in the initial stages of cognitive skill acquisition, learning from

worked-out examples is more effective than learning by problem solving [10][11]. It is considered that controlling cognitive load by only adjusting the speed of video playing could not promote the additional effects of "worked-out examples."

Moreover, note the shorter learning times in our study. Subjects made the product only once, and the learning time was about 4 minutes in each of the two learning phases where the speed of video playing varied and subject cognitive load was manipulated. Future work includes investigations of the effects of increasing or decreasing cognitive load in long-term learning.

4.2 Effects of Cognitive Load on Learning Activities

An interesting phenomenon is that subjects in the accelerated video playing situation significantly increased video operations more than in the normal speed situation, but not those in the decelerated video playing situation. Previous studies have confirmed that learning time increased by using interactive features in an interactive learning environment [5][6][12]. Therefore, we predicted that the learning time of subjects in the accelerated video playing situation would increase with an increase of operations. Moreover, the number of operations was almost equivalent between the decelerated and normal video playing situations. In such a case, it would be a natural prediction that learning time would increase in the decelerated video playing situation. Despite these predictions, learning time was equivalent regardless of the acceleration or deceleration of video playing. This is surprising.

There are two ways to create the product in the learning phase: (1) viewing the video to understand the creation process and then pausing the video and constructing it; and (2) constructing the product while viewing the video. Even though we did not give any instructions, all subjects used the former strategy. In such a case, learning time can be divided into two categories: (1) viewing period when the subjects viewed the video and (2) pausing period when they created the product while pausing the video.

We analyzed the pausing time from the viewpoint of the relation of learning time and the number of operations. Pausing time was calculated by accumulating the time consumed for pausing throughout the process. Since the mean number of pausing operations was significantly larger in the accelerated video playing situation, we analyzed the mean pausing time per pausing, as shown in Figure 7.

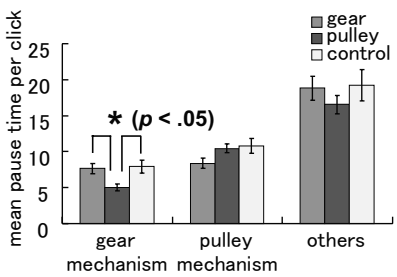


Figure 7: Mean pause time per pause

A one-way ANOVA showed a main effect of the experimental conditions in the gear mechanism, a marginal main effect in the pulley mechanism, and no effect in the other parts (gear mechanism: F (2, 48) = 4.70, $p < .05$; pulley mechanism: F (2, 48) = 2.73, $p < .10$; others: F (2, 48) = 0.70, n.s.). A multiple comparison (Tukey's HSD) reached significance between the gear and the pulley conditions, and between the pulley and the control conditions in the gear mechanism (MS = 9.08, $p < .05$). In addition, we confirmed a tendency that the mean pausing time in the gear condition is shorter than in the control condition even though a statistical analysis did not detect such a difference in the pulley mechanism. These results indicate that pausing time was equivalent between the accelerated video playing and normal speed situations, whereas pausing time decreased when the speed of video playing decreased. In addition, pausing time was equivalent when the speed of video playing was not manipulated.

Therefore, subjects in the accelerated video playing situation paused and replayed more and felt the difficulty of following the creation process with a large cognitive load. However, learning time did not increase because accelerated video playing shortened viewing time. On the other hand,

subjects in the decelerated video playing situation replayed immediately after pausing because they felt that they could follow the creation process easier than the normal speed situation. Yet learning time did not decrease compared to the normal speed situation because the decelerated video playing lengthened viewing time.

These findings suggest that learners adaptively regulated cognitive load by two different strategies: (1) frequently pausing the video when cognitive load was increasing and (2) shortening the pausing time when cognitive load was decreasing. Learners apparently regulated their cognitive load by different strategies: frequently pausing and short pausing times reflecting the change of cognitive load. This is impressive.

Studies confirming the effects of cognitive load in multimedia learning environments have pointed out that learner cognitive load vary depending on levels of expertise even if the learning contents are equivalent [13]. Therefore, it is difficult to control identical cognitive load for all learners when constructing educational materials because they cannot adjust their cognitive load even if there is a gap between the cognitive load predicted by instructional designers and the load actually imposed on the learners when using a system without interactivity. However, an interactive system enables learners to behave adaptively, including frequent pausing and short pausing times that depend on various learning situations. Our study successfully indicated the empirical evidence of such learners' adaptive behavior.

The generalization of these findings needs careful considerations. The subject matter is assembly skills, and it has features that learners can learn by actually making a product while viewing the video. Future work includes investigation whether the same effects are confirmed in other types of learning situations.

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