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# INTRODUCTION OF COMPUTER-BASED SIMULATED EXPERIMENTS IN UNIVERSITY PSYCHOLOGY CLASS: A CLASS PRACTICE OF LEARNING DUAL STORAGE MODEL OF HUMAN MEMORY

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**ABSTRACT**

This paper examines the possibilities and limitations of introducing simulated experiments in the psychology domain by practicing a course with graduate students in psychology, in which simulated experiments were conducted in place of real human experiments. The class-learning object was the dual-storage model of human memory. The simulation results showed anomalous results that differed from intuitive predictions. The results were also inconsistent with the results of prior human experiments. Analysis of reports submitted by 15 participants revealed that they focused on the anomalous results emerging in the simulation results and examined them based on the dual-storage model theory. On the basis of these results, future directions for this practice are discussed.

**KEYWORDS**

Science Education, Inquire-Based Learning, Cognitive Model, Simulations, Psychology

## 1. INTRODUCTION

The planning of experiments based on hypotheses and refinement of hypotheses based on feedback from the results of experiments are the basic inquiry processes of scientific activities. Numerous studies have confirmed the benefits of introducing computer-based simulated experiments instead of real experiments in science education to provide students with a hands-on understanding of these inquiry processes (Rutten et al. 2012). This advantage has also been used in a variety of inquiry-based learning initiatives, where students themselves drive the inquiry process on their initiative (De Jong 2006).

In inquiry-based learning, it is difficult for students to engage in real-world experimentation (Hennessy et al. 2007). First, conducting real-world experiments can be dangerous and expensive. Second, these experiments may not be feasible in practice. In general, conducting experiments is often complicated and time-consuming and may require tedious preprocessing when analyzing the collected data. In many cases, the costs associated with conducting such experiments are unrelated to the learning objectives, increase extraneous cognitive load, and reduce learning effects (Sweller et al. 1998). By introducing computer-based simulated experiments, students are protected from such time-consuming manual labor and can focus on their original learning goals, that is, experiencing the process of inquiry itself, with improved work efficiency. Hence, students will be able to focus on "what-if" exploration by immediately checking the results of the experiments using simulations (Wen et al. 2020).

The introduction of computer-based simulated experiments into educational settings has been overwhelmingly practiced in the field of natural sciences (Rutten et al. 2012, Smetana & Bell 2012). Such advantages are also expected to have beneficial effects on training classes for human experimentation in the psychology domain at universities.

Experiments in psychology often require more human resources than experiments in natural sciences. Specifically, psychology experiments are conducted on human subjects and require recruitment of a large number of participants. In university classes, participation in these experiments is often supported by volunteers, which is a destabilizing factor in conducting such classes. In addition, it is often practically impossible to control experimental factors in human subjects, and various confounding factors are likely to be involved. Experimental reproducibility has also been reported to be relatively low (Collaboration 2015). These conditions work negatively in the educational context. Computer-based simulations are expected to provide effective responses to these problems.

Inquiry-based learning is classified into four levels, depending on whether the three aspects of scientific activities—source of the question, data collection methods, and interpretation of results—come from a teacher or student (Blanchard et al. 2010). Of the four levels, level 2 is called guided inquiry. At this level, inquiry questions are posed by the teacher, but the collection of data and interpretation of results are student-directed. In current practice, this level of inquiry-based learning is conducted in the psychology domain.

The introduction of simulated experiments greatly improves the economics of data collection in this context, as data collection is performed through simulations. In addition, there is an important contribution to the interpretation of the results whereby the patterns that emerge are explained based on the theory of the domain. In cognitive psychology, theory is often described as a mechanism of cognitive information processing. Students are asked to explain how the patterns of the experimental results obtained are brought about by the cognitive information processing that they focused on. In response, cognitive information processing is explicitly disclosed in the model used therein, making it easier for students to understand the relationship between the two in simulated experiments (Miwa et al. 2015). Furthermore, the causal relationship between the two can be clarified by manipulating the model's information processing parameters to determine the effects that appear in the simulation results. These are expected to work positively in the educational context.

This study examines the possibilities and limitations of introducing computer-based simulated experiments in the psychology domain with graduate students, through a class in which simulated experiments are conducted instead of real experiments, by observing their learning activities. The research questions of this study are to observe how participants perceive and interpret the results of simulation experiments when used in place of real human experiments. This effort will discuss the possibilities and limitations that emerge prior to conducting a full-scale practice in the future. In particular, we examine what the differences are between participants who extracted valid findings and those who did not.

# 2. METHOD

## 2.1 Participants

Fifteen graduate students majoring in psychology from the Department of Psychology and Cognitive Sciences, Graduate School of Informatics, Nagoya University, participated in this class. With a few exceptions, the participants had undergraduate-level knowledge and skills in experimental design and psychological statistics.

## 2.2 Class Topics

The topic of the class comprised the serial position effect (Murdock Jr 1962), which is a widely known phenomenon discussed in many psychology textbooks as a typical human memory phenomenon explained by the dual-storage model of memory (Atkinson & Shiffrin 1968).

In human memory experiments, the serial position effect is a phenomenon in which the degree to which words are remembered depends on the order in which they are presented. Normally, the first and last few items are remembered better than the middle items. If the order of word presentation is shown on the horizontal axis and the recall rate on the vertical axis, the graph will show a U-shaped curve with a concave center. The phenomenon in which the recall rate of the first presented items is higher is called the primacy effect, and the phenomenon in which the recall rate of the last presented items is higher is called the recency effect.

## 2.3 Cognitive Model

Simulated experiments require a model that accurately simulates the phenomena being investigated. Although models that simulate natural phenomena often take the form of mathematical and statistical models, models of cognitive information processing that are focused on here are symbolic processing models. When focusing on cognitive information processing, the most representative framework is rule-based modeling (Klahr et al. 1987). In this class, the production system modeling framework was used for the simulated experiments.

The model is expressed as follows: the presented words are first stored in the short-term memory. Each word stored in the short-term memory has an activation value for recall. Over time, the activation value in the short-term memory decreases, and when it falls below a certain value, it becomes inactive and is forgotten. One of the words stored in the short-term memory is randomly selected and rehearsed, and its activation value increases. When the activation value exceeds a certain value, it is transferred to the long-term memory. The transferred items are never forgotten.

In this class practice, the time interval between word presentations and the increase in the activation value of a word by a single rehearsal were manipulated. The former is the factor that is manipulated in the experiments, and the latter is the working memory capacity of the experimental participants, which is usually measured by memory span tests, such as the operation span test, OSPAN (Unsworth et al. 2005).

## 2.4 Class Design

Participants attended seven class sessions in a cognitive science class at Nagoya University. In the first four sessions, an introductory lesson on production system modeling was given in which all participants constructed a cognitive information processing model to solve the multi-column subtraction arithmetic problem. The educational environment for implementing the model was DoCoPro, an educational production system architecture developed by the authors (Miwa et al. 2014).

The latter three sessions were used for class practice. First, participants were taught the theory of the dual storage model of human memory through the instructor's lecture. The computer model used in the class was then outlined. For this practice, the model for simulating the human memory phenomenon was not developed by the participants, but was given by the instructor.

Participants performed the simulations individually and obtained the resulting data. Based on a preliminary study, the parameter for the word presentation interval was set to 3 and 6 s, and the amount of increase in the activation value of a word by rehearsal was set to vary between 40 and 80. When the activation value exceeded 200, the word in the short-term memory was transferred to the long-term memory.

Participants completed 40 trials in each of the experimental conditions for word presentation intervals (3 s and 6 s). Although participants were not presented with a specific analytic methodology, they were presented as an example of the data analysis, with a graph format in which the vertical axis shows the recall rate, and the horizontal axis shows the three positions of presenting the first five, middle ten, and last five words.

# 3. RESULTS

## 3.1 Simulation Results

Figure 1 shows the simulation results. Figure 1(a) shows the analysis from the viewpoint of the presentation intervals, that is, the recall rates were separately depicted in the long-time condition (6-second condition) and in the short-time condition (3-second condition). Figure 1(b) shows the analysis from the viewpoint of the participants' working memory capacity, that is, the recall rates were depicted in the lower and higher capability groups. Since the participants performed simulations individually, there were some differences in their results; the basic patterns of the results are as shown in Figure 1.

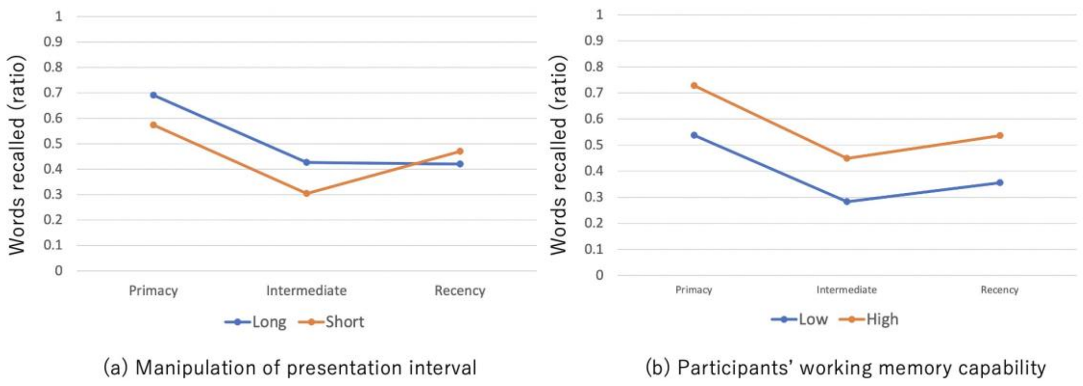


Figure 1. Results of simulated experiments

Figure 2 shows the results of the human experiments conducted in a different class (n=122).

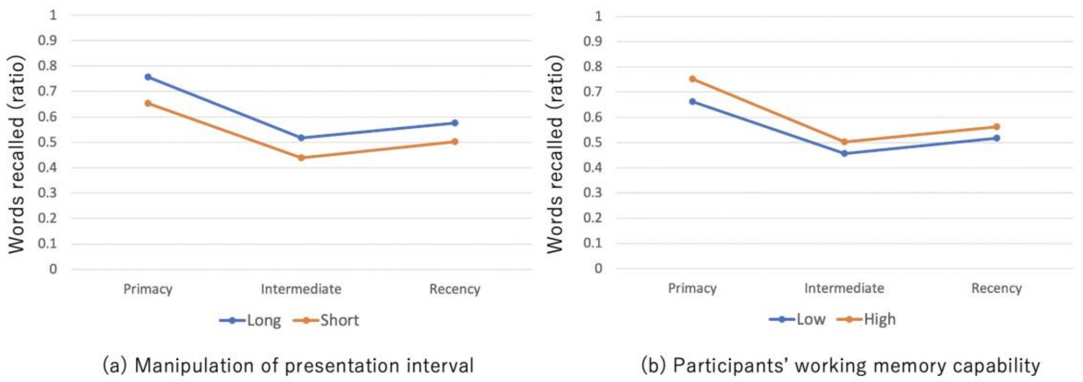


Figure 2. Results of human experimentation

Common features that emerge in both the simulation and human experimental results include the following:

- The primacy effect was pronounced, while the recency effect was small.
- The main effect of participants' working memory capacity was observed.

Unlike the human experimental results, the following was found in the simulation results:

- In the simulated experiments, the effect sizes of both the main effect of working memory capacity and the main effect of word presentation intervals were larger than those in human experiments.
- The results of the simulated experiments showed that the effect of word presentation intervals depended on the position at which the words were presented. Specifically, the effect of presentation intervals occurred in the first and middle positions of the presentation but disappeared in the last position. However, in human experiments, such an interaction effect was not observed.

Notably, the second feature was confirmed in the simulated experiments. In general, it is intuitively predicted that the higher the participants' working memory capacity and the longer the word presentation intervals, the more positive the effect on the word recall rate. The results of the experiments with humans in Figure 2 reflect this natural prediction. Contrarily, in the simulated experiments, the effect of presentation intervals disappeared later in the presentation, which is an unexpected result. We refer to this as an anomalous result. In scientific activities, it is important to explain these anomalies (Kulkarni & Simon 1988).

## 3.2 Analysis of Participants' Reports

Figure 3 shows a summary of the analysis of reports submitted by the participants.

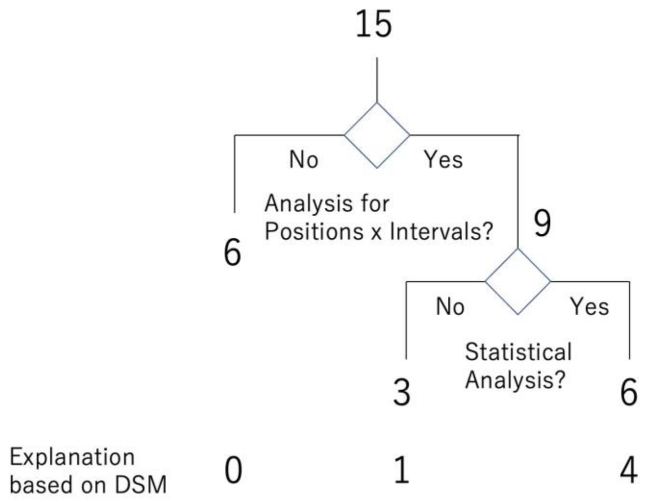


Figure 3. Summary analysis of participants' reports

To perceive the anomalous pattern in the results, participants were required to draw a graph such as 1(a), indicating the interaction effect of the word presentation intervals and the positions of word presentation. Nine of the fifteen participants in the class depicted a graph(s) in which an anomaly pattern was revealed, as shown in Figure 1(a). Contrarily, the other six participants depicted other types of graphs. Specifically, four of them drew a graph(s) from the viewpoint of their working memory capacity, similar to Figure 1(b). The other two participants depicted graphs that violated the representative format of the analysis.

Next, six of the nine participants who drew similar graph(s), as shown in Figure 1(a), detected a statistically significant interaction between the presentation interval factor and the word presentation position; the other three participants did not perform the statistical analysis or did not detect a significant interaction. Four of the former six and one of the latter three participants successfully explained the anomalous pattern based on the dual storage model of memory (DSM).

The following is an example of a normative explanation for the anomalous pattern found in the simulation results:

> The larger primacy effect in the long interval condition is due to the fact that longer word presentation intervals increase the number of times words in short-term memory are rehearsed, increasing the probability that they will be sent to long-term memory. However, this effect in the long interval condition disappears in the recency effect because the increased likelihood that the words in the short-term memory are forgotten due to time decay, cancels out the effect of rehearsal.

# 4. DISCUSSION AND CONCLUSIONS

Figure 3 indicates that all the participants who successfully explained the anomalous pattern in the experimental result depicted a graph(s) that is profitable for the analysis of the interaction between the word presentation position factor and the presentation interval factor. Contrarily, the participants who performed the analysis based on other factors, could not successfully explain the pattern because they did not find an anomalous pattern in the graph(s) they depicted. This means that the type of graph depicted first, is crucial for successful explanation. We note that the crucial factor that determines whether a successful or failed explanation is constructed, depends on accidental matters.

Importantly, this explanation requires a clear understanding of how primacy and recency effects are caused by different reasons. That is, the former is brought about by the transfer of words in the short-term memory to the long-term memory, whereas the latter is brought about by the recall of encoded items in the short-term memory. We believe that the participants developed this understanding as they attempted to explain the interaction pattern between the word presentation intervals and presentation positions in the results of the simulated experiments.

In the simulated experiments, the cognitive information processing process of the simulation model is clearly disclosed, and the results of the simulations are based on that process faithfully executed by the model. The participants were likely attempting to explain the results of the experiments through mental simulations (Chi 2009) of the cognitive information processing process of the computer model to explain the results that appear in the simulations. It is important to clarify what types of learning activities can be facilitated by the introduction of simulated experiments in the future.

However, it is important to note that the results of the simulated experiments do not accurately reflect the results of the human experiments. The interaction effect observed in the simulated experiments was not observed in experiments with human subjects. In this practice, participants referred to and discussed only the results of the simulated experiments. Furthermore, it is expected that by comparing and contrasting the results of the simulations with the results of human experiments, a more in-depth discussion of the results will be presented (Gadgil et al. 2012).

We have not been able to examine how students perceive the application of simulated experiments and how they feel about using them instead of human experimentation. In future work, we would like to pay more attention to this point by collecting interview data from participants to find out why they chose the strategy to explain the anomaly.

The authors also conducted a similar class practice with undergraduate students who did not major in psychology. Analysis of the submitted reports showed that a significant number of participants did not perform normative analysis in psychological experiments. Thus, they were not able to reach the depth of understanding obtained in the current class practice for graduate students. These results imply that careful consideration of knowledge, skills, and abilities of participants should be done when introducing the practice of computer-based simulated experiments in the classroom.

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