Wong, L.-H. et al. (Eds.) (2013). Proceedings of the 21st International Conference on Computers in Education. Indonesia: Asia-Pacific Society for Computers in Education

Construction of a Cognitive Simulator for Human Memory Process and Class Practice

Kazuhisa MIWA[a*], Junya MORITA[b], Hitoshi TERAI[a], Nana KANZAKI[c], Ryuichi NAKAIKE[d], Kazuaki KOJIMA[e], Hitomi SAITO[f]
[a]*Graduate School of Information Science, Nagoya University, JAPAN*
[b]*Graduate School of Knowledge Science, Japan Advanced Institute of Science and Technology, JAPAN*
[c]*Junior College, Nagoya Woman's University, JAPAN*
[d]*Graduate School of Education, Kyoto University, JAPAN*
[e]*Learning Technology Laboratory, Teikyo University, JAPAN*
[f]*Faculty of Education, Aichi University of Education, JAPAN*
*miwa@is.nagoya-u.ac.jp

Abstract: For practice-based science education, the authors developed a cognitive simulator that demonstrates the human memory process and simulates the serial position effect in different experimental situations. Our cognitive simulator as a learning tool is established on the basis of the dual storage model; it visualizes the items stored in the short-term and long-term memories. The participants learn how the model works while confirming which items are rehearsed in the short-term memory, encoded into the long-term memory, or overflowed from the memory. We designed and performed practice-based psychological training through two university class sessions of the author's cognitive science class. The results of the practice showed that participants' data interpretation and data prediction were improved through class activities. More specifically, the participants explained the observed data using naïve concepts prior to the learning phase, but they subsequently explained them using theoretically defined concepts of the dual storage model. Furthermore, the participants were successfully guided to predict the experimental results more accurately by the learning activities using the cognitive simulator.

Keywords: Cognitive model, Dual storage model, Serial position effect, Psychology education

1. Introduction

Computational cognitive models have a central role in the investigation of the human mind in cognitive science. Such models exemplify hypotheses regarding cognitive information processing performed in the human mind as a computer program and empirically examine the hypotheses through the comparison of computer simulation results and human data obtained in psychological experiments. Computational modeling has opened a new era of science concerning the human mind through the development of this new and innovative research tool. The utilities of computational cognitive models as *research tools* have been widely approved through a long history of cognitive science studies.

In a previous study, we have investigated the functions of computational cognitive models as *learning tools* (Miwa, Morita, Nakaike, and Terai, in press). Further, we have proposed a new instructional design, learning by creating cognitive models, and confirmed empirical evidence of its effectiveness thorough actual class activities. The computational model used in this study works as a cognitive simulator, visualizing the inner statuses of the cognitive system and flows of information.

The purpose of this study is to demonstrate that participants' scientific activities improve by using such a cognitive simulator as a learning tool. We focus on two learning activities: data interpretation and data prediction in psychology domain. In general, practice-based psychology education is performed by having participants perform experiments, analyze the data, and interpret the results. We add the model-based approach in such a practice-based training. This approach teaches participants top-down and theory-based thinking, whereas the former approach teaches them bottom-up and evidence-based thinking. These two types of thinking are critically important not only in psychology but also in various types of natural and human sciences.

Before presenting our hypotheses, we should make a clear distinction between a theory and model. In the following description, a theory refers to a conceptual theory. In general, such a conceptual theory is described using natural language, and sometimes, it is depicted by diagrammatic representations such as a flowchart. A theory may offer abstract prediction, but it does not lead to more precise observed data (such as concrete experimental results) in a specific condition. On the other hand, in the present study, a model refers to a computational model. A model is described as a computer program that runs on a computer. It predicts specific experimental results in a hypothesized condition by computer simulations. A theory is given empirical feedback from the comparison between simulation results and psychological experiments.

Our first hypothesis is as follows: learning with computational cognitive models may activate participants' theory-based data interpretation. Theory-based data interpretation means that participants interpret experimental data from the viewpoint of a theory by using theoretical terms and concepts defined in the theory. Science develops as initial regularities and patterns of observed data are identified (data description), and then, the reasons why such patterns emerge are explained (data interpretation). In the learning of science, such explanative activities are crucially important. Because a theory is conceptually indicated, participants may not be capable of directly connecting the theory and data. Such participants very often face difficulties about explaining why specific data patterns in experimental results emerge based on a theory. Our cognitive simulator demonstrates the process of generating the output, helping participants grasp the relation between theory and data. This may improve participants' theory-based data interpretation.

In addition, data prediction is essential in scientific activities. For data prediction, we should be familiar with the mechanisms behind observed data. If we do not obtain knowledge about such mechanisms, we cannot know anything about what happens in advance prior to observing the phenomenon. In psychology, observed data refers to experimental results and mechanisms are described as cognitive information processing performed in the mind. Our cognitive simulator is expected to help participants grasp the inner behavior of the system. When participants understand information processing of the system accurately, they learn to perform mental simulations of the system in their mind; thus, they accurately predict the experimental results in a hypothesized situation.

Our second hypothesis is as follows: learning with computational cognitive models may lead to a participant's deeper understanding regarding the mechanisms of the cognitive system; thus, participants may predict the experimental results in a hypothesized situation more accurately.

We examine the two aforementioned hypotheses through participants' learning activities in an actual classroom setting.

2. Learning Material

2.1 Serial Position Effect

In our practice, we selected a popular and well-known psychological phenomenon concerning human memory, the serial position effect, as a learning material (e.g., Murdock, 1964). The serial position effect is one of the most famous findings that has been confirmed in many laboratory studies and is a learning topic in almost all introductory textbooks of experimental psychology. A representative characteristic of the serial position effect is as follows: when participants are presented with a list of words, they tend to remember the first few and last few words and are more likely to forget those in the middle of the list. The tendency to recall earlier words is called the primacy effect; the tendency to recall the later words is called the recency effect. Figure 1 shows a representative result reported in Rundus (1971).

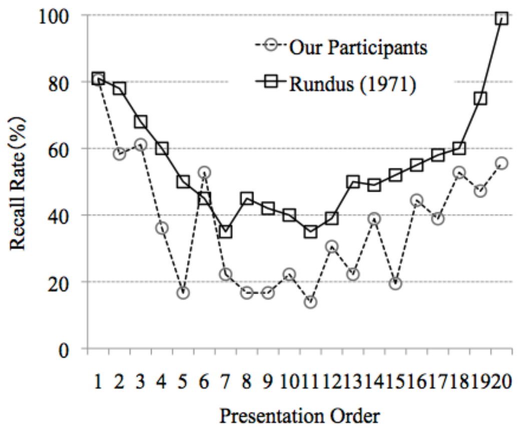

Figure 1: A representative experimental result indicating the special position effect. The horizontal axis shows the order of presentation items, and the vertical axis shows the average recall ratio of each item. The bold line shows a representative example result reported in Rundus (1971), and the dotted line shows the result of our participants (see Section 4).

2.2 Dual Storage Model

The serial position effect is explained on the basis of the dual storage model of human memory (Atkinson and Shiffrin, 1971), which hypothesized a multiplicity of the memory system. A primary concern of our practice is the distinction between the short-term and long-term memories. Sensory information obtained from the outside world is temporally stored in the iconic memory. Subsequently, information selectively focused in the iconic memory is sent to the short-term memory; however, it is maintained only for about 15–30 s. Without rehearsals of items, they are soon erased from the short-time memory. Through rehearsal activities, the information in the short-term memory is encoded into the long-term memory. Once the information is encoded in the long-term memory, it is never forgotten. The primacy effect emerges because only the words presented earlier are put into the long-term memory through rehearsals. The recency effect appears because the words from the end are left in the short-term memory and directly retrieved from the memory when asked to be reported. In contrast, the words in the middle of the list have been there for too long to be held in the short-term memory and not long enough to be encoded into the long-term memory.

3. Cognitive Simulator

Figure 2 shows the summary of our production system model.

Our model on the server consists of nine production rules.

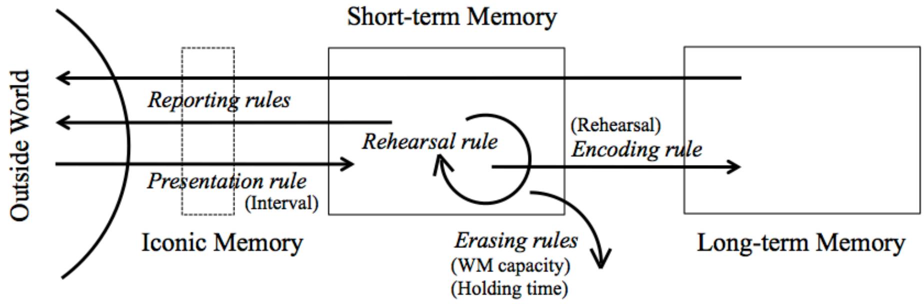

Figure 2: Summary of the production system model. Italic letters indicate the production rules and letters in parentheses indicate the parameters involved in the rules.

- A presentation rule: presenting an item and encoding it into the short-term memory.

- Two erasing rules: erasing items from the sort-term memory after the time limit for holding items has passed, and erasing items from the short-term memory when the number of items has exceeded the working memory capacity.
- A rehearsal rule: performing rehearsals of items in the short-term memory.
- An encoding rule: encoding items into the long-term memory.
- Two reporting rules: reporting items from the short-term and long-term memories when asked to report memorized items after all items have been presented.
- Two rules for stopping the system and increasing the time counter.

4. Class Practice

Our class practice was performed in a cognitive science class in the Graduate School of Information Science of Nagoya University. Two class sessions were assigned in this practice. A summary of the flow of the sessions is as follows.

In the first class session, the participants joined a memory recall experiment. They were presented with a series of 20 words with an interval of 3 s. After the presentation phase, they were immediately asked to recall memorized items and write them on a sheet of paper. A total of four experimental sessions were repeated. The words recalled by each participant were gathered via a web-based data collection system and analyzed using a semiautomatic analysis system. The participants were presented with the analyzed result immediately after the data were gathered. The results presented to the participants are shown in Figure 1. The result replicated crucial characteristics of the serial position effect such as the recency effect, primacy effect, and decrease of recalls of the middle terms. Subsequently, the participants were required to explain why such a U-shaped pattern emerged. We treated this result as a pretest regarding data interpretation. The participants were also required to predict the experimental results when the words were presented with intervals of 1 and 5 s. They reported the prediction by drawing two additional lines with a pencil, each of which corresponded to each of the predicted results whose presentation intervals were 1 and 5 s, on a graph in which the simulation result at 3 s was indicated.

Next, the dual storage model was conceptually explained to the participants by an instructor. They were taught fundamental functions of the model's components such as the short- and long-term memories; they received instructions concerning how the model works. Following the lecture, the participants were again required to predict the experimental results when the intervals were 1 and 5 s. The result was treated as a middle test regarding data prediction.

The second class session was conducted a week after the first session. In the second session, the participants learned how the model processes information by using our cognitive simulator. Our cognitive simulator visualized the items stored in the short-term and long-term memories. The participants were taught how the model works while confirming which items are rehearsed in the short-term memory, encoded into the long-term memory, or overflowed from the memory.

After the learning phase using the cognitive simulator, the participants were again required to explain why the U-shaped pattern emerged (as a post-test regarding data interpretation) and predict the experimental results when the words are presented with intervals of 1 and 5 s (as a post-test regarding data prediction).

5. Results

A total of 11 graduate students participated in our cognitive science class. Eight among the eleven participants who participated in both class sessions were analyzed.

5.1 Data interpretation

First, we analyzed the pre- and post-tests for data interpretation. The following are representative descriptions of two participants.

The following two descriptions were recorded in the pretest: “Words presented in the former phase are well memorized because memorizing activities can be concentrated without interest in other words. Words in the final phase are also well memorized because the delay from the memorizing timing to reporting is small” (Subject A), and “The human brain has a nature that objects initially and finally faced are well memorized” (Subject B).

The descriptions were changed in the post-test: “Words presented in the former phase are memorized in the long-term memory through plenty of rehearsals before overflows from the short-term memory. Words in the final phase are reported directly from the short-term memory even when they are not memorized in the long-term memory” (Subject A), and “Many rehearsals of the former words can be performed and sent to the long-term memory. The middle terms are impossible to be rehearsed, so they are erased from the short-term memory. The last words are memorized in the short-term memory” (Subject B).

Even in the initial phase, all participants were aware of the U-shaped pattern and demonstrated the primacy and recency effects in the experimental results. The above examples clearly indicate that the participants explained the observed data using naïve concepts before the learning phase, but they subsequently explained the data using theoretically defined concepts of the dual storage model. However, this explanation shift from the pre- to post-tests may arise from conceptual understandings of the dual storage model by a tutor’s lecture and not by the experiences of using the cognitive simulator.

5.2 Data prediction

Next, we analyzed data prediction. We examined the extent to which participants accurately drew the two lines corresponding to the results in the cases where the presentation intervals were 1 and 5 s. The drawn lines and plotted points were digitalized. For the estimation, we utilized the Euclid distance (*ED*) between a predicted line drawn by a participant and a target line obtained by computer simulations as the degree of correct prediction. The *ED* is defined by the following equation. **T** indicates a vector of the target line that consists of the simulated 20 recall rates, each of which corresponds to a recall rate of one of the presented words. **P** indicates a vector of the predicted line that consists of 20 recall rates plotted by each participant. A smaller value of the *ED* indicates a more correct prediction.

$$ED(\mathbf{T},\mathbf{P}) = \sqrt{\sum_{i=1}^{20}(T_i - P_i)^2} \quad (1)$$

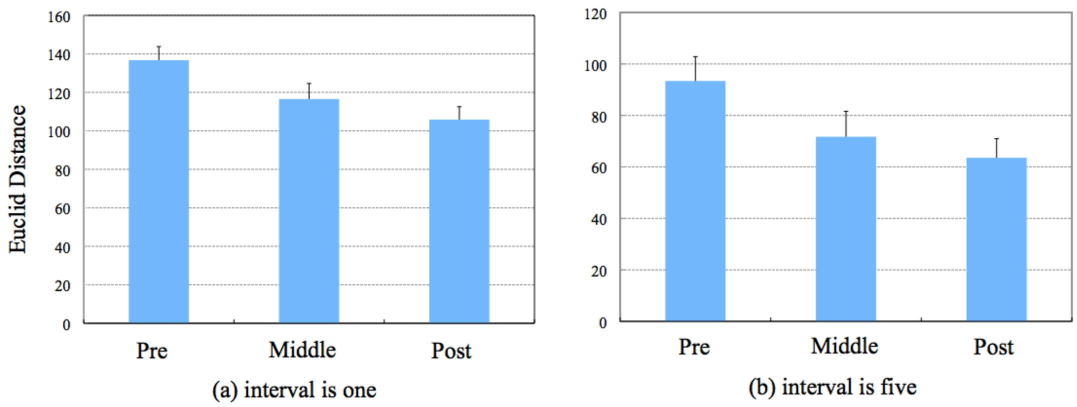

Figure 3: One-way ANOVA showed that the main effect of tests was significant ($F(2, 14) = 9.23$, $p < .01$ when the interval is 1 s; and $F(2, 14) = 5.31$, $p < .01$ when the interval is 5 s). The results of multiple comparisons using Holm’s method showed that the *ED*s between the simulated and predicted lines in the middle and post-tests were shorter than the *ED* in the pre-test when the interval was 1 s ($MSe = 213.09$, $p < .05$). The *ED* in the post-test was also shorter than the *ED* in the pretest when the interval was 5 s ($MSe = 358.07$, $p < .05$).

Figure 3 illustrates the results. Regarding data prediction, we conducted three tests: pre-, middle, and post-tests. A decrease in the value from the pre- to middle tests indicates effects of only conceptual explanations by a tutor; a decrease from the pre- to post-tests indicates effects of the experiences using the cognitive simulator with conceptual explanation.

The value of the *ED* gradually decreased from the pre- to post-tests, indicating that the participants were successfully guided to accurately predict the experimental results by the learning activities in the class practice using the cognitive simulator. In particular, in the case of 1 s interval, a statistically significant improvement was only detected between the pre- and post-tests but not between the pre- and middle tests, indicating the efficiency of the practice with our cognitive simulator.

6. Discussion and Conclusions

In this paper, we developed a cognitive simulator that demonstrates the human memory process and simulates the serial position effect in different experimental situations. We designed and performed practice-based psychological training through two university class sessions of the author's cognitive science class. The results of the practice showed that the participants' data interpretation and data prediction were improved through the class activities, indicating the advantages of using a computational cognitive model as a learning tool.

J. R. Anderson (1993) proposed the theory–model–data perspective in a research program of cognitive science. The improvement of the participants' data interpretation implies that a cognitive computational model actually functions as a mediator connecting a theory with empirical data. Even if a theory is conceptually taught, the participants may face difficulties interpreting the data from the viewpoint of the theory because of the difficulty of ascertaining a direct reference between the theory and data. The participants in our practice confirmed the behavior of the model while confirming the memory process on the computer display one by one. This activity may lead the participants to a more precise understanding of the dual storage model as a conceptual theory of human memory.

Moreover, the participants were guided to predict data patterns more precisely in hypothesized situations. For prediction, the participants need to perform the model in their mind, and infer the results through such mental simulations. This implies that through practice, the participants successfully established the dual storage model as a mental model of the human memory process that can be executed mentally. A mental model has an important role in actual science history. For example, thought experiments are believed to have played decisive roles in the discoveries of Einstein's theory of relativity and Maxwell's equations of electromagnetism. Such thought experiments are likely to be considered as a qualitative mental simulation (Nersessian, 2008). In education, the importance of instructions to support a learner's mental model construction has been recognized (Clement, 2000; Gilbert, 2004).

References

Anderson, J. R. (1993). Rules of the Mind. Hillsdale, NJ: Erlbaum.

Atkinson, R. C., & Shiffrin, R. M. (1971). The control of short-term memory. Scientific. American, 225, 82–90.

Clement, J. (2000). Model based learning as a key research area for science education. International journal of science education, 22, 1041-1053.

Gilbert, J. (2004). Models and modeling: Routes to more authentic science education. International Journal of science and mathematics education, 2, 115-130.

Miwa, K., Morita, J., Nakaike, R., & Terai, H. in press. Learning through Intermediate Problems in Creating Cognitive Models. Interactive Learning Environments

Murdock, B. B., Jr. (1962). The Serial Position Effect of Free Recall, Journal of Experimental Psychology, 64, 482-488.

Nersessian, N. (2008). Creating Scientific Concepts. Cambridge, MA: MIT press.

Rundus, D. (1971). Analysis of rehearsal processes in free recall. Journal of Experimental Psychology, 89, 63-77.