Designing the Learning Environment of Learning Laboratories: Cognitive Strategy, Learning and Transfer

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ABSTRACT

The problems of video game syndrome has been an obstacle to prove the value of Management Flight Simulators . This paper proposed a theoretical perspective of cognitive strategy to explain this phenomenon: that is, due to the reasons of (1) rational allocation of limited cognitive resources, (2) passive generation alternative methods when failed, (3) faulty mental model to represent the dynamic complexity, the cognitive strategies used by subjects, e.g., feedback control, feedforward control and memory control, are different from the cognitive strategy of mental model simulation expected by researchers. Task salience and transfer-oriented task setting were manipulated to facilitate learning with provoking the appropriate cognitive strategy. The effects of these two learning aids are tested by one laboratory experiment, and tested by multiple index with multiple measurement methods. Experimental results support the proposed theoretical perspective. The mental model simulation strategy seems not the natural cognitive strategy used by subjects. The learning aids had significant positive effects on inducing the cognitive strategy of mental model simulation, on the learning of cognitive skill of systems thinking, on the improvement of task's performance, and on the transfer performance in two transfer tasks.

Introduction

Management Flight Simulators (MFS's) has obtained more and more attentions in the system dynamics field. However, the popularity of these simulators has far outstripped the research on their effectiveness. MFS's are effective when they engage people in what Deway called "reflective thought" and what Schön calls "reflective conversation with the situation" (Sterman, 1994). However, a commonly observed behavior in MFS's is "trial and trial again" or so called "video game syndrome", where players tend to treat MFS as a video game and rapidly try many different actions without reflection. They do not take time to reflect on the outcomes, identify discrepancies between the outcomes and their expectations, formulate hypotheses to explain the discrepancies, and then devise experiments to discriminate among the competing alternatives. They simply keep trying until "their score" improves (Isaacs and Senge, 1992; Sterman, 1994). In such conditions, how can we feel confident on the effectiveness of MFS?

Since the problem of video game syndrome is so threatening to recognize the effectiveness of MFS, investigating the underlying mechanism of the phenomenon is a very important task before researching about MFSs' effectiveness. This study aimed at the investigation of the video game syndrome, particularly focused on the underlying cognitive processes behind the phenomenon, and on the methods to overcome it. In the following context, we firstly discussed the theoretical perspectives on the video game syndrome in the literature, then proposed a new perspective to see this problem. The video game syndrome would be redefined as a phenomenon of dissociation between performance and learning in dynamic complexity task. Based on the new definition, a theoretical explanation was proposed from cognitive point of view. *Task salience* and *transfer-*

oriented task setting were proposed as prescriptive methods to overcome the problem. Experimental methods were employed to examine the effect of the proposed treatments.

The theoretical perspectives on the video game syndrome

There were three theoretical perspectives about the video game syndrome in the related literature. Firstly, Isaacs and Senge (1992) argued that the video game syndrome was just the tip of the iceberg, it was caused by the defensive mechanism existed in individual, group and organiza-tional level. Participants and interventionists bring Model 1 ways of operating into the settings of MFSs' learning environment and learning methods. The video game syndrome in MFSs' environment just reflects the very tendency of human's Model 1 behavior and defensive routine (Argyris, 1990).

Although there were no experimental data to support Isaacs and Senge's argument, we believed this perspective had explanatory power especially when using MFS in organizational workshop. However, it was not the whole story. The video game syndrome was also existed in school's education system and in laboratory experiment (Paich and Sterman, 1993; Wang and Young, 1992; Young, et al., 1992), where the defensive need are much lower than that of manager's workshop in corporate. There seems existed some underlying reasons caused by humanbeing's cognitive process.

The second perspective lied in the humanbeing's poor cognitive ability to represent the dynamic complexity task of MFSs. Researches of dynamic decision making show that human-being's faulty mental models of the task environment cause the dysfunctional behaviors and misperceptions of feedbacks (Diehl, 1992; Dörner, 1980; Kleinmuntz, 1993; Sterman, 1989a, b). For example, decision makers may have an "open loop" representation of the task, attributing endogenous behavior of the system to exogenous events (Sterman, 1989a). Even decision maker might want to "close the loop", but they seem to be incapable of generating appropriate close-loop models to represent the system, they seem do not know how to do so effectively (Diehl, 1992, p.291-292). Due to lacking suitable representation, subjects were thus tend to "try and try again" and the video game syndrome occurred.

As we would discussed here, lacking suitable representation was one important cause of the video game syndrome. But, it was not the whole story. For example, if the video game syndrome was just only caused by lacking suitable representation, then the only thing left to do was how to aid subjects to shape suitable representation. In deed, offering systems thinking's tool to aid subjects to represent the task and to involve into the modeling process, was suggested by many system dynamists (Graham, et al., 1992; Senge and Sterman, 1992; Vennix, 1990). However, Wang (1994a) had offering systems thinking's tool to his experimental group, the experiment results showed that the treatments' effect were covered by the tendency of the cognitive strategy of feedforward control (see following discussion). There existed similar results in the experiment of Paich and Sterman (1993), a large part of performance improvement was caused by the knowledge of last trial's demand pattern, not by the deeper understanding of task's dynamic structure. The aid of systems thinking's representation might had it's potential effect when subjects used the cognitive strategy of mental model simulation. When using mental model simulation, subjects produce a mental model to represent the task system based on their information and knowledge. Subjects formulate decision policy from the model and test it on the MFS, and they can modify their mental model based on decision outcomes (Isaacs and Senge, 1992). If subjects do not use the mental model simulation strategy, e.g., they used trial and error, how could we expect systems thinking's tool would aid subjects to formulate effective mental model? There is no represented mental model of the task system in subject's mind.

Therefore, if we could not clarify what cognitive strategies were used by subject and how to induce the expected mental model simulation strategy, the problem of video game syndrome seemed could not be completely solved. This paper would propose a third theoretical perspective about the video game syndrome, which lied in the cognitive strategies used by subjects.

The theoretical perspectives of cognitive strategy

Redefine the problem: the dissociation between performance and learning

From cognitive point of view, the video game syndrome might be redefined as a phenomenon of dissociation between performance and learning in dynamic complexity task. The phenomenon demonstrates that practice improved subjects' performance significantly but had no effect on the inquiry of task knowledge (Berry and Broadbent, 1988; Sanderson, 1989). Recent experimental results in the task of MFSs supported such kind of definition. Paich and Sterman (1993) found that subjects' performance was significantly improved through practice, but little deeper learning was detected. Wang and Young (1992) had similar findings that performance was dissociated with task specific knowledge.

When redefined the problem as a phenomenon of dissociation between performance and learning, we found there existed a few serial researches (e.g., Berry, 1991; Berry and Broadbent, 1984, 1987, 1988) concerned about the dissociation between performance and learning and the underlying cognitive processes behind the dissociation phenomenon in simple dynamic control task . In next section, we will discuss those research results, and then used them to MFS's.

The cognitive process behind the dissociation in simple dynamic control task

A series of studies by Berry and Broadbent (e.g., Berry, 1991; Berry and Broadbent, 1984, 1987, 1988) have suggested the dissociation between task performance and associate verbalizable knowledge in simple dynamic control task. The typical tasks used by Berry and Broadbent are combined by a set of linear equations. For example, in the task of Sugar Factory, P = (2W-Pt-1) + Random Value (1, 0 or -1) , where P is the production, W is the workforce which only can vary from 100, 200,...to 1200. Subjects are asked to use W to control P to reach and maintain a target value. The task knowledge to be learned is the relations of polarity and/or quantity between decision variables and objective variables.

They showed that practice significantly improved the ability to control the task, but had no effect on the ability to answer post-task written questions. In contrast, verbal instruction on how to reach and maintain the target value significantly improved the ability to answer questions but had no effect on control performance. Moreover, there was an overall significant negative correlation between task performance and question answering. The findings were similar to those found by some system dynamists, except for the tasks used by system dynamists were more complicated.

Two possible cognitive processes were adopted to explain the dissociation (for more detail, see Sanderson, 1989). The first lies in the distinction between explicit and implicit modes of learning. That conscious self-report task specific knowledge is not available, because some information processing is done unconsciously. This is related to the long-standing idea that cognitive activity takes place in parallel at multiple levels. Another explanation lies in the idea of production-system that verbal knowledge might decay in the process of cognitive skill acquisition. As learning progresses, simple productions are replaced by more complex, inclusive productions through the knowledge-compilation process. However, the simple productions can support verbalizable knowledge about performance, but the more complex one can't, because the latter compresses a large number of initiating conditions and resulting actions. This explanation is similar to the idea that human cognitive capacity is limited, thus only the most salient information will be processed and reported.

Different cognitive strategies may be a cause to lead to the foregoing two cognitive processes. Broadbent, et al. (1986) proposed two kinds of cognitive strategies, namely, *model manipulation* and *situation matching*. For the model manipulation strategy, subjects have known relations among variables. Thus, the strategy can proceed by calculating the future consequences of each possible action, using the observation of the current situation and the knowledge of the structure of the world, and then choose the best one. For the situation matching strategy, subject stores a previously generated table that records the correct action to be taken in each of an array of situations. Using the current situation as input, subject can lookout a better action from the "situation-action-performance" table. Model manipulation strategy is based on task knowledge, then explicit learning occurred. Subjects can modify their task knowledge through the comparison between forecasts and outcomes. While the understanding about task systems is not necessary for situation matching, the only thing subject must do is to accumulate the "situation-action-performance" table, explicit learning thus does not occur. The situation matching process may be done unconsciously, so that conscious self-report of task specific knowledge is not available or the productions of situation matching become too complex to support verbalizable knowledge.

In short, the relations between performance's improvement and task knowledge's learning depend on the cognitive strategy used. The argument is comprehensive to the dissociation in MFS and will be discussed later.

Cognitive strategies most frequently employed in dynamic complexity tasks

As discussed previously, whether the relations between performance's improvement and task knowledge's learning are associate or not, depend on the cognitive strategy used. However, due to the difference between the tasks used by Berry and Broadbent and MFS researches, the cognitive strategies employed in the dynamic complexity task of MFSs are different.

For the *situation matching strategy*, since the interdependence and the shift of dominant loops in MFSs' dynamic complexity task, using the situation matching strategy in MFS's task is not so effective than used in Berry and Broadbent's task. For example, suppose one subject uses two cues to identify the situation. Based on the current situation of these two cues, he chooses one decision numerical value from the stored "situation-action-performance" table. However, this decision value may bring high score when a certain loop dominated, but worsen performance when other loop dominated. In deed, the timing of decision is at least as important as the numerical value of decision in the dynamic complexity task of MFS's.

Feedback control, feedforward control and memory control were found to be used often in MFS tasks (e.g., Brehmer, 1990; Paich and Sterman, 1993; Sterman, 1989a, b; Wang, 1994a, b; Wang and Young, 1992). For the *feedback control strategy*, system structure is treated as a black box when subjects use feedback control. While using feedback control, no more than the knowledge of polarity relations between decision and objective variables is needed to approach the goal. The pattern of decision behavior in the use of feedback control is similar to a "anchoring and adjustment" under the framework of the goal-seeking negative feedback loop (Kleinmuntz, 1993, p.228). The efficacy of feedback control strategy depends on whether the decision negative feedback loop can dominate the system.

Feedforward control is similar to feedback control that system structure is treated as a black box. To use feedforward control, forecasting based on historical data, theory, or expert's experience is the base to make decision rather than on outcomes in feedback control. For example, the pattern of production life cycle was used by subjects in Paich and Sterman's study (1993); Books' law was used by subjects in the study of Sengupta and Abdel-Hamid (1993); forecasting by experience of previous trial's pattern of system behavior in Wang and Young's study (1992). These ways of control need lower level of cognitive effort comparing to mental simulation where understanding about systems structure is necessary (Brehmer, 1990).

For the *memory control* strategy, subject test some aggregated alternatives by trial and error and memorize their effects. For example, the pricing decision in one game trial may be aggregated as some alternatives, e.g., low, median and high prices. If the pricing decision is the leverage of the system, then performance will be improved by testing, memorizing and selecting alternatives, but without understanding system's structure(Wang, 1994c).

Although these three cognitive strategies (feedback control, feedforward control and memory control) are preferred by subjects and advantageous for the improvement of performance, they are not helpful for deeper learning in MFS.

In contrast, the expected cognitive strategy by system dynamists is *mental model simulation* for its theoretical effectiveness for learning (Isaacs and Senge, 1992; Sterman, 1994). When using mental model simulation, subjects produce a mental model to represent the task system based on their information and knowledge. Subjects formulate decision policy from the model and test it on the MFS, and they can modify their mental model based on decision outcomes (Isaacs and Senge, 1992). Then, the learning about the task system occurs.

To use *model manipulation* strategy is difficult in MFS. The distinction between model manipulation and mental model simulation lies in the representation of task where the former represents task with mathematical type, the latter with a way which is comparable with rule of human thinking. Subjects can simulate policies for a long-term period with mental simulation but just one period decisions with model manipulation in MFS because of the complexity of task. In fact, subjects could hardly use model manipulation in MFS because subjects just can not compute the high order and nonlinear differential equations in MFS. Therefore, model manipulation is ignored in the following discussions.

The cognitive causes of the cognitive strategies' tendency

The foregoing discussions demonstrate that dissociation in MFS resulted from the cognitive strategies chosen by subjects are not the expected ones by system dynamists. Three main explanations, but were not mutually exclusive, for subjects tend not to use mental model simulation, had been offered in the literature (Diesel, 1992; Kleinmuntz, 1993) .

(a) *people consciously make a cost-benefit trade-off of limited cognitive resources*: Although the cognitive strategy of mental model simulation can obtain higher decision performance than other strategies, it must spend much more cognitive resources than others. Subject may rationally allocated his cognitive resources on the consideration of cost-benefit ratio, and thus choose the cognitive strategies of memory control, feedback control or feedforward control, but not the costly strategy of mental model simulation (e.g., Brehmer, 1990) .

(b) *people passively generate alternative methods, which they test by experiment and abandon only when failed*: The delay times for develop an effective strategy of mental model simulation, memory control, feedback control and feedforward control were different. To develope an effective mental model simulation takes much longer time than other three strategies. Even subjects want to employ the mental model simulation strategy, there are opportunities for subjects to passively develop another effective strategy (memory control, feedback control or feedforward control) before the shape up of mental model simulation. It is difficult for human being to abandon an effective method, thus subjects tend to hold this strategy until it break down (e.g., Wang, 1994a) .

(c) *people rely upon faulty mental models that do not capture the dynamic complexity nature of the task*: Researches of dynamic decision making show that humanbeing's faulty mental models of the task environment causes the dysfunctional behaviors and misperceptions of feedback (Brehmer, 1990; Dörner, 1980; Kleinmuntz, 1993; Sterman, 1989a, b). Due to lacking suitable representation, subjects had difficulty in formulating mental model that could capture the dynamic complexity nature of the task. Thus subjects were either tend not to use the mental model simulation strategy, or they want to use it but do not know how to do it effectively (Diesel, 1992).

Methods to overcome the dissociation

Task salience for dynamic complexity task

Rather than simply demonstrating dissociation, an alternative approach has been to look at conditions that give rise to either implicit or explicit learning. Berry and Broadbent (1988) propounded that "salience" of task could affect the used cognitive strategy. They found low salience led to implicit learning, and the relation between performance and task knowledge is vague or even negative, vice versa. Task salience, defined by Berry and Broadbent, is the probability that, if a person learns by the explicit rather than the implicit mode, the key variable will be chosen. There are three ways to increase the level of task salience as follow:

(1) To reduce irrelevant factors in situation (Broadbent, et al., 1986); for example, to reduce the number of relations of variables to be processed in a decision.

(2) To make the key events act in accordance with general knowledge from outside the task; for example, to remove the delay between actions and outcomes (Berry, 1991; Berry and Broadbent, 1988), or to add a positive feedback loop to increase the impact of actions on outcomes (Broadbent, et al., 1986).

(3) To give an explicit verbal direction as to which are the key variables; for example, to instruct subjects what kind of variables are relevant (Berry and Broadbent, 1988).

Accordingly, for system dynamists, it is possible to lead subjects to use the expected cognitive strategy through the manipulation of task salience in order to overcome the dissociation in MFS. Nevertheless, the manipulation of task salience should be modified, because task properties in MFS are different from those in the research by Berry and Broadbent.

The manipulation of task salience to induce mental model simulation strategy in MFS is possible. First, to provide subjects reference mode of the task system can increase task salience, because the key variables and their pattern of behavior are given. Second, to provide causal loop diagram can eliminate redundant information and hint subjects the polarity relations and delay between those key variables. Furthermore, causal loop diagram can instruct subjects how to represent a complex dynamic system, and reduce the barrier of using mental model simulation. Third, partial model test divides a whole complex system into several controllable parts and thus increase the salience of task (for more detail, see Young, et al., 1994). This design is similar to that in the study by Broadbent, et al. (1986) where subjects were instructed to test the relations between variables once at a time.

Attitude toward learning and transfer-oriented task setting

Attitude toward learning is the other factor to affect the use of mental model simulation strategy (Isaacs and Senge, 1992; Kleinmuntz, 1993). Subjects who are willing to learn will more likely put more cognitive resources to use mental model simulation. In contrast, subjects who have lower motivation to learn may apt to use memory control, feedback control and feedforward control to avoid severe exertion.

Goal setting, as suggested by Kleinmuntz (1993) and Brehmer (1992, p.238), may be one method to motivate subjects' motivation to learn. However, in Wang's (1994c) experiment, although high motivation was induced by goal setting, but the induced motivation and cognitive effort might be used in the wrong place. Some subjects spent their time in the cognitive strategy of memory control, but not the expected mental model simulation. They found some way to get high score, although they do not know why. The setting goal was satisfied, but the learning was not occurred. In the present study, "transfer-oriented task setting" is used to replace the method of goal setting.

Experiment Design

Table 1 describes the experimental design. The experiment had two manipulated variables and one block variables, thus shape a 2*2*2 proportional full factorial between-subjects design. The manipulation of *task salience* was contrast by *non-salience*. The manipulation of *transfer-oriented* task setting was contrast by *control-oriented* task setting. Subjects of 24 MBA students were randomly assigned to four cells of these two manipulated variables. Subjects of 20 undergraduate students, majoring in business management, were also randomly assigned to those four cells.

Table 1. Experimental Design

	MBA students		undergraduate students	
	transfer-oriented	control-oriented	transfer-oriented	control-oriented
task salience	6	6	5	5
non-salience	6	6	5	5

STRATAGM-2 was used to run the experiment(for details, see Sterman, 1989b, Sterman and Meadows, 1985). All the information of 13 variables of STRATAGM-2's model were shown in computer's monitors. Subjects made decision on computer. The 44 subjects were paid volunteers from National Sun Yat-Sen University in Taiwan, aged between 21 and 28. None had participated in such experiments used dynamic complexity task.

Subjects were asked to finish 4 trials (25 periods in one trial) of the STRATAGEM-2 task. The manipulations were manipulated during these four trials. After these four trials, one questionnaire and two transfer tasks (play 2 trials each task) were given to evaluate the used cognitive strategies and the learning performances.

Manipulation

Subjects in the group of *task salience* received an animated pattern-structure explanation in the end of every trial, while subjects in the contrast group of *non-salience* do not received this material. The explanation included the typical behavior when subjects first time interact with the task (see Sterman, 1989b), and the causal loops that produced those pattern of behavior.

Subjects in the *transfer-oriented* group received the task setting that "your task is to learn to transfer into the transfer task, the rewards are paid based on the decision performance of the transfer task." Subjects in the *control-oriented* group were not announced about the transfer task, and the every trial's decision performance of the task will influence their reward. They are forced to calculate their reward in the end of each trial.

Dependent Variables

As shown in Table 2, there are four dependent variables in the experiment: the decision performance, the learning of systems thinking, the tendency of using mental model simulation strategy and the learning transfer of the *changing-goal loop*. The dependent variables were tested by multiple index with multiple measurement methods. For example, the *learning of systems thinking* is constructed by whether or not subject can perceive and/or treat the four dominance loops (as shown in Table 2), which are assumed to be the basic cognitive schema subjects might learn and can transfer to other situations (e.g., the learning transfer of the *changing-goal loop* in Table 2). The perception and treatment of almost every one loop are operationalized by three measurement methods, include the decision rule analysis, protocol analysis of the cognitive map, and the scenario testing index. For the limitation of pages, we will only introduce the methods of the decision rule analysis (for the entire measurement method, see: Wang, 1994b).

As shown in Table 3, there are three groups of decision policies in the task. The first is the typical behavior as observed by Sterman (1989b) that increase capital to satisfy demand. The dominance loops are the *changing-goal loop A* and, if considered, the *supplyline-adjustment loop*. Based on the work of Sterman (1989b), the perception and treatment about these two loops can be observed by the variance conditions (across trials) of two parameters s1 and p.

The second group of decision policies is to increase demand to suit surplus capital. As shown in Table 3, based on different cue, there are three policies to do this. Due to the basis for comparison are different, the parameters of subjects decision rules are not suitable to represent the perception and treatment about the *changing-goal loop B*. Since this group of policies are exclusive with the first one, we decide to use the method that "what is the cost due to the use of these types of policies instead of the first one." Figure 1 showes the method. If subject keeps to use the origin policy, the performance index is 1559. However, this subject use another policy after period 15, and obtain the performance index as 2662 . So, the cost of this policy (due to he does not perceive and/or treat the *changing-goal loop B*) is 1103 (2662-1559).

The third group of decision policies is tend not to react to change, for example, keep constant decision value. All these three groups of policies are exclusive to each other, but subjects can use them in the different periods in one trial. Thus, we also use the cost index to treat this group of policies.

Results and Conclusions

Experimental results showed that these two learning aids had significant positive effects on

Table 2. The measurement methods of the dependent variables

Dependent Variables	Index	Sub-Index
decision performance		
the learning of systems thinking	perception and treatment about	
	* the *changing-goal loop A*	*parameter s1 (from decision rule analysis) *the report of the *changing-goal loop A*
	*the *changing-goal loop B*	*cost index 1 (from decision rule analysis) *the report of the *changing-goal loop B* *scenario test index: capital surplus
	*the *implicit loop*	*cost index 2 (from decision rule analysis) *the report of the *implicit loop* *scenario test index: second wave
	*the *supplyline-adjustment loop*	*parameter p/s1 (from decision rule analysis) *the report of the treatment level of delay *scenario test index: supply will over demand
the tendency of using mental model simulation	*the block box memory control	
	*the quality of the policy theory in the cognitive map	*number of concepts *number of task's concepts *number of new concepts *number of relationships *% of polarity relationships *% of correct relationships * number of material relationships *number of information relationships *number of material paths *number of information paths *length of material paths *length of information paths *the existence of the control loop
	*cognitive resource's allocation	*time taken per trial
	*the active attitude to try divergent policy	*interaction between trials and adopt policy *trials with planning
the learning transfer of the *changing-goal loop*	*the learning transfer in the transfer task A	*decision value's mean, standard deviation, maximum, average fluctuation *decision performance
	*the learning transfer in the transfer task B	*decision value's mean, standard deviation, maximum, average fluctuation *policy of no-action

Table 3. The decision policies

Policy Group	Decision policy
group 1	D=CD+s1(BT-KI)+p(CD*DD-BK)
group 2 (only existed when KI>BT)	D=s2a*(KI-BT) D=s2b*(KI-BG) D=s3c*(KI-BT+2CA-CD)
group 3 (only existed when KI<BT)	D=costant D=costant+s3*(KI-BT)

Note: BG: Backlog of Good sector CD: Capital Depreciation
BK: Backlog of Capital sector D: Decision
BT: Backlog-Total DD: Delivery Delay
CA: Capital Acquisition KI: Capital Inventory

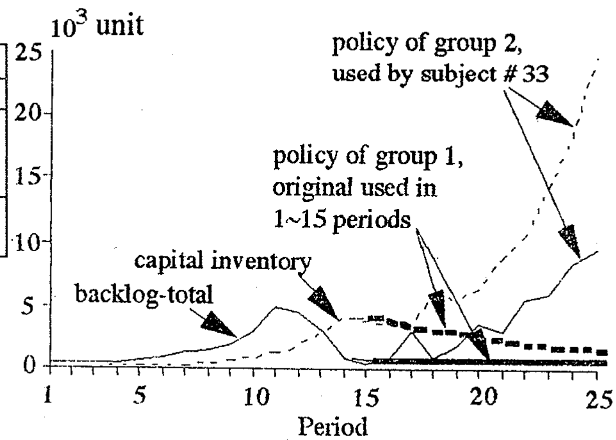

Figure 1. Measurement Method of Cost Index

inducing the cognitive strategy of mental model simulation, on the learning of cognitive skill of systems thinking, on the improvement of task's performance, and on the transfer performance in two transfer tasks. Based on those experimental results, it seemed safely to conclude that: without any learning aids, the "natural" cognitive strategy subjects used in dynamic complexity task was not the mental model simulation strategy. In contrast, the cognitive strategies of memory control, feedback control and feedforward control seem were mostly employed by subjects. Researchers of MFS's should not expect that subjects would use the mental model simulation strategy automatically, we should take the theoretical perspective of cognitive strategy into consideration .

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