Measuring the Learning of Systems Thinking: Theory and Method

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Introduction

To measure the learning of systems thinking is an important issue which challenges researchers of organizational learning laboratories and dynamic decision making. In recent years, researchers had developed some operational measurement methods, especially for dynamic decision making. In the same time, there was also existed research efforts in the study of the cognitive learning process of systems thinking. However, little research that linked the cognitive learning process of systems thinking and the operational measurement methods was done. This paper tries to construct one measurement method from the cognitive learning process of systems thinking to its operational method.

Cognitive learning process of systems thinking

There are two perspectives to analyze the contents of systems thinking. One is to divide systems thinking to some "sub-thinking abilities" (for example, dynamic thinking, close-loop thinking, generic thinking..., etc.) (Richmond, 1993). The other is to analyze systems thinking as the form of systems archetypes and generic models (Senge, 1990; Graham, 1988). From cognitive point of view, these two perspectives take very different viewpoint to hypothesize human beings' learning and transferring process. In the continuum of whether transfer is general or specific (Singley and Anderson, 1989)," sub-thinking abilities" viewpoint tends to see transfer as general. The learning of one "sub-thinking ability" in one ecology task can be transfered to another business task. The work of the teacher is to train those "sub-thinking abilities" as "mental muscles." Learning laboratories play the role as gymnasium to enhance those "mental muscles".

Nevertheless, systems archetype viewpoint is comparatively closed to the specific side. The transfer amount depends on the overlapped cognitive elements between the learning task and the transfer task (Singley and Anderson, 1989). The teacher's work is to facilitate the formulation of cognitive schema and the knowledge network structure of these schemata. The role of learning laboratories is to fasten the cumulating process of expert's knowledge which can only be constructed from experiences through learning by doing various cases.

Recent psychology literatures show that learning transfer tend toward the specific side. The durable transfer amount depends on the procedural cognitive elements shared by the training task and the transfer task (Kieras and Bovair, 1984, 1986; Polson, 1987; Singley and Anderson, 1989). So, we assume the systems archetype's viewpoint is much closed to human beings' cognitive system. In the assumed cognitive learning process, to learn systems thinking is to formulate the cognitive schemata and the knowledge network structure of these schemata. Thus, the learning amount is measured through observing the formulating process. In order to observe the formulating process, the first thing we must know is to understand the formulating process. It is good to start from analyzing what systems thinking experts will do when faced the dynamic complexity task, and what and how they will learn to enrich their knowledge structures.

When faced the dynamic complexity task, we found that experts of systems thinking will (1) consciously perceive their "policies," (2) try to understand what feedback loops will be formed by the interactions between their policies and the task's infrastructure, (3) detect the dominant loops existed in the task's infrastructure, (4) perceive the delay time and its effects, (5) integrate loops and delays to explain system's behaviors, (6) reflect and challenge the deeper assumption in their policies, and (7) design new policies to produce desired system's behavior.

Those characters form a more complete learning process from observation, hypothesis formulation, testing to evaluation. After experiencing the task, experts may learn one new system structure, may learn what behavior cues was associated to what loops, may enhance the ability to reflect the interactions between mental model and the real world...etc. In sum, experts then can enrich their knowledge structure by learning cognitive schemata which were something like systems archetypes. Using the same process, people can also learn system thinking's knowledge structure, although they may learn less than expert.

Measurement Method

So, the next thing we need to do is to analyze what cognitive schemata existed in the experiment task, and to design operational measurement indices to measure what schemata subjects have learned. This paper use Stratagem-2 as experiment task (Sterman, 1989). We categorize five schemata in the Stratagem-2 task, as shown in column 2 of Table 1. We use three methods to construct sixteen indices for these five schemata. The first is cognitive map method and the theory of "quality of policy." The second is the scenario testing questionnaire. The third is the decision rule analysis by fitting subjects' decision rules with statistic method.

Schema 1: Degree of consciously perceived policy (inventory control policy)

Stratagem-2 can be described as inventory control task (Sterman, 1989). To perceive one's own "policy" is one thing worth to be learned in systems thinking. To learn the general form of the inventory control policy is another thing worth to be learned.

In the end of the experiment, subject was asked to answer two questions. (1) if someone wants to play the task, please suggest him some policies, decision rules, decision methods (include should use and should not use). (2) explain why you suggest so (McGeorge and Burton, 1989). The answer was coded as cognitive map by the representation of causal loop diagram as done by Vennix (1990). However, information links were specially distinguished to study the degree subjects can perceive their own policies. Based on the theory of "quality of policy" (Vennix, 1990), three indices were coded, include (1) number of information relationships, (2) number of information paths, and (3) length of information paths.

Schema 2: the changing-goal loop A (understand the loops formed by policy and task's infrastructure)

The typical behavior subjects shaped in the first trial (one trial contain 25 periods) can be described as Figure 1 (Bakken, 1989; Sterman, 1989). The dominant loop is so called "the changing-goal loop A". The decision rule can be described as Policy A.1 (Table 1) in we so called "policy series A" (Sterman, 1989).

If subjects perceived the virtuous effect of "the changing-goal loop A", they would change their decision methods in the next three trials. Then, the parameter s1 would be changed. Therefore, to observe the variant conditions of parameter s1 across trials would show the condition subjects learned the schema of "the changing-goal loop A".

Finally, the learning condition can also be measured from the report in cognitive map. In the following schemata, this measurement indices will be the same.

Schema 3: the supplyline-adjustment loop (perceive the delay time and it's effects)

Policy series A contain another form, that is, so called Policy A.2 (Table 1). It means subjects had considered the delayed flow in supplyline (Sterman, 1989). If subjects perceived the delayed supplyline effect, the variant conditions of parameter p across trials would show the learning sign.

The other index is a scenario test index. In the end of the experiment, subjects were asked to respond one pre-set scenario. Figure 2 was an example. The scenario is a condition which needs to cut investment (decision variable) because the capital in supplyline will soon lead to over capacity. From the answer, we can know whether subjects have learned the knowledge in action or not. Also, in the following schemata, this measurement indices will be the same.

Schema 4: the changing-goal loop B (understand the loops formed by policy and task's infrastructure)

In the Stratagem-2 task, policy series A were not the only policy series. There are two more policy series. If subjects used series A, the system behaviors were dominated by the changing-goal loop A and/or the supplyline-adjustment loop. However, if subjects used policy series B (or series C, see Schema 5), the system behavior would be dominated by "the changing-goal loop B" shown in Figure 3.1 (or "the implicit loop" in Figure 4).

When capital inventory was higher then demand, there are two ways can be choosen. One is to cut investment decision while waiting capital inventory depreciated (that is, policy series A). The other is to invest aggressively to stimulate demand to fit the existed capital inventory (policy series B).

However, due to the anchored variables in these three B series policies were different (Table 1), the parameters of s2a, s2b, s2c could not be compared directly. This paper then map those differences to the same dimension, that is, the cost index. As shown in Figure 3.2, The cost index is measured by the cost caused by subject used policy B series when he choose not to use policy A series. In general, "the changing-goal loop B" is more costly then "the changing-goal loop A". If the subject had used policy B series, subject who perceived this virturous loop would not use these B policies. Then, the variant condition of the cost index would reflect the learning condition.

Schema 5: the implicit loop (detect the dominant loops in the task's infrastructure)

The C series policies used a passive strategy. That is, subjects did not respond the changing system's behavior. As shown in Figure 4, the system behavior was dominated by the so called "implicit loop." The measurement index was also mapped to the cost index. Finally, the consideration of the depreciation term was also mapped into this cost index.

Results

Experiment results showed that the fitness degree of these decision rules or policies is very good[1]. The average R-squares of four trials were 0.803, 0.845, 0.855, 0.844. There were respectively 77%, 79%, 88%, 79% of subjects whose R-squares were larger than 0.7. The degree to reproduce the system behavior is also good enough. Using the fitted decision rules to simulate, the average differences between simulated performance and original performance were 6.9%, 5.0%, 6.4% and 8.4% respectively in four trials.

Experiment results also showed that different indices of the same variable produce very similar results. Subjects who had not learned the archetype's schemata in the training task would have worse performance in the transfer task. In contrast, subjects who had better learning effect in the training task would get better transfer effect in the transfer task.

Although the experiment was not designed to test the correct degree between the systems archetype's perspective and the sub-ability perspective (The experiment design can see Young and Wang ,1995), the archetype's perspective seems to have the potential to predict the transfer effect in our experiment. It seems to support that the systems archetype's perspective is more fitted to human's cognitive learning process.

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[1] It is important to notice that, subject usually do not use one policy series , only especially in the next three trials. In the same trial, subject might use all three policy series (but not at the same time). If we do not fit subjects' decision rules in this way, the fitness degree is very poor.

Table 1 The measurement methods of the learning of systems thinking

expert's character	cognitive schema in task	operational measurement index	policy series in each schema
perceive policy consciously	*inventory control policy (schema 1)	*number of information relationships *number of information paths *length of information paths	–
understand the feedback loops formed by policy and task's infrastructure	*the changing-goal loop A (schema 2) *the changing-goal loop B (schema 4)	*variant condition of parameter s1 across trials *report of the changing-goal loop A *variant condition of cost index 1 across trials *report of the changing-goal loop B *scenario test index: capital surplus	A.1 D = s1*(TB- KI) B.1 D = s2a*(KI - TB) B.2 D = s2b*(KI - BGS) B.3 D = s2c*(KI - TB + 2*KA -KD)
detect the dominate loops in infrastructure	*the implicit loop (schema 5)	*variant condition of cost index 2 across trials *report of the implicit loop *scenario test index: second wave	C.1 D = constant C.2 D = constant + s3*(KI - TB)
perceive the delay time and it's effects	*the supplyline-adjustment loop (schema 3)	*variant condition of parameter p across trials *report of the treatment level of delay *scenario test index: supply will over demand	A.2 D = s1*(TB - KI) + p*(KD * DD - BKS)

(Note for column 4): BKS: Backlog_of_Capital_Sector; BGS: Backlog_of_Good_Sector; D: Decision; DD: Delivery_Delay; TB: Total_Backlog; KA: Capital_ Acquisition; KD: Capital_Depreciation; KI: Capital_Inventory

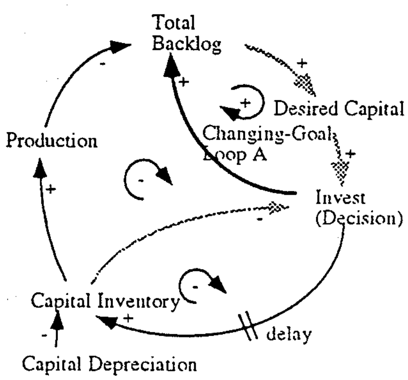

Figure 1: Policy A.1 and the Structure

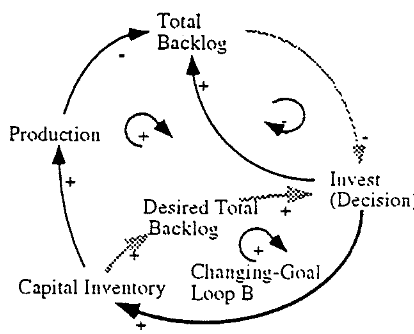

Figure 3.1: Policy B series and the Structure

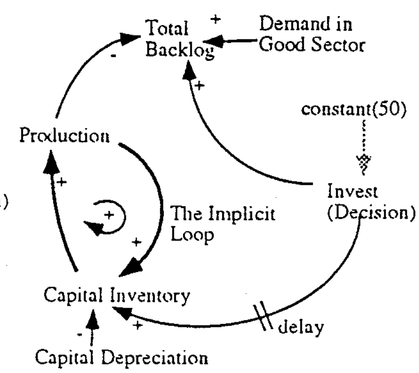

Figure 5: Policy C.1 and the Structure

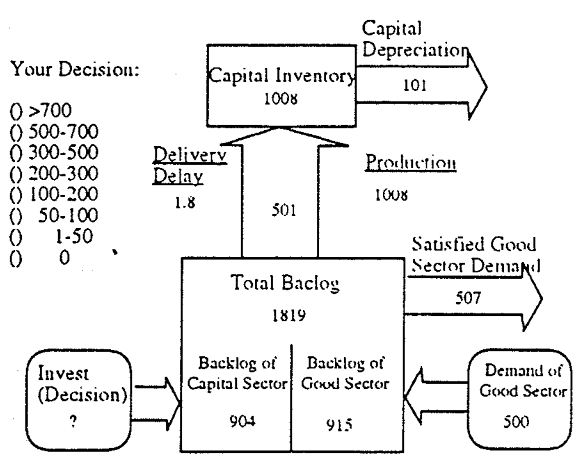

Figure 2: Measurement Method of the Scenario Test Index

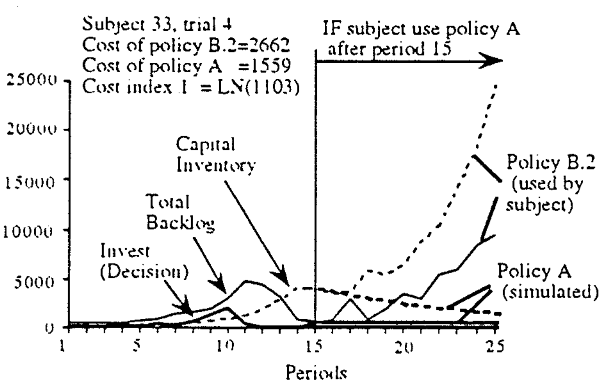

Figure 3.2: Coding Method of the Cost Index 1

References(please see the virtual proceedings for other references)

Singly, M. K. and Anderson, J. R., 1989, The Transfer of Cognitive Skill, Cambridge, MA: Harvard University Press.