Systems Thinking Tools in Management: Some Lab Experiences

Carlos Capelo
PhD Student
ISCTE
Ald. Vale S.Gião, 50, 2665-381 Milharado, Portugal
Phone: +351962831740
carlos.capelo@galpenergia.com

João Ferreira Dias
Associate Professor
ADETTI/ISCTE
Av das Forças Armadas, 1649-026 Lisboa, Portugal
Phone: +351938450825
fdias@iscte.pt

Introduction

As the world changes ever faster, managers increasingly recognize how important is to understand the dynamic complexity below the management problems.

In the last fifty year, a tremendous development has been done in the system theory not only in the conceptual field but also in applied methodology and technology. So are the System Dynamics theory and the Balanced Scorecard, this one a systemic approach to the strategic management of a firm. Both are tools that may help decision makers to enrich their mental models.

Simultaneously, the bounded rationality has been studied in several perspectives, like the cognitive limitations associated with the nonlinearities of system dynamics and the decision consequences of nonsimilarities between the perception and the reality.

In this paper we present some results of the experiments we have done in a Strategy Lab to evaluate the importance of system dynamics tools, like the Balanced Scorecard, to reach a correct perception of the reality and to analyse the performance implications of erroneous mental models, both in the structural and behavioural dimensions.

Key words: System Dynamics; Strategy Simulators; Balanced Scorecard

Theoretical Framework - Mental Models

Mental model can be defined as “a relatively enduring and acessibile, but limited, internal conceptual representation of an external system (historical, existing, or projected) whose structure is analogous to the perceived structure of that system.” (Doyle & Ford,1998, 1999), that is used to describe, explain and predict system behavior (Craik, 1943, Johnson-Laird, 1983).

Managers build their mental models as they interact with the business system they are embedded and make decisions and learn in the context of feedback loops. Decisions are the result of applying decision rules and policies that are in turn governed by manager’ mental models (Forrester, 1961; Sterman, 2000).

In the single-loop learning, managers compare information about the state of real system to goals, perceive deviations between desired and actual states, and make the decisions they believe will move the system towards the desired state. In this process, the information about system state is the only input to decision making.

The single-loop learning does not change the managers' mental models. In the double-loop learning (Argyris, 1999), information about the business system is not only used to make decisions within the context of existing frames, but also feeds back to alter managers' mental models (Sterman, 2000). As their mental models change, managers define new strategies and policies.

Doyle, Ford, Radzicki and Trees (2001) based their work on a dynamic model of decision-making process based on 5 feedback loops (figure 2: C1 - heuristic decision making loop; C2 - attention/scanning loop; C3 - mental model formation/ perception loop; C4 – strategy/objectives-changing loop; C5 mental model based decision making loop) where the mental models assume a central role. In that model, managers define strategy and objectives by mentally simulating their mental models about the business system.

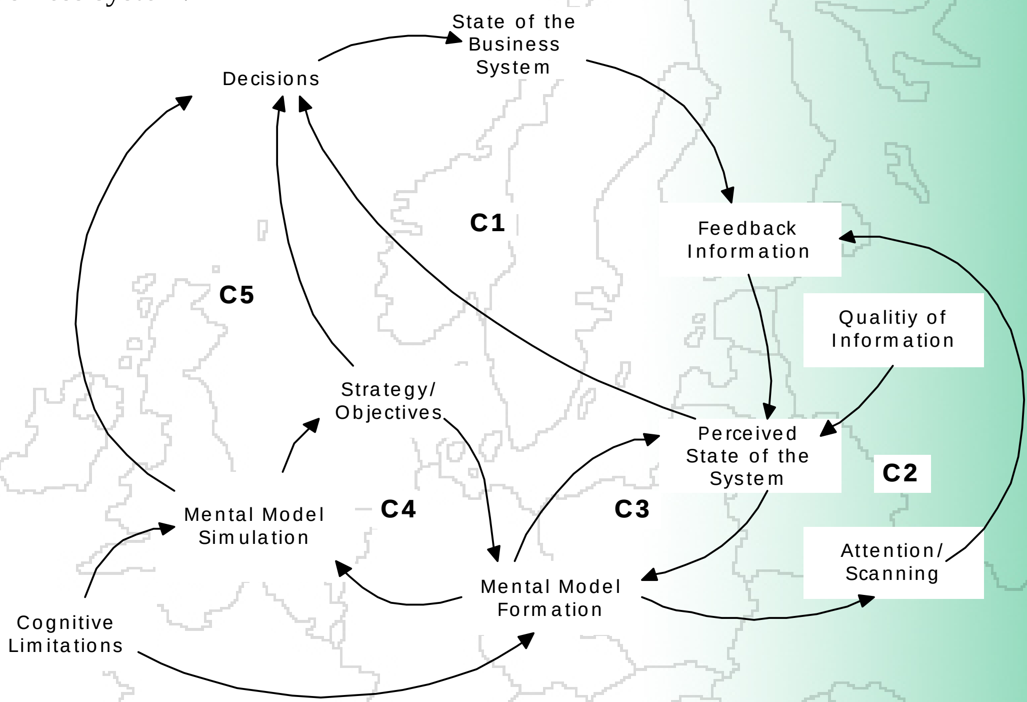


Figure 1 – Dynamic model of decision-making process
Adapted from Doyle, Ford, Radzicki and Trees (2001, p 22)

As represented in figure 1, cognitive limitations and quality of feedback information influence the potential for strategic learning and performance by limiting managers' understanding about the real business system. Cognitive limitations are related to the bounded rationality of human decision-making (Simon, 1997). Due to limitations of cognitive capabilities, first - the mental models managers use to make their decisions are deficient – second – even managers form adequate mental models, are unable to correctly infer the dynamic behaviour of the business system (Sterman, 2000). Strategic learning process is also strongly influenced by the quality of the feedback information about the state of the business system. Managers use that information to interact with business system. Using imperfect feedback information, managers have an incorrect perception about the impact of their decisions, and so they are unable to build their mental models accurately (Sterman, 2000). Thus, performance measurement systems must be defined in order to overcome or minimize these barriers to strategic learning.

Theoretical Framework - System Dynamics

System dynamics is a methodology that is framed by the systemic paradigm and was firstly proposed by Forrester, in the fifties. Contrasting with the econometric models that start from the relationships between the behaviour of the variables in order to estimate the underlying relational model, system dynamics starts from modelling the structure of the system that determines the behaviour of the variables.

Based on the homomorphism proprieties – systems from different nature but with the same structure have the same dynamic behaviour – Forrester (1961) postulated that: (1) the internal structure determines the system's dynamic behaviour, and (2) the structure can be formally modelled by a network of feedback loops linking only two types – stock or level and flow or rate - of relevant variables, and (3) the dynamic behaviour must be simulated using computers.

The start point of system dynamics methodology is to identify a problem. This problem with its dynamic hypothesis will guide the border delimitation and the selection of relevant variables and their causal interactions. The relations are only causal, while the causality could be delayed. All the variables and relations must be algebraically defined to allow simulation. The system representation by system dynamics is no more than a reprint of an individual mental model by a causal cognitive map. Once the model built, it can be feed with data and the dynamic behaviour analysis through simulation can start. The modelling and the simulation process can be assisted by specialized software like Powersim, Vensim, Stella or others.

Theoretical Framework - Balanced Scorecard

The Balanced Scorecard (BSC) is an integrated and holistic approach to business management and performance proposed by Kaplan and Norton (1992, 1996) with the aim to overcome some strategic management limitations of the traditional performance measurement systems that were based mainly on financial measures.

BSC framework is based on strategy maps and performance measures. Strategy maps provide a medium by which managers can describe their perceptions about the business system structure, i.e. the causal interrelations between relevant variables, while four scorecards, linking key lead (performance drivers) and lag (outcome measures) indicators, gives a balanced perspective, in the financial, customer, process and, learning and growth dimensions, of the dynamic behavior of the whole organization.

It is clear that BSC is consistent with the systemic and dynamical view of business management and performance measurement. Strategy maps provide a medium by which managers can externalise and improve their mental models about the business structure and dynamics and the performance indicators of the balanced scorecards aims to capture the essential of the organization behaviour. These key performance indicators are linked together in a causal diagram that represents the hypotheses given on the strategy maps.

Kaplan and Norton (2001) propose that the BSC approach also supports Argyris double-loop learning, what facilitates the strategic learning of the managers and leads to better performance. In a continual process, managers use the BSC and strategy map to reflect on the assumptions that were used in the previous strategy. They review the assumed cause-and-effect relationships and identify new ones. Then they improve their understanding about the business system and a new strategy can emerge. In other words, the BSC approach provides a process by which managers can explicit and improve their mental models about the business system. They adapt the company strategy and define the new short and middle term objectives by simulating their mental models to infer the future behavior of the business system.

BSC Experience

We use the BSC framework to understand how the strategic decision process and its performance were affected by the quality of the mental models.

To do this we conducted a simulation-based research using a system dynamics-based micro world, developed by Ritchie-Dunham (2002) that captures the dynamic complexity of real management roles in the wireless telecommunication industry.

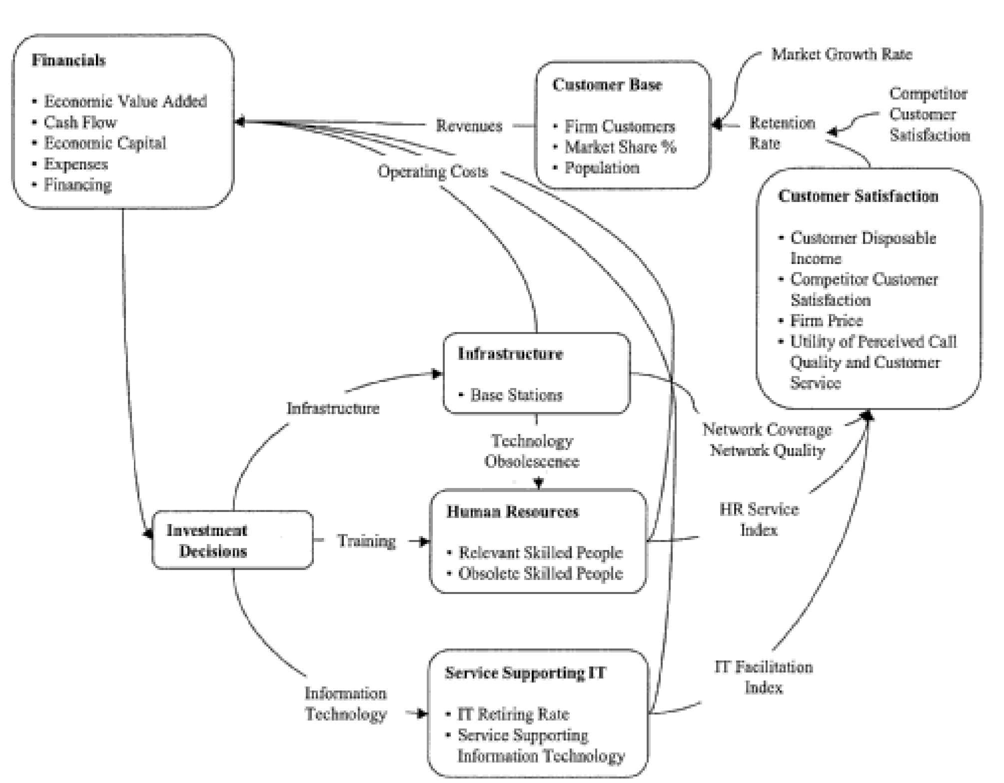


Figure 2 – Overview of the simulator model (Ritchie-Dunham, 2002)

The model considers two independent variables, the Level of Scorecard and the Level of Strategy Map. The Level of Scorecard was classified as high or low, depending if the performance set was a balanced scorecard or a simple financial one. The Level of Strategy Map was classified as high or low, depending if a strategy map was or was not used.

The quality of the mental model was measured by the similarity between the structure of the elicited mental models from the participants and the structure of the simulated business system, the last one known by us but not by the participants. This can be done by the Pathfinder procedure (Schvaneveldt, 1990; Rowe and Cooke, 1995). Mental Model Similarity ranges from 0 (low similarity) to 1 (high similarity) and is determined by the number of links in common divided by the total number of links in both networks.

The performance dependent variable value is estimated by summing the yearly discounted economic profit or EVA (=NOPLAT – Capital Employed x WACC), (Copeland, Koller and Murrin, 2000).

The research model allows us to test the following four hypotheses (Fig. 3).

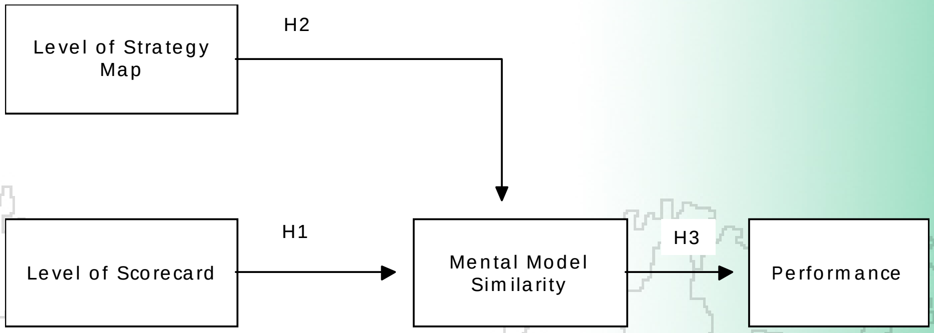


Figure 3. Model of Hypotheses

H1: If managers use the performance measurement system from BSC in the process of strategy review and implementation, they have a more effective double-loop learning. It means that Level of Scorecard utilization positively influences Mental Model Similarity.
H2: If managers use the strategy map tool of the BSC to support strategy review and implementation, they have a more effective double-loop learning. It means that Level of Strategy Map utilization positively influences the Mental Model Similarity.
H3: Mental Model Similarity positively influences Performance (financial value creation).
H4: Mental Model Similarity positively mediates the effect of Level of Scorecard and the effect of Level of Strategy Map, on Performance.

Subjects and Procedures

This research was conducted with a realistic simulator of a wireless telecommunications firm by making strategic decisions every six months for a simulation period of seven years. Participants interacted with simulator by two different interfaces: a financial scorecard or a balanced scorecard. The initial conditions and the structure of the model are the same for all participants. The participants are asked to make strategic decisions in order maximize the value creation.

The participants came from ISCTE (a business graduate school in Lisbon) and from Galp Energia, one of the biggest Portuguese firms (the Portuguese oil company). At the ISCTE the group consisted of 14 undergraduate students in their last year of Business Degree. Their age ranged from 22 to 25 and they had no work experience. At Galp Energia the task were performed by a group of 59 managers. Their age ranged from 25 to 54 and they had an average 13 years of work experience. The simulation task were individual, anonymous and without rewards. The participants had no experience with the simulator and they also had no prior specific knowledge about wireless telecommunications business.

Each participant was provided a full experiment guide with (a) demographics questionnaire; (b) description and objective of the simulation task; (c) case text; (d) instructions for accessing and starting the simulator in the computer network; (e) instructions for running the simulator; (f) questionnaire about strategy and objectives; (g) sheets for strategy map review (only for participants using strategy map); (h) questionnaire about the relatedness of some simulator variables.

The decisions made on the simulation and its results were automatically stored in a protected spreadsheet on the participant's computer. The game stopped automatically when the stop time of the simulation was reached.

There were three different treatments:
A – The participant run the firm by using a financial scorecard
B – The participant run the firm by using a balanced scorecard
C – The participant run the firm by using a balanced scorecard and reviewing a strategy map

In the treatments A and B, after simulation participants were asked to fill out a questionnaire about their final understanding on simulated business system. In this questionnaire subjects rated on a nine-point scale, the relatedness of 14 nodes in the simulation model. These 14 variables are relevant to understand the simulated business system. The 91 - (14^2 – 14)/2 - pairings were presented in random order. The structure of participant mental model is elicited by this pair-wise relatedness ratings technique. These elicited pairings are transformed into a network diagram using a network scaling procedure Pathfinder (Schvaneveldt, 1990; Rowe and Cooke, 1995).

The strategy map that was used in this experiment (treatment C) consists of a causal diagram with the same variables that are considered in the questionnaire regarding to participants' understanding of business system. These variables are spatially organized in four set of indicators respectively related to the four perspectives of the balanced scorecard.

In the treatment C, the participants after reading the case text filled out the questionnaire. This questionnaire captured their first understanding about the business system. Participants were given an initial strategy map that was drawn from the previous network diagram. This diagram represents the initial strategy that is expressed as a system of causal hypotheses. During the simulation, C participants are asked to review the causal diagram. They cut or insert links in order the causal diagram expresses their last understanding about the simulated business system. After simulation subjects produce a final strategy map. This final strategy map represents the elicited structure of subjects' mental model.

Mental Model Similarity was evaluated by the similarity between the structure of the elicited mental models from the participants and the structure of the simulated business system. MMS ranges from 0 (low similarity) to 1 (high similarity) and is determined by the number of links in common divided by the total number of links in both networks (Schvaneveldt, 1990; Rowe and Cooke, 1995).

Results
The 73 participants were distributed across the three treatments (A – 24, B – 24, C – 25). Table 1 presents minimum, maximum and mean values, and standard deviations for the dependent variables for each treatment group. Table 2 shows the test of significance for difference in means between treatment groups.

Treatment	Description	Mental Model Similarity			Performance		
		Min/Max	Mean	Standard Deviation	Min/Max	Mean	Standard Deviation
A	Low LSC, Low LSM	0.122/ 0.406	0.250	0.080	-715/ 854	329	450
B	High LSC, Low LSM	0.093/ 0.429	0.295	0.077	-1148/ 1189	310	687
C	High LSC, High LSM	0.205/ 0.708	0.443	0.126	-432/ 1089	628	409

Table 1 – Means and standard deviations for Mental Model Similarity and Performance for each treatment group

Pair	Mental Model Similarity			Performance		
	Mean Difference	Standard Deviation	Significance p	Mean Difference	Standard Deviation	Significance P
A-B	-0.045**	0.102	0.043	18	939	0.925
B-C	-0.144***	0.153	0.000	-313**	632	0.023
A-C	-0.189***	0.139	0.000	-295**	592	0.023

*p<0.1; **p<0.05; ***p<0.001

Table 2 – Test of significance for difference in means between treatment groups

The C participants showed on average the best MMS and the best Performance. As shown in table 2, the mean values of MMS and Performance for group C were significantly different from same values for groups A and B.

On average, B participants showed a better MMS than A participants (table 2 shows that such difference was significant at p<0.05). A and B participants showed similar mean value for Performance.

Table 3 shows the correlations (Pearson) for variables Initial Mental Model Similarity, Mental Model Improvement, MMS and Performance within group C. Unexpectedly, there does not seem to be a significant effect of Initial Mental Model Similarity on Mental Model Similarity or Performance. It suggests that IMMS, that represents the initial understanding about the simulated business system, does not significantly influences Performance. Thus, Performance is mostly driven by MMI, that represents the improvement of participant' understanding about the simulator.

	MMS	Performance
C - Initial Mental Model Similarity	0.246	-0.033
C – Mental Model Improvement	0.770***	0.633***

***p<0.001

Table 3 – Correlations (Pearson) for variables Initial Mental Model Similarity, Mental Model Improvement, MMS and Performance within group C

Table 4 shows the regression results on Mental Model Similarity and Performance for all independent variables. Performing a stepwise regression procedure in order to exclude the variables that do not seem to significantly explain the dependent variables and to keep the most explanatory variables, we obtain the following results:

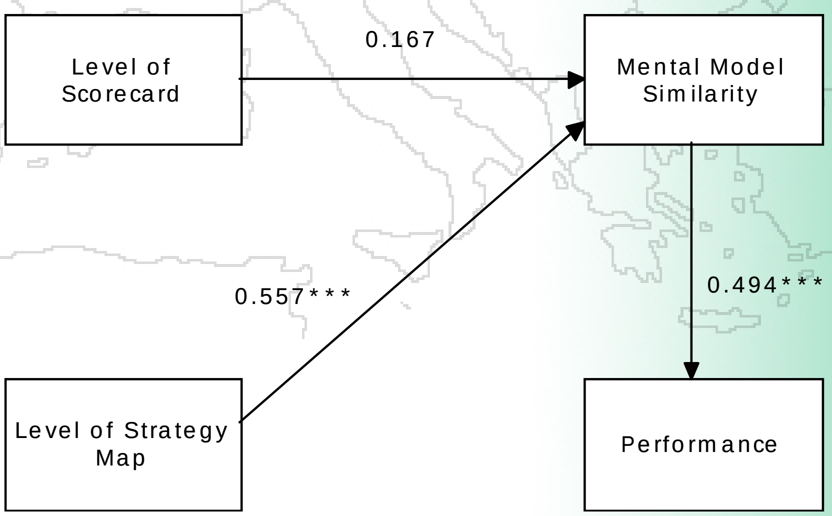
- Regressing Mental Model Similarity on the most explanatory independent variables (R^2adjusted=0.453, p<0.001) showed a very strong effect for LSM (β=0.679, p<0.001). LSC was excluded, as the effect for this variable was not significant.
- Regression on Performance (R^2adjusted =0.213 p<0.001) showed a very significant effect for MMS (β=0.421, p<0.001) and a suggestive effect for Simulation Experience (β=0.212, p<0.1).

Independent Variables	Dependent Variables			
	Mental Model Similarity		Performance	
	Standardized Beta	Significance	Standardized Beta	Significance
Time	-0.025	0.811	0.004	0.973
Age	0.132	0.227	-0.123	0.357
Simulation Experience	-0.079	0.443	0.278**	0.028
LSC	0.166	0.137	-0.154	0.264
LSM	0.615***	0.000	0.072	0.656
MMS			0.540***	0.001
Adjusted R^2	0.450		0.195	

*p<0.1; **p<0.05; ***p<0.001

Table 4 - Regression results for all independent variables

Figure 4 shows the regression model by considering the main variables that were defined in the research model. Regression on Mental Model Similarity (R^2adjusted=0.415, p<0.001) showed not very significant effect for LSC (β=0.167, p=0.115) and a very significant effect for LSM (β=0.557, p<0.001). Regression on Performance (R^2adjusted =0.233, p<0.001) showed a very significant effect for MMS (β=0.494, p<0.001).



***p<0.001

Figure 4 – Regression for research model

On average, the participants of group B - balanced scorecard interface - showed a better MMS than participants of group A - financial scorecard interface - (table 1), and such difference were significant (table 2). But the regression results did not point out a significant positive effect for LSC on Mental Model Similarity. Thus, the present research does not provide full support to Hypotheses H1 - the Level of Scorecard positively influences Mental Model Similarity.

As shown in table 5, LSM significantly influences MMS. The regression analysis “Performance (1)” shows a significant effect of LSM on Performance ($\beta=0.280$, $p<0.05$). When MMS is added to the regression analysis “Performance (2)”, MMS significantly influences Performance ($\beta=0.565$, $p<0.001$) and the influence of LSM on Performance decreases greatly and is not significant ($\beta=-0.034$, $p=0.810$). These results provide support for the mediation of Mental Model Similarity on the effect of the independent variable Level of Strategy Map on the dependent variable Performance (Hypotheses H4).

Independent Variables	Dependent Variables					
	Mental Model Similarity		Performance (1)		Performance (2)	
	Standardized Beta	Significance	Standardized Beta	Significance	Standardized Beta	Significance
LSC	0.167	0.115	-0.016	0.905	-0.110	0.372
LSM	*0.557****	*0.000*	*0.280***	*0.039*	*-0.034*	*0.810*
MMS	-	-	-	-	*0.565****	*0.000*
Adjusted R^2	0.415		0.048		0.223	

*p<0.1; **p<0.05; ***p<0.001

Table 5 - Regression Analysis: Test for Mediation of MMS

Interestingly, the results indicated that the total time participants spent on the task did not influence Mental Model Similarity or Performance.
As we expected, previous experience in business game simulators positively influenced participant performance.

Hypotheses	Description	Results
H1	LSC positively influences Mental Model Similarity	Not Full Supported
H2	LSM positively influences Mental Model Similarity	Supported
H3	MMS positively influences Performance	Supported
H4	MMS mediates the effect of LSM on Performance.	Supported

Table 6 – Summary of Hypotheses Testing

Implications to Management and Future Research
On synthesis, the results confirmed all hypotheses but H1 (table 6). The research pointed out that managers significantly improve their mental models by using strategy map in the process of strategy review and implementation, and that improved mental model similarity led to better performance. It also showed that previous experience in business game simulators positively influenced participant performance.

These results reinforces the idea that is very important to management to have a clear and systemic view of the problem and for that the system tools, like simulators and strategy maps, can help.

The virtual world experience allows (1) questioning the assumptions generally hidden, and eventually change them, (2) an insight in the system structure, its rules and vulnerabilities, and (3) a foresight of its dynamic behavior as a consequence of internal decisions and external effects (Dias, 1999).

Strategy lab must be seen as a knowledge tool that facilitates the individual and organizational double cycle learning in Argyris (1985) sense. It is possible to predict that in few years much of the teaching and the discussion of policies in management and others social sciences will be made in laboratory using virtual worlds.

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