Learning to Think in Circles:
Improving Mental Models of a Dynamic System

Paper to be presented at the

30th International System Dynamics Conference 2012,

St. Gallen, Switzerland

Martin Schaffernicht

Facultad de Ciencias Empresariales

Universidad de Talca

Avenida Lircay s/n

3460000 Talca, CHILE

martin@utalca.cl

Stefan N. Groesser

University of St. Gallen

Institute of Management

System Dynamics Group

Dufourstrasse 40a

CH - 9000 St. Gallen, Switzerland

Tel: +41 71 224 23 82 / Fax: +41 71 224 23 55

stefan.groesser@unisg.ch

Learning to Think in Circles:
Improving Mental Models of a Dynamic System

Abstract

This paper addresses the learning of feedback-thinking. Feedback-thinking is the ability to perceive circular causal relationships. Untrained individuals are known to misperceive feedback dynamics that experienced feedback-thinkers perceive with ease. What are the changes in perception of feedback that are triggered by an introduction course on system dynamics? We report on an experiment in the context of a business case study. We represent mental models of dynamic systems (MMDS) by variables, links and feedback loops. Then, we compare MMDS by using an innovative method (Schaffernicht & Groesser, 2011). We found that most of the management students in our experiments perceive feedback loops after a training intervention. However, many of the variables, links, and feedback loops that are perceived stem not from the case study description; it seems that they originate from the imagination of the individuals. This suggests that becoming a feedback-thinker is a learning process and begs the question if there are different stages of expertise. For further research, we suggest to study the performance of feedback-thinkers with different level of systems dynamics expertise and domain knowledge. By this, we detail our understanding of how feedback-thinking can be learned.

Keywords: Misperception of Feedback, Mental Models of Dynamic Systems, Learning, Experiment

1. Introduction

This paper deals with feedback-thinking. It contributes to how feedback-thinking can be learned. Misperception of feedback is the failure of a person to recognize circular cause-and-effect relations and time delays. In other words, decision makers do not realize that their actions have an influence on a specific situation which then impacts on the context of future decisions.

Previous research provides strong evidences for that the misperception of feedback hypothesis is valid even under different context conditions (Moxnes, 2000, 2004; Sterman, 1989a, b; Sweeney & Sterman, 2007). Untrained individuals tend to interpret the situations they encounter as causally linear. This type of thinking prevails even in vastly simplified laboratory settings, i.e., in settings which are based on a simple feedback loop model.

Untrained individuals can become feedback-thinkers (Sterman, 2010). However, this learning process includes a conceptual change. This change alters the intuitive, but dominant way of perceiving situations by means of linear-thinking to one of circular- or feedback-thinking.[1] Such significant changes require long periods of time and tend to occur only successively (Tardif, 2006). During this phase of change, it is likely that a learner makes decisions which are considered wrong because of his lack of experience. Hence, we have to take into account that a learner may not fail to perceive the feedback dynamics of a situation, but rather misperceive the dynamics and therefore works with insufficient mental representations. In addition, individuals in the process of learning feedback-thinking may well perceive feedback relations where the expert feedback-thinker will argue there are none. Moreover, psychological studies (Kahneman, 2011) and organizational-research (Weick, 1995) provide evidences that humans tend to make sense of new situations by using previous experiences retrieved from memory and

---

[1] We ought regard perception as an active process. System dynamics has long stated that mental models govern what we perceive and what we do not perceive, and psychologists have manifold confirmed that perception is selective. As long as an individual believes himself to be living an a world where causality goes linearly from cause to effect, and this believe is so deeply ingrained that there is not awareness of it, of course the mental representation will be construed such as to comply to what is already taken for granted. In this sense, we may compare the belief to what Kuhn termed "paradigm". Then it becomes visible that transforming oneself into a feedback thinker is also changing assumptions about the nature of the world that were not even conscious before. It also becomes clear that, once the conceptual change has occurred, one cannot easily move backward. For a discussion of "conceptual change", readers are referred to Vosniadou, S. 2007. Conceptual Change and Education. ***Human Development***, 50(47–54).

unknowingly treating them like parts of the situation. This expands the conceptual domain of the situation, and since different individuals have memorized different experiences, there is the possibility of them to construct MMDS that are different from each other.

We are not aware of studies that analyze how decision makers understand dynamically complex situations that are driven feedback relations. A gap exists about the elicitation and expression of individuals' mental models about feedback-driven systems. In the field of dynamic decision making, studies have concentrated on the processes of accumulations and delays. A few studies have taken feedback loops into account (e.g., Sweeney & Sterman, 2007), but their focus was on reasoning and they did not try to analyze MMDS with regards to their similarity with an expert's representation (for an overview of existing studies, see Groesser and Schaffernicht, 2012). One essential insight from the existing studies is the hypothesis about stock-and-flow failure; i.e., the difficulty of individuals to account for accumulations. However, these studies are silent on the issue of the individual's conceptualization of feedback dynamics and how this can be learned. This is where our study contributes. Of particular interest is the following question: What is the effect of an intervention, i.e., an introductory course in system dynamics, on the ability of decision makers to perceive feedback loops?

To answer the research question, we utilize the concept of a *mental model of dynamic systems* (MMDS). It is "a relatively enduring and accessible, but limited, internal conceptual representation of an external dynamic system (historical, existing, or projected). The internal representation is analogous to the external system and contains, on a conceptual level, reinforcing and balancing feedback loops that consist of causally linked stocks, flows, and intermediary variables. The causal links are either positive or negative, are either linear or non-linear, and can be delayed." (Groesser & Schaffernicht, 2012). A method for comparing external MMDS, which we will use in this article, has been developed by Schaffernicht and Groesser (2011). Based on the MMDS concept, we used a quasi-experimental research design. 33 undergraduate management students had to analyze a dynamic situation. By means of existing MMDS research, we were able to quantify the degree of similarity between an MMDS of the individuals and a reference model of the situation. This allowed us to attain the following two insights. First, students who were unable to perceive feedback loops at the outset of the course did recognize feedback loops to a significant degree after the intervention. And second, more interestingly, a significant fraction of the feedback loops they have perceived were actually not derived from the case description.

The paper is structured as follows. Section 2 discusses a learning model about feedback-thinking. Section 3 explains the design of our experiment and the methods we have used as interventions and for elicitation of the mental models of the participants. Section 4 provides the results of the analysis. Section 5 discusses the results. Section 6 concludes the paper by suggesting similar studies with a variety of participants.

2. Literature and Learning Theory

Let us consider a simple example. Figure 1 proposes a model with expertise in the *domain area* on the vertical axis and expertise in *feedback-thinking* on the horizontal axis. Even though we wish to focus on the dimension of feedback-thinking, we have to recognize the other dimension because it is not enough to know how to think in terms of circular causality; one has to think also about a specific content. The area is delimited by the extremes of the two dimensions with poor (on the left) and rich feedback-thinking (on the right) as well as a poor accuracy of the specific domain (on the bottom) and a rich and highly accurate knowledge (on the top). The mental representations' accuracy depends on the expertise of the individual, and while the expert can draw upon personal experience, the novice depends on his or her imagination.

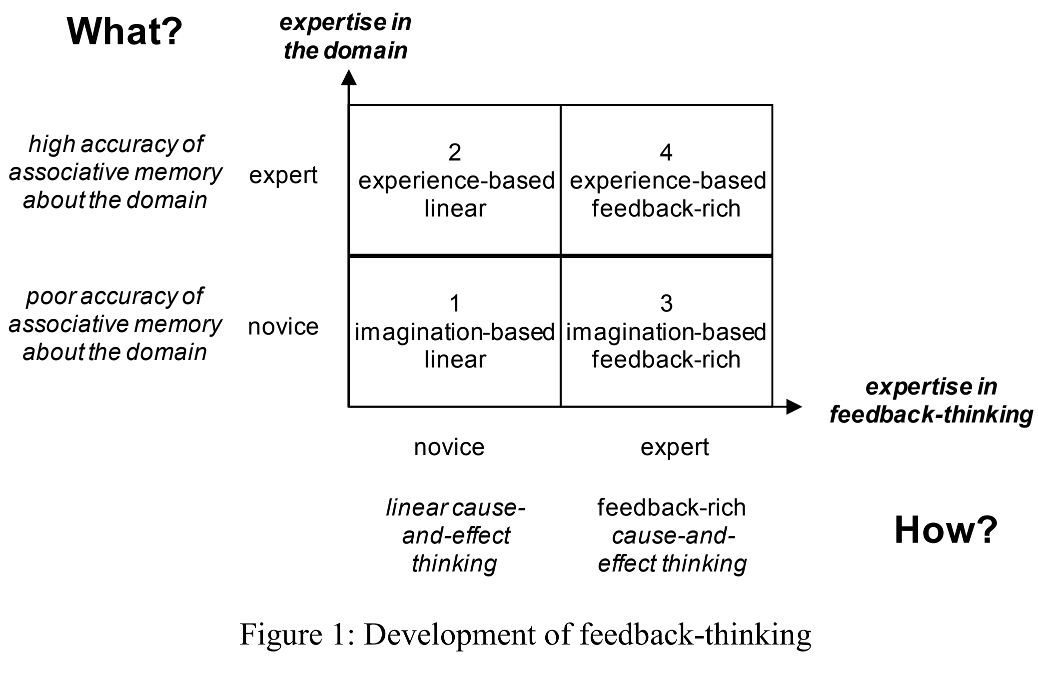

Figure 1: Development of feedback-thinking

The area is subdivided into four quadrants. According to this view, we can classify individuals of a group according to their level of expertise in two dimensions. However, since we are interested in the improvement of feedback-thinking, we have to take a process perspective (Figure 2).

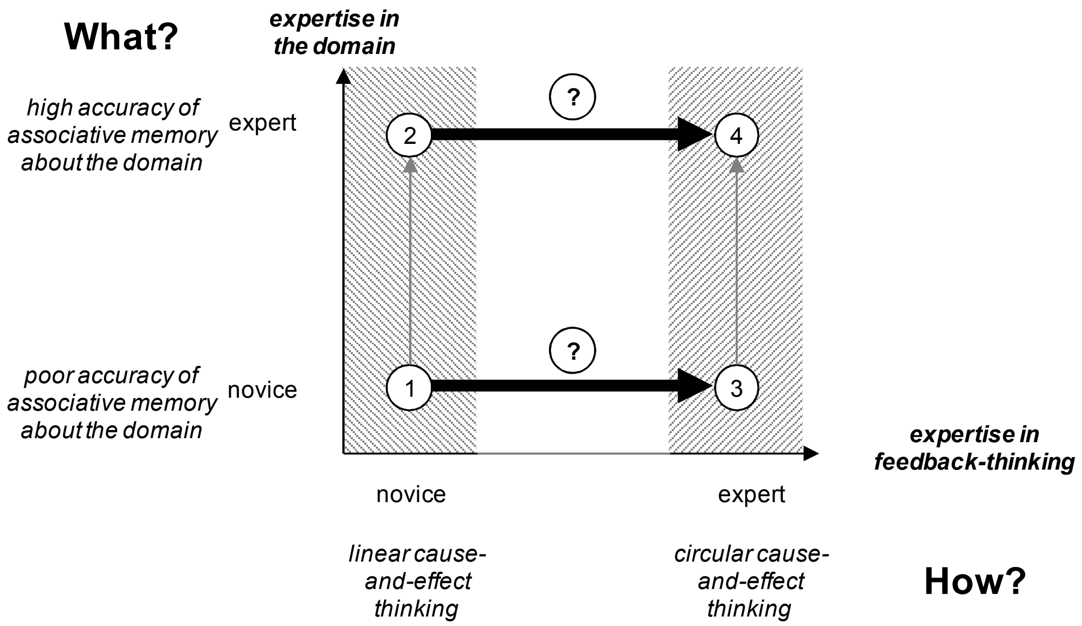

Figure 2: Process of developing feedback-thinking

In this view, the quadrants have been replaced by areas; the numbers represent the skill profiles as was shown already in Figure 1. The development of expertise in specific domains has been studied extensively (especially, Kahneman, 2011). Therefore, the changes from state 1 to stage 2 and from stage 3 to stage 4, which is shown by thin, grey arrows, occur in areas which have already been investigated. These fields are indicated by the grey surface. What is not known is how people advance from stage 1 to stage 3 and from stage 2 to stage 4. It is also not know if there are intermediate stages of development. For the time being, we assume that it is an overly complex undertaking to advance on both dimensions simultaneously. Hence, we refrain from including an arrow from stage 1 to stage 4.

In the model in Figure 2, the white area represents the gap in scientific knowledge about learning in feedback-thinking. Here is where our paper contributes. We intend to improve the understanding of the process to become feedback-thinkers at different levels of domain expertise. Especially, we have asked by how much the mental representations of individuals in stage 1 would change due to an experimental intervention. Additional knowledge about this subject would allow educational institutions to develop programs that systematically teach this skill.

3. Research Methodology

Experimental Study Design

We wanted to understand the level of feedback-thinking in undergraduate management students. Therefore, we used a quasi-experimental study design; more specifically, a post-test design without control group. Figure 3 shows the experimental design of our research.

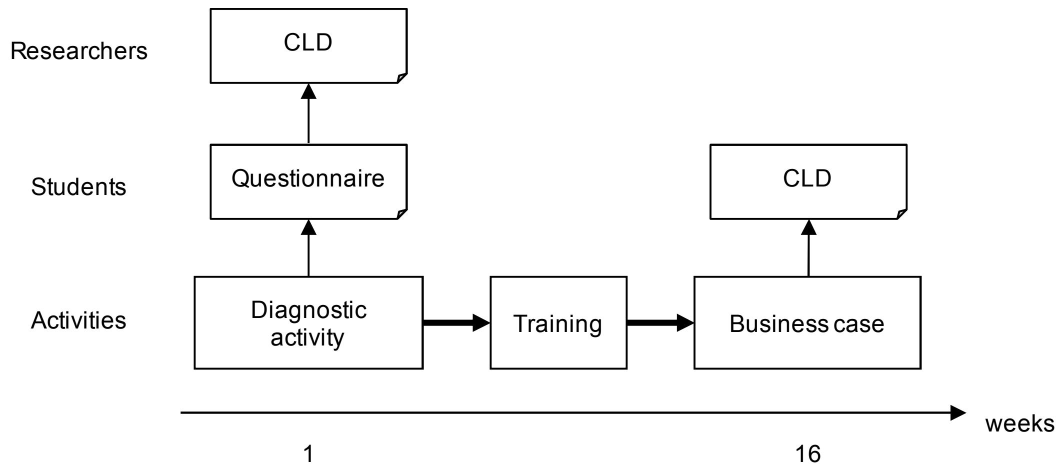

Figure 3: Research design

The students are enrolled in the third year of business informatics at the University of Talca, Chile. This course is their first exposure to system dynamics and feedback-thinking and is organized into three phases: the first session is a diagnostic assessment activity which allows knowing the initial competencies of students. The initial diagnostic is based upon a two-loop fishery fleet management simulation included in the first chapter of Morecroft's textbook (2007) and allows to know the initial stare of feedback-thinking and stock-and-flow-thinking (details are described in Appendix 1).

The training phase is an introductory course about system dynamics which proceeds from simple generic structures and behaviors towards more complex ones. An abbreviated syllabus, including a description of the initial assessment, is included in the paper's appendix; a detailed syllabus in included in the online supplementary material. The overall course duration is 16 weeks (15 for the teaching sessions, the last week for the experiment), with 2 hours lecture, 2 hours exercises plus individual study time. Over the course of the semester, this sums up to 54 hours of guided training and 54 hours of individual training before the experiment, which is part of the final exam.

The training phase is the intervention of our study. The quasi-experiment to measure the level of feedback-thinking of the participants is a part of the final exam. The students were asked to solve a dynamic problem about a specific company case, which we will introduce later. The task was to answer the questions: (1) how did a specific company in country A end up in an unsatisfactory economic situation? And (2) could this pattern repeat itself for the company in another country? The participants had to detail their arguments by means of a CLD. Even though it would in principle be possible to compare the findings of the experiment to those of the initial assessment, we concentrate on the post-exposure situation.[2] However, the diagnostic test at the beginning of the course allowed us identify that none of the students participating in the final test had recognized any of the feedback loops of the diagnostic situation. Therefore, we assume that the level of feedback-thinking shown in the final assessment is because of the training intervention. For our research reported here, 33 students (42% female, 58% male) were enrolled in the training course and have completed all required coursework to be eligible to participate in the experiment. Next, we describe the assignment used for the final test. Then, we detail the methods used for comparing the elicited MMDS.

Final Assignment: Starbucks Company

We use the dynamic development of Starbucks Company for the final assignment. During 2008, Starbucks USA underwent a crisis. After having set ambitious growth targets several of years before, the number of outlets and employees had grown rapidly. A relative sudden decline of profits urged Starbucks to close most of its newly opened outlets and lay-off thousands of employees. In the years after this process, a rapid

---

[2] We did not confront students with the same challenge in week 1 and week 16, since we were not interested in assessing how much their mental representations had changed. Instead, we are looking for the absence or presence of feedback loops; therefore, we only used the initial assessment to know if the students were able to recognize feedback loops, which was not the case.

growth of Starbucks outlets has been observed also in Santiago de Chile. The pattern of rapid expansion is strikingly similar and triggers the question if the boom-and-bust dynamics shown in the US is likely to occur also in Chile. Two major theories about the causes of the Starbucks crisis exist (for more details, see the case description in the Appendix). One position is that the crisis occurred because of external factors such as additional rivals and/or a downturn of the US economy.

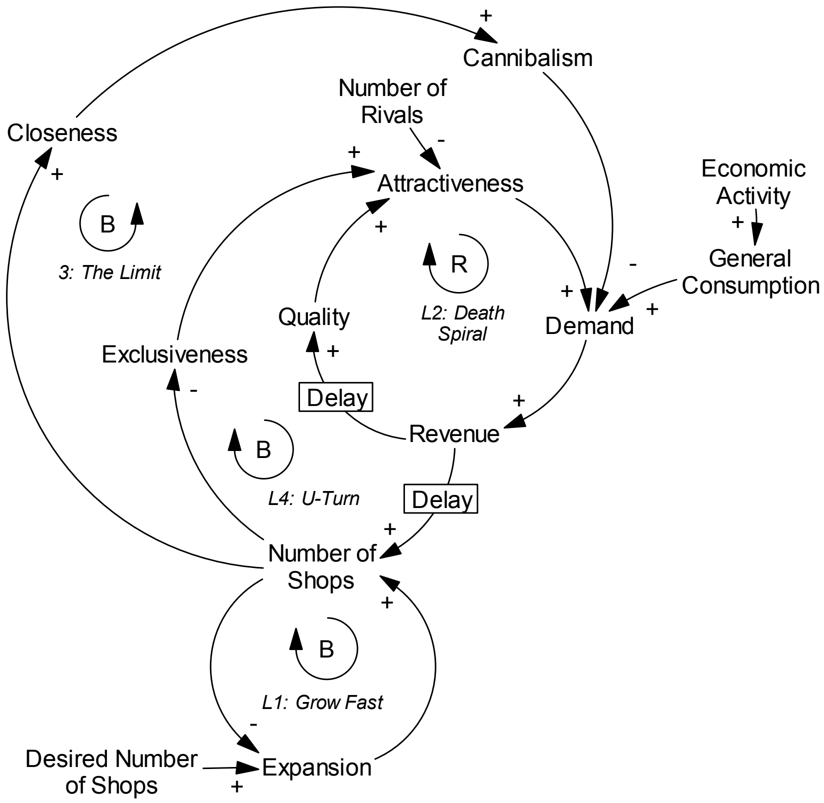

Figure 4: The reference model for the Starbucks case assignment

The second position argues that the rapid-growth targets resulted in lowering the feasibility requirements a possible location had to satisfy before a Starbucks store could be opened. In addition, the occurrence of economic cannibalism amongst stores due to their geographical proximity. The last two arguments suggest that Starbucks had changed internal policies in order to achieve the growth targets. The students had to develop a model about the feedback dynamics based on information sources which had been handed out to the students; this information is included in the paper's appendix. Figure 3 shows the *reference model* which depicts the necessary and sufficient content to understand the crisis of Starbucks.

Representing and Comparing Mental Models of Dynamic Systems

According to the definition in Section 1, we use the means of a CLD for representing the basic elements, feedback loops, and delays of a MMDS (Groesser & Schaffernicht, 2012). Elements are variables and causal links. We compare the resulting CLDs on the level of (1) elements, (2) feedback loops, and (3) the complete model. At the elements' level, we examine variables and clausal links to compute the *Element Distance Ratio* (EDR) which expresses the differences between two MMDS as the fraction of all possible differences between the two MMDS. Possible differences can result from differences in the set of variables, i.e., one of the models may have a variable the other model does not contain. Also, differences can result from differences in the causal links, i.e., one model may have a link the other model does not, or a common link differs in its polarity and/or strength of delay.

The level of feedback loops is the second level of comparison. Two feedback loops which, according to the analyst, correspond to each other in terms of their content are compared. Loops may differ in their polarity, in the length of their delay and/or in their variables and causal links.[3] We compute the *Loop Distance Ratio* (LDR) which indicates the fraction of similarity of two feedback loops. This ratio is calculated for each pair of loops for the two MMDS which are compared. The third level of comparison addresses the complete model. We calculate the *Model Distance Ratio* (MDR) as the weighted average of the LDRs.

In order for two CLDs to be comparable, the researcher has to make sure that the same names are used for the same variables and that the equivalent loops are compared. For the variables, we used the following procedure: we create a list of reference variables from the reference model. Then, each of the variables of the student models is compared: if the variable refers to the same entity as one in the reference list, then the variable's name is recorded as synonymous. In case the variable has not correspondence in the reference model, it is treated as a new entity and it is added to the list of variables. For the feedback loops, the procedure is similar. First, each model's loops are registered, i.e., ID number, polarity, elements, delays and list of variables. Then, each of

[3] Different variables may have been included into a loop due to a variety of reasons, ranging from varying degrees of aggregation to inaccurate representation of relationships. In such cases the EDR-logic is used to quantify how different two loops are at the level of their elements.

the feedback loops in the student models is compared to the list of feedback loops in the reference model. If the inspection of the entities suggests that the two loops of the compared models are equivalent, the two ID numbers are recorded as a synonymous.

At the end of the comparison processes, a MMDS is represented by several documents/files: a CLD in Vensim code, one table about the models' feedback loops (ID, polarity, number of elements, number of delays), one table for the list of variable names. In addition, for each combination of reference and individual student model, we have the equivalence table between both models. These files are then used by an algorithm which carries out the distance ratio calculations. The algorithm has been programmed in Mathematica©.

4. Results

Diversity of variables and causal links

In the initial activity of the course, i.e., the fishery case, none of the individuals recognized any feedback loop. Therefore, we are sure to attribute the findings that will be discussed now to the intervention. The reference model consists of 13 variables which are shown in Table 1; on the right hand side one finds the percentage of the 33 students who has recognized the variables.

Reference model variables	***Recognition***
shops	91%
demand	67%
revenue	67%
exclusivity	64%
cannibalism	52%
rivals	42%
economic activity	27%
quality	21%
expansion	12%
attractivity	9%
closeness	3%
shops desired	3%
general consumption	0%

Table 1: Variables of the reference model

Some of the variables have been recognized or mentioned by many of the participants. Other variables have been recognized by hardly anyone. Beyond not mentioning variables that did play a role in the case, most students have used variables not contained in the reference model and not directly used in the case description (Table 2).

Reference variables	***All variables***		
shops	actions	distraction	preference
demand	shareholders	employability	proX of brand
revenue	financial activity	employees	non_customers
exclusiveness	Strarbucks activity	employment	economic recession
cannibalism	rich neighbourhoods	jobs	restructuring
rivals	luxury coffee shop	physical space	performance
economic activity	coffee quality	standards	zonal performance
quality	infrastructure quality	business strategy	profitability
expansion	perceived quality	success	rivalry
attractiveness	product quality	accelerated expansion	market savior
closeness	service capacity	expansion in Latinamerica	satisfaction
shops desired	installed capacity	franchises	Starbucks USA
general consumption	carrying capacity	gains	shops closed
	total carrying capacity	inauguration	international shops
	capacity used	infrastructure	rival shops
	capital	houshold income	growth rate
	capital desired	shops opening	domestic growth rate
	local crisis	investment	competitivity rate
	customers	investment abroad	growth rate
	potential customers	investment in advertising	employment rate
	comfortability	leadership	workers
	competition	profit margin	profitability
	competitivity	growth goal	sales
	rivals	new strategies	
	consumption	new shops	
	costs per shop	new employees	
	growth	new markets	
	shop growth	latinamerican countries	
	economic crisis	perceived homelyness	
	internal financial crisis	percieved quality	
	Starbucks crisis	customers lost	
	expected demand	growth plan	
	potential demand	population	
	marked desnity	purchasing power	
	unemployment	growth opportunities	
	layoffs	possible shops	
	difference	possible sales	
	disposition to pay	customer potential	
	distance between shops	prices	

Table 2: Complete set of variables

Clearly, most of the 110 variables come from the mental effort of the students to understand the situation; being novices in terms of domain expertise (*Figure 1*, p.5), their efforts are imagination-driven.

Some of what we commonly call 'variables' may be input variables or output variables, others may be endogenous variables. Table 3 displays how accurately the 33 subjects could recognize the variables of the reference model.

	economic activity	attractivity	cannibalism	quality	closeness	rivals	general consumption	demand	exclusivity	expansion	revenue	shops	shops desired
Classification	I	E	E	E	E	I	E	E	E	E	E	E	I
Recognized	***0,09***	***0,03***	***0,27***	***0,06***	***0,06***	***0,09***	***0,52***	***0,06***	***0,03***	***0,21***	***0,03***	***0,03***	***0,03***
Endogenous	0,06	***0,03***	***0,03***	***0,00***	***0,06***	0,09	***0,39***	***0,00***	***0,03***	***0,15***	***0,00***	***0,03***	0,03
Input	***0,03***	0,00	0,24	0,06	0,00	***0,00***	0,06	0,06	0,00	0,03	0,03	0,00	***0,00***
Output	0,00	0,00	0,00	0,00	0,00	0,00	0,06	0,00	0,00	0,03	0,00	0,00	0,00
Not included	0,91	0,97	0,73	0,94	0,94	0,91	0,48	0,94	0,97	0,79	0,97	0,97	0,97

Table 3: Recognition of variables as input, endogenous or output

In Table 3, the first row indicates the type of variable ("I" for "input"; "E" for "endogenous"; "O" for "output"). As becomes apparent, even if these variables have been recognized as such, in most cases they have not been adequately classified. This means that, for instance, cannibalism has been understood as endogenous variable only by 3% of the students, even though 27% have used it in their CLD. Attractiveness has been correctly classified by all of the 3% who mentioned it; external rivals have been recognized by 9%, but nobody perceived it as an input variable. Exploring the elements of the model further, the adjacency matrix (Table 4) shows the causal links of the reference model.

	economic activity	**attractivity**	**cannibalism**	**quality**	**closeness**	**rivals**	**general consumption**	**demand**	**exclusivity**	**expansion**	**revenue**	**shops**	**shops desired**
economic activity							**1**						
attractivity								**1**					
cannibalism								**-1**					
quality		**1**											
closeness			**1**										
rivals		**-1**											
general consumption								**1**					
demand											**1**		
exclusivity		**1**											
expansion												**1**	
revenue				**2**								**2**	
shops					**1**				**-1**	**-1**			
shops desired										**1**			

Table 4: Adjacency matrix of the reference model

The adjacency matrix contains all variables as rows and columns; cells with non-zero values represent causal links going from the row variable to the column variable. Positive numbers represent positive polarity; negative polarity is indicated by negative numbers. Usual links are represented by a "1", and if there is a delay by a "2". For instance, there is a positive link from "attractivity" to "demand" and a negative link from "cannibalism" to "demand". It is interesting to understand how students have recognized these links. Table 5 shows the fraction to which causal links of the reference model have been adequately recognized, but also which percentage of the participants perceived links where there are none in the reference model.

	economic activity	attractivity	cannibalism	quality	closeness	rivals	general consumption	demand	exclusivity	expansion	revenue	shops	shops desired
economic activity							**0**	0,85			0,94		
attractivity								***0,03***			0,97		
cannibalism								***0,06***			0,97	0,85	
quality		***0,03***						0,94	0,97				
closeness			***0***						0,97		0,97	0,97	
rivals		***0***		0,97				0,85			0,94	0,88	
general consumption								***0***					
demand				0,97		0,97			0,94	0,97	***0,27***	0,91	
exclusivity		***0,06***				0,97		0,82			0,97		
expansion			0,97					0,97				***0***	
revenue				**0**				0,91		0,97		***0***	
shops			0,73	0,91	**0**	0,94		0,91	***0,39***	***0***	0,88		
shops desired										***0***			

Table 5: Recognition of causal links

The numbers in bold italics correspond to links in the reference model. We can note that that most participants have failed to perceive the same causal links that are part of the reference model, as for example in the case of the "closeness between shops" influences "cannibalism". In addition, in many cases some students have formed causal links where the reference model has none, for example students thought that "demand" influences "quality", which is not stated in the reference CLD.[4] Table 6 compresses the counts of links over the extended adjacency matrix, i.e., the matrix in which all variables with at least one causal link are displayed independent from being an element of the reference model.

[4] This leads to asking how a MMDS comparison method may deal with different degrees of aggregation. However, this is relegated to a further development, as noted in the conclusions of this paper..

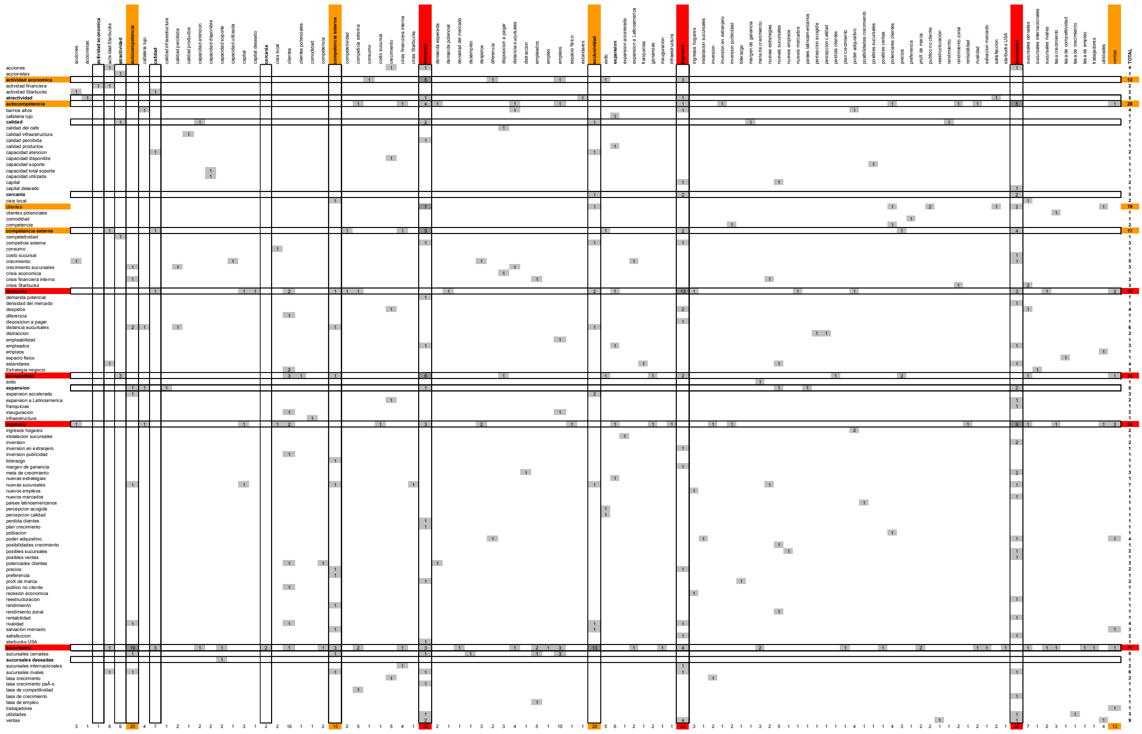

Table 6: Spread of causal links over the variable space

The reference model's variables can be recognized by the box drawn around their row/column. Variables that receive between 10 and 14 causal links are colored in orange; variables with more than 25 causal links are colored in red. The full matrix is provided in the supplementary material under the file name "LinksTotal.xls". Next we, turn to the different distance ratios to gain a somewhat more compact view on the MMDS.

Element Distance Ratio (EDR)

The differences between each subject's model and the reference model can be expressed in a very compact manner by the "Element Distance Ratio" (EDR) shown in Table 7.

Model	EDR
16	77%
6	79%
22	83%
5	84%
15	84%
18	86%
28	86%
20	88%
7	88%
3	88%
4	89%
10	90%
8	91%
26	93%
1	93%
17	93%
27	93%
12	93%
33	94%
14	94%
9	94%
11	94%
23	94%
21	95%
29	95%
19	96%
30	97%
2	98%
24	98%
31	99%
13	99%
25	99%
32	99%

Table 7: Element Distance Ratios (EDR)

The EDR expresses the relationship between the differences found between two models and the total quantity of possible differences between them. It takes into account the variables and the causal links (with polarity and delay mark). Models have been clustered together to form three groups: the first group counts the two models that have an ERD below 80%; the middle group has 80%<ERD<90% and the last group has ERD>90%.

Loop Distance Ratio (LDR) and Model Distance Ratio (MDR)

The assessment if a given feedback loop in one individual's MMDS "is equivalent to" a given loop in the reference CLD requires some judgment, since there may be substantial differences in elements (variables and links in the loops). This equivalence judgment is performed by the human analyst on a one-to-one comparison basis answering the question “what did this individual mean with this loop and does it come close to the meaning of one of the loops in the reference model?” This section presents the situation found in our case. Most of the participants in this group produced CLDs with loops – only 3 individuals (individuals 6, 10 and 19 corresponding to 9%) expressed a purely linear understanding of the situation. Table 8 displays some relevant observations about the pattern of recognition of the reference model’s feedback loops in this group.

Recognized			
Number of loops	**Individuals**	**Percentage**	**Cumulative**
0	11	33,33%	100,00%
1	12	36,36%	66,67%
2	9	27,27%	30,30%
3	1	3,03%	3,03%
4	0	0,00%	0,00%
	33	*100,00%*	

Table 8: Number of recognized feedback loops by participants

One third of the group did not recognize any of the reference feedback loops. Another third of the students recognized one of the four loops, meaning that two thirds of the population recognized one loop or less. Another 30% have recognized two loops, which means that only 33% of the students recognize two ore more of the four feedback loops. Table 9 illustrates how the different individuals performed.

Ref	**1**	**2**	**3**	**4**	**5**	***6***	**7**	**8**	**9**	***10***	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	***19***	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**Σ**
1																									1							1		**2**
2				1			1		1		1			1	1	1	1			1														**9**
3			1	1	1		1						1								1									1		1		**8**
4					1		1		1			1		1	1	1	1	1				1				1	1			1			1	**14**
	1	1	1	1	1		1		1			1		1		1	1	1		1	1	1	1	1	1	1	1	1	1		1	1	1	
	1	1	1				1					1		1				1		1	1	1	1	1	1	1		1	1		1		1	
	1		1															1			1		1	1				1	1				1	
	1		1															1			1		1	1				1	1				1	
	1																	1						1					1					
																								1										
																								1										
																								1										
Σ	**5**	**2**	**5**	**3**	**3**	***0***	**5**	**0**	**3**	***0***	**1**	**3**	**1**	**4**	**2**	**3**	**3**	**6**	***0***	**3**	**5**	**3**	**4**	**8**	**3**	**3**	**2**	**4**	**5**	**2**	**2**	**3**	**5**	
Rec	**0**	**0**	**1**	**2**	**2**	**0**	**3**	**0**	**2**	**0**	**1**	**1**	**1**	**2**	**2**	**2**	**2**	**1**	**0**	**1**	**1**	**1**	**0**	**0**	**1**	**1**	**1**	**0**	**0**	**2**	**0**	**2**	**1**	

Table 9: Loop recognition of the individuals'

Table 9 is subdivided in two sets of rows. The first one contains the four loops making up the reference model; the second one refers to loops formulated by individuals (whose mental efforts were imagination-driven). A “1” indicates that the individual expressed a loop. The first column shows the reference model, the remaining columns represent the individuals in the group. Apparently, some of the four loops in the reference model were easier to perceive than others: clearly, loop 4 has been salient to these subjects, since almost half of the group has articulated a loop which was sufficiently similar to be treated as equivalent. Figure 5 displays the four loops with arrow size representing the frequency of recognition by the participants.

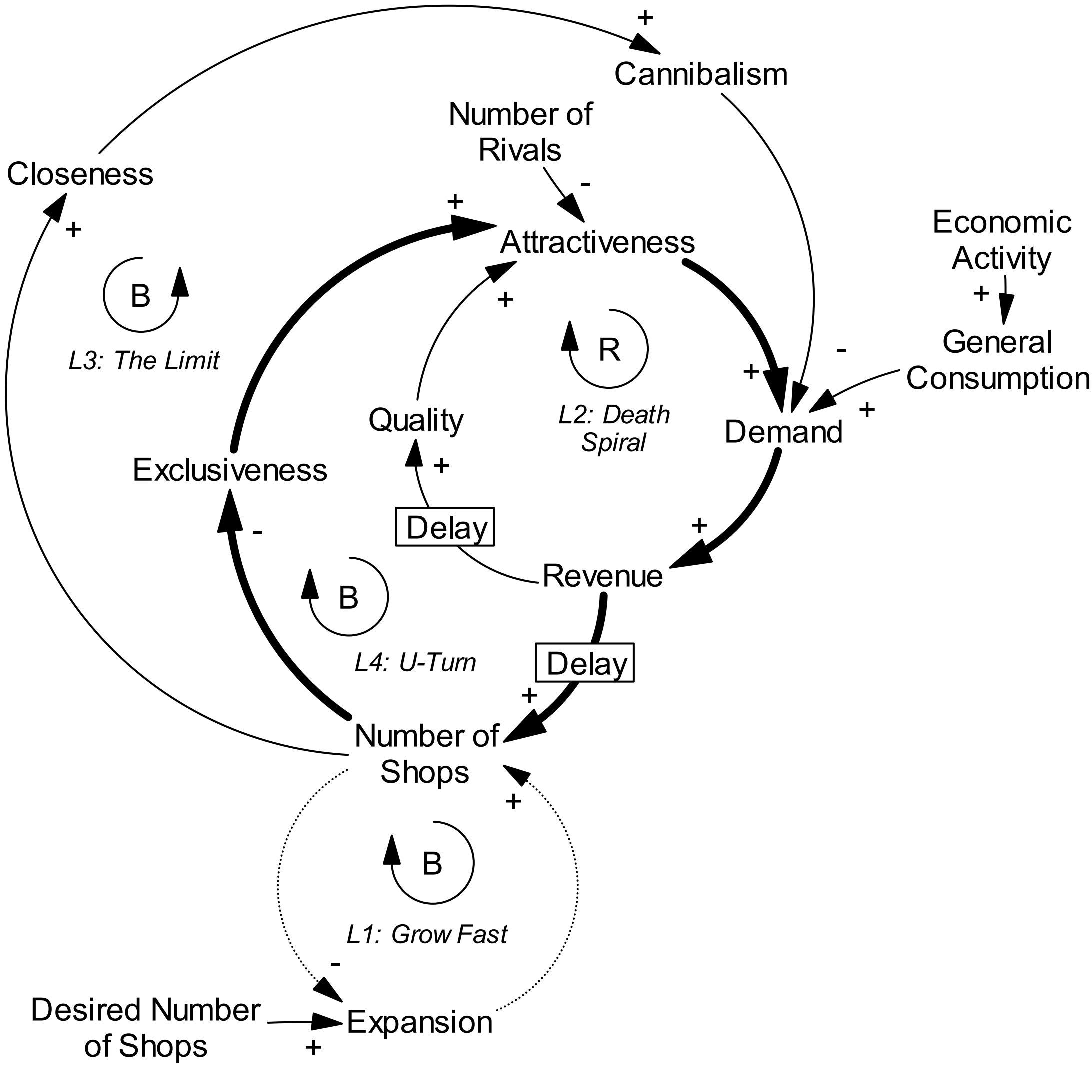

Figure 5: Recognition of reference loops

The second section of Table 9 shows how many feedback loops in the individuals' CLDs are not equivalent to any of the reference loops. The Σ row sums the number of loops per individual, and the last row ("Rec") indicates the number of recognized reference loops. In total, 100 loops have been expressed, but only 32, i.e., about one third, are equivalent to the loops in the reference model.

The discrepancies between the feedback loops expressed by the individuals and those of the reference model show in the “Loop Distance Ratios” (LDRs). This ratio is computed for each of the feedback loops when comparing a given model to the reference model. It compares the two loops’ polarities (0 for equal, 1 for unequal), their delay (0 for equal, 0.5, for somewhat different and 1 for strongly different) and their elements (in form of a loop EDR) and is expressed as the arithmetic mean. For detailed explanation, please refer to Schaffernicht and Groesser (2011). The results of these comparisons are reported in the Table 10; and the detailed data will be available in the supplementary material.

Models	**LDR**				**MLDR**	**EDR**	**MDR**
	1	**2**	**3**	**4**			
1					1,00	0,93	0,97
2					1,00	0,98	0,99
3					1,00	0,88	0,94
4		**0,38**	**0,36**		**0,37**	0,89	0,63
5			**0,35**	**0,35**	**0,35**	0,84	0,59
6	1,00	1,00	1,00	1,00	1,00	0,79	0,90
7						0,88	0,88
8	1,00	1,00	1,00	1,00	1,00	0,91	0,96
9		**0,40**		**0,38**	**0,39**	0,94	0,67
10	1,00	1,00	1,00	1,00	1,00	0,90	0,95
11	1,00	**0,40**	1,00	1,00	**0,85**	0,94	0,90
12	1,00	1,00	1,00	1,00	1,00	0,93	0,97
13	1,00	1,00	**0,40**	1,00	**0,85**	0,99	0,92
14	1,00	1,00	1,00	1,00	1,00	0,94	0,97
15	1,00	1,00	1,00	1,00	1,00	0,84	0,92
16	1,00	1,00	1,00	1,00	1,00	0,77	0,89
17	1,00	1,00	1,00	1,00	1,00	0,93	0,97
18	1,00	1,00	1,00	1,00	1,00	0,86	0,93
19	1,00	1,00	1,00	1,00	1,00	0,96	0,98
20	1,00	1,00	1,00	1,00	1,00	0,88	0,94
21	1,00	1,00	1,00	1,00	1,00	0,95	0,97
22	1,00	1,00	1,00	**0,34**	**0,84**	0,83	0,83
23	1,00	1,00	1,00	1,00	1,00	0,94	0,97
24	1,00	1,00	1,00	1,00	1,00	0,98	0,99
25	**0,33**	1,00	1,00	1,00	0,83	0,99	0,91
26	1,00	1,00	1,00	**0,35**	**0,84**	0,93	0,88
27	1,00	1,00	1,00	1,00	1,00	0,93	0,97
28	1,00	1,00	1,00	1,00	1,00	0,86	0,93
29	1,00	1,00	1,00	1,00	1,00	0,95	0,97
30	1,00	1,00	1,00	1,00	1,00	0,97	0,99
31	1,00	1,00	1,00	1,00	1,00	0,99	0,99
32	**0,66**	1,00	**0,40**	1,00	**0,77**	0,99	0,88
33	1,00	1,00	1,00	1,00	1,00	0,94	0,97
					0,91		**0,91**

Table 10: Loop and Model Distance Ratios

Table 10 shows the LDR for each loop of the respective models; where equivalences have been detected, the LDRs are below zero. In these cases, the “model loop distance ratio” (the mean value of each model’s LRDs) is also below zero. Of course, in those cases where a student did not recognize any of the reference model’s feedback loops, the LDR is equal to 1 (100%).

Besides the LDRs, EDR are reproduced newly, just to allow computing the “Model Distance Ratio” (MDR) which appears in the rightmost column. Visual inspection suggests that in almost all cases, except model 22, recognizing feedback loops lowers the overall MDR. In our view, this is coherent with the statement that dynamic systems are driven by feedback loops. Therefore, differences at the level of the elements, i.e., variables and causal links, appear as less important.

5. Analysis and Discussion

Figure 6 shows the most relevant findings of our study. First of all, there was a change in recognizing feedback-loops. At the outset of the course, none of the students recognized feedback loops in a simple setting. By the end of the course, there were on average three loops in each of individual’s CLDs. 90% of the students who did not perceive loops at the beginning of the course, developed feedback-rich representations in their MMDS in the final assignment. The reference model used for the final assignment has four feedback loops. One could initially state that the quantity of loops that have been perceived corresponds, on average, to 75%. However, because many loops which the participants have identified are actually not part of the reference model, a significant change of this figures results. If we limit the analysis only to the loops in the reference model, then, on average, the participants could recognize 25% of the feedback loops. The average MDR with 91% is smaller that in the diagnostic assignment where the MDR has been 100%. In other words, the distances between the models is smaller—the similarity of the model of the participants and the reference model is higher than in the case of the diagnostic assignment. However, we consider the improvement in similarity as modest given that the improvement is small (9%). One might expect higher levels of improvements given the number of loops appearing in the MMDS.

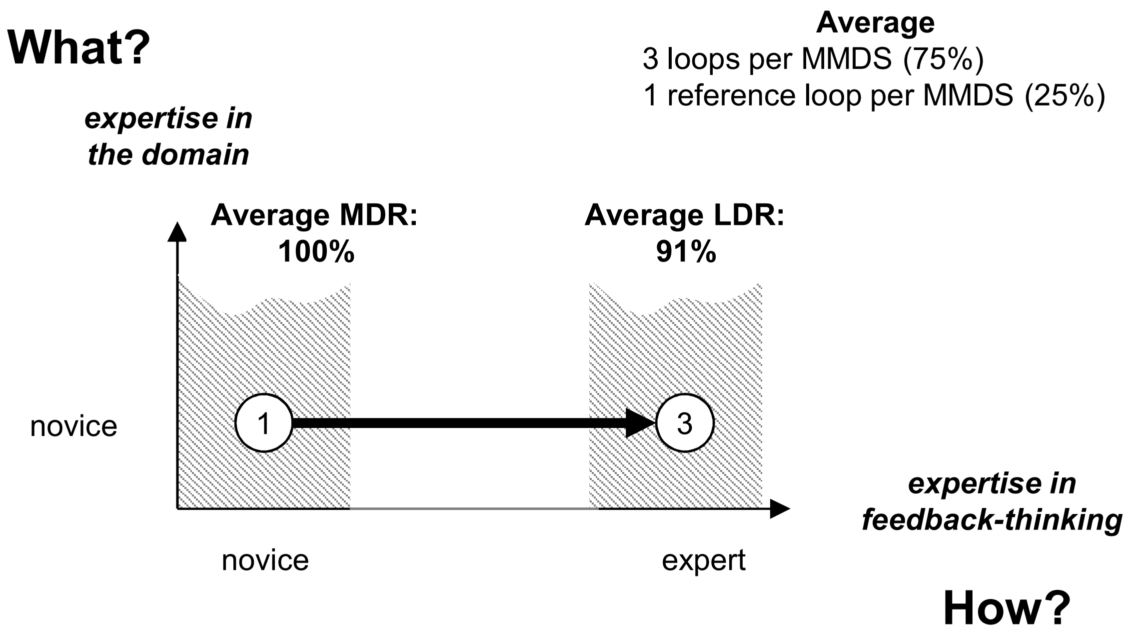

Figure 6: The study's key findings

The quality of most of the expressed MMDS is low at the description level of variables and links, and also at the level of feedback loops. The majority of the variables were not taken from the case description, but from the students' imagination. The same is true for the majority of the feedback loops.

We believe this is to be expected when the participants come from stage 1 (cf. Figure 1). Since these participants lack business experience, but they have taken courses in business administration during the two years previous to our study, their mental models have imagination-driven contents which they draw from these courses and believe to be relevant. This is congruent with psychological research (especially, Kahneman, 2011), which has found that humans cannot avoid that the test stimuli first activate a mental search in the associative memory and then generate causal narratives that produce cognitive satisfaction.

We can apply this argumentation to the four stage model with. In this study, we have analyzed the MMDS of individuals who begin as novices and improve their expertise in feedback-thinking. Then, we expect participants with relevant domain expertise to move from stage 2 to stage 4 and to produce MMDS with only a few imagination-based variables and feedback loops, but with errors in formulating the

MMDS in the CLD. Experts in feedback-thinking would on average not make such errors. In addition, participants who already have system dynamics skills but lack domain expertise should tend to express MMDS with less formulation problems, but more imagination-based variables.

We propose that the methods to represent and compare MMDS, which we have used in this study, enable a transparent and objective comparison. In addition, it allows taking into account the relevant concepts of dynamic systems when mental representations are analyzes. Researchers of the mentioned method can analyze a large set of MMDS at different levels of description, i.e., at the level of elements, loops and the whole model. Moreover, the researchers can analyze the MMDS at varying degrees of detail; the different ratios, i.e., EDR, LDR, MDR, are a synthetic description of the models on the one extreme. The overviews about recognition of variables, links, and loops occur at a level that is sufficiently detailed to have a general understanding of the set of MMDS.

6. Conclusions

This study contributes to the understanding of how people go from “misperception of feedback” to become feedback-thinkers. In addition, it applies and thereby demonstrates new methods for measuring and comparing mental models of dynamic systems.

We performed quasi-experiments with 33 undergraduate students finishing a first course in system dynamics. We have tested how the participants recognize the variables, causal links, and feedback loops in a textual description of a business case. The participants have recognized most of the variables of the reference model. However, the participants provided even more: most of them have added variables to the expressed MMDSs from their associative memory. We call these variables now *“experience-based variables”*. An experience-based variable is one that is not directly taken from the situation’s stimuli but drawn on previous experiences retrieved by the associative memory process (of course, at the other extreme of the domain expertise scale we will find “imagination-based variables”). Regarding feedback loops, the participants have recognized a part of the feedback loops of the reference model (two thirds recognized 25% of the looks, one third recognized 50%). Again, the participants contributed with many other loops which did not exist in the case description but which stem from the associative mental database. The individuals have learned to articulate mental models with causal loop diagrams. However, at the time of the experiment, they did not learn to recognize useful and accurate loops.

This study is limited in that it has only used one group of individuals, novices in system dynamics who have no experience in the problem domain.

However, there are also challenges at the level of the comparison method. Mojtahedzadeh (2011) has argued that representing a dynamic system by the visual means of causal loop diagrams (CLD) results in a rapid growth of the number of feedback loops because of the disaggregation of the flow rate equation into multiple auxiliaries. Of course, this also affects individual mental models. As discussed by Kampmann (1996) and Oliva (2004), the multiple overlaps between feedback loops in a model (due to the fact that one causal links belongs to several loops) there are many ways to construct a feedback-loop representation of a situation. An experienced feedback-thinker will assure the set of loops is sufficiently developed (that all the causal links which belong to one or several loops are included in at least one of the identified loops). This can be avoided by developing a system structure diagram of the decision situation (Groesser, 2012; Groesser & Schaffernicht, 2012), but currently the decision to consider two feedback loops as equivalent to one another is taken by the human analyst mainly because different degrees of aggregation/disaggregation leads to loops that look very different when judged by the variables they are made of, but still express a very similar – or equivalent – meaning. This remains a challenge to be responded by future work.

Last not least, in the current state of development, we do not distinguish between stocks and flows. Also, the focus on structure hinders an assessment of the degree of use and of usefulness of the causal structure represented.

For further research, we intend to conduct studies with different types of individuals, i.e., individuals with varying degrees of expertise both in feedback-thinking and the domain. In addition, we could proceed by analyzing for inherent relationships; for instance, between the level of “EDR” and the level of “LDR”. Moreover, we hypothesize that there are distinguishable patterns in the development process from a notice to an expert. While we do current not use the full potential of the approach to analyze MMDS, we believe that its application provided in this paper demonstrates the approaches' usefulness and versatility.

References

Groesser, S. N. 2012. Mental Models of Dynamic Systems. In N. M. Seel (Ed.), ***Encyclopedia of the Sciences of Learning***. Heidelberg et al.: Springer Science+Business Media.

Groesser, S. N., & Schaffernicht, M. 2012. Mental Models of Dynamic Systems: Taking Stock and Looking Ahead. ***System Dynamics Review***.

Kahneman, D. 2011. ***Thinking Fast and Slow***: Farrar, Straus and Giroux.

Mojtahedzadeh, M. 2011. Consistency in Explaining Model Behavior Based on its Feedback Structure. ***System Dynamics Review***, 27(4): 358-373.

Moxnes, E. 2000. Not only the Tragedy of the Commons: Misperceptions of Feedback and Policies for Sustainable Development. ***System Dynamics Review***, 16(4): 325-348.

Moxnes, E. 2004. Misperceptions of Basic Dynamics: The Case of Renewable Resource Management. ***System Dynamics Review***, 20(2): 139-162.

Oliva, R. 2004. Model Structure Analysis Through Graph Theory: Partition Heuristics and Feedback Structure Decomposition. ***System Dynamics Review***, 20(4): 313-336.

Schaffernicht, M. 2008. ***Indagación de situaciones complejas mediante la dinámica de sistemas***: Editorial Universidad de Talca.

Schaffernicht, M., & Groesser, S. N. 2011. A Comprehensive Method for Comparing Mental Models of Dynamic Systems. ***European Journal of Operational Research***, 210(1): 57-67.

Sterman, J. D. 1989a. Misperceptions of Feedback in Dynamic Decision-Making. ***Organizational Behavior and Human Decision Processes***, 43(3): 301-335.

Sterman, J. D. 1989b. Modeling Managerial Behavior - Misperceptions of Feedback in a Dynamic Decision-Making Experiment. ***Management Science***, 35(3): 321-339.

Sterman, J. D. 2010. Does Formal System Dynamics Training Improve People's Understanding of Accumulation? ***System Dynamics Review***, 26(4): 316-334.

Sweeney, L. B., & Sterman, J. D. 2007. Thinking about Systems: Student and Teacher Conceptions of Natural and Social Systems. ***System Dynamics Review***, 23(2-3): 285-312.

Tardif, J. 2006. ***L'évaluation des Compétences: Documenter le Parcours de Développement***.

Vosniadou, S. 2007. Conceptual Change and Education. ***Human Development***, 50(47–54).

Weick, K. E. 1995. ***Sensemaking in Organizations***. Thousand Oaks, CA: Sage.

Appendix 1: Outline of the Course about System Dynamics

a) Introduction (1st session): Fishery fleet management game; based upon the simulation model used in Chapter 1 of Morecroft's textbook (2007), students have to decide the number of fishing boats such as to achieve the largest possible capture without extinguishing the fish population. After a video introduction the simulator is used. The model is visible (implemented with iThink) and clearly shows two feedback loops. At the end of the simulation, students are required to complete an assignment where they have to (1) identify variables of the situation, (2) undertake pairwise comparisons of these variables to indicate how a change in one variable would effect another variable, and (3) to present a description of the situation by means of a free-form diagram. The pairwise comparisons allow inferring causal links with polarity and delay, and the final diagram informs about the recognition of loops. From these data, we then can construct a CLD and therefore have an indicated about the feedback-thinking capabilities of these students.

b) Causality and CLDs (1 week)

c) Flows and accumulation (1 week)

d) Basic structures and behaviors

   i. Exponential behavior and positive feedback (1 week)
   ii. Logarithmic behavior and negative feedback (2 weeks)
   iii. S-shaped behavior (2 week)
   iv. Growth and crisis (2 weeks)
   v. Oscillation (2 week)
   vi. Delays (2 week)
   vii. Aging chains and co-flows (1 week)

The coursework is supported by a Spanish textbook (Schaffernicht, 2008)which is freely available in PDF at http://editorial.utalca.cl/ebook_frm.php and a series of Spanish video presentations available at http://dinamicasistemas.utalca.cl/.

Appendix 2: the Starbucks case description

Starbucks is an exclusive coffee shop where you go "to meet the right people". Traditionally, strict criteria for installation assured that shops would open only in economically well-going and robust neighborhoods. Earlier this decade, the company decided to pursue an ambitious growth goal and achieve to double the number of shops in the USA over only a couple of years. Apparently, trying to implement this growth goal, the standards of pre-opening checks have been lowered; then, coincident with the financial and economic crisis of 2008, also coincident with the proliferation of rival coffee shop chains, and above all in a scenario of cannibalism between Starbucks shops operating too close to one another, occurred a crisis. The following pieces of text show what different analysts argued.

After an accelerated expansion of its shops I the USA, Starbucks has entered a profound crisis. The fast expansion has diverted the company from making its shops be homely places with exciting products and affairs, more attractive than rival chains' shops. "At the end of the day, we have created this problem ourselves", said Schultz (co-founder and general manager) in an interview.

(http://www.starbucksunion.org/node/1936; 1/8/2008)

The formerly succesful northamerican coffe shop chain Starbucks has sunk into a profound crisis. This crisis is not exclusively provoked by north-america's economic recession (the chain's main market), which has provoked a huge downturn of consumption. The company's problems are structural, too.

For this reason, the company's founder – Howard Schultz – has taken back the command. Stock prices have gone down 40% and sales keep dropping. Schultz has dedicated himself to developing a plan which would transform the company back into what it used to be.

One of the causes of Starbuck's fall was the huge quantity of shops that had been opened across the USA, and which have provoked market saturation. Consider these figures: in 1990, the company had 84 shops, in 1996 the numer had ascended to 1,000 and today it has been multiplied tenfold and is near 10,000.

This has provoked a loss of the exclusivity for which customers were willing to pay exorbitant prices for a cup of coffee. Stores compete against one another because they are geographically very close to each other, and if we add to this the growing presence of rival coffee shops, the panorama is very complicated.

To goals behind the transformation are to reach a condition where it becomes something special again to have a cup of coffee in Starbucks, but also to include not-so exclusive sectors into the consumption possibilities.

(http://www.economiafinanzas.com/2008/02/04/la-cafeteria-norteamericana-starbucks-en-crisis/, 4/2/2008)

The popular northamerican coffee chain Starbucks announced plans to close 600 shops across the USA, eliminating 12,000 jobs (part time and full time). This measure will have considerable impact on the company which draws its major revenues from the northamerican market (even though the total of 16,000 shops covers 45 countries).

The measure also means than one hundred shop openings planned for this year in the USA will not take place. Most of the closings are scheduled to occur in the second half of 2008 and the firs semester of 2009 and will concern those shops with the worst performance. 70% of these shops have only be operating since early 2006.

The chain has been suffering the decline of its business model during months. In March, the company from Seattle (Washington) announced a strategy to regain customers and combat the growing competition and the economic slowdown. However, customers do not seem to think this way and blame the company's crisis on the loss of quality of the coffee sold in the shops as well as the loss of the charming atmosphere the stores used to offer.

(http://www.elpais.com/articulo/economia/crisis/economica/golpea/Starbucks/elpepueco/20080702elpepueco_3/Tes; 8/7/2008)

In the face of falling sales in the USA, the coffee giant has opted for expansion in Latin America – a market not developed yet which offers great growth potential. Alsea, the local franchised company. has announced the opening of shops in Mexico, Argentina, Brazil and Chile.

At a safe distance from the policies to face recession, the chain has an ambitious expansion plan in this part of the world. Alsea, the company franchised by Starbucks for Latin America, has revealed plans to open 14 new shops in Mexico and 12 sales points in Argentina, 17 in Brazil and 4 in Chile. Taking into account the dire situation the chain is going through in the USA, this is a considerable bet on expansion.

(http://www.emprendedoresnews.com/tips/franquicias/america-latina-puerta-de-salvacion-a-la-crisis-de-starbucks.html; 9/2/2009)

Starbucks landed in Chile in 2003, opening a shop in a strategically chosen neighborhood where residents and working population would know the brand, in the "El Golf". The incursion was slow, and instead of moving towards the city center, it progressed upwards towards the oriental part of the metropolitan area and established profitable outlets[5]. However, over time, slowly Starbuck's market started moving out of this zone, and new shops in the center of Santiago achieved a close relationship with a more massive clientele. This was the first step towards expanding over the capital. Currently, Starbucks has 29 coffee shops in Santiago and announced the objective to open 3 shops in the surrounding 5^{th} Region[6]. After these openings will have been achieved, plans are to refurbish the shops in Santiago. Chile is the only country of Latin America where Starbucks operates directly.

(http://es.wikipedia.org/wiki/Starbucks#.C2.A0Chile; 31/5/2011)

Currently, Starbucks has more than 30 shops operating in grand Santiago (source: http://www.starbucks.cl/, 31/5/2011).

1. What has caused the crisis of Starbucks in the USA?
2. Can a similar crisis happen in Chile?

Develop a Causal Loop Diagram (CLD) to analyze the case and these two questions. Consider the likely behavior of the variables in the CLD: which ones grow, which ones decline, which ones are stable? Why (according to the CLD)?

Can you identify the causes of the crisis in the USA?

Can you justify your response to the second question using the CLD?

[5] Santiago de Chile's historic city center is located at the lowest point of a basin right in front of the Andes Mountains. Over the decades, there was a constant movement of business and high income residents up the slope (with is geographically east or "oriental"). Currenty the business center of Santiago, often called "Sanhattan" is in this part of the city, together with Santiago's two leading shopping malls.

[6] Chile is politically organizad into "regions"; geographically Spreads from North to South, the territory was tradicionally divided into 12 "regions" with the "metropolitan tregion" (grand Santiago) lying inside the 5th "region".