Are you experienced? –
a model of learning systems thinking skills

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Abstract

This paper proposes a contribution to the domain of systems thinking skills. Empirical studies have repeatedly shown surprising misperceptions and inabilities in subjects confronted with tasks involving very simple stock and flow systems. Here it is proposed to represent these skills as implicit integration, by which Polanyi modeled our ability to know. In this framework, Dreyfus and Dreyfus' five stage model of learning is used to construct three hypotheses concerning the learning of systems thinking and its importance for learning from modeling and interaction with models. The tests elaborated by Ossimitz are adapted for this purpose and some tasks are added, to serve in the experimental corroboration of the hypotheses. Since the empirical work is currently under way, only few results can be presented; consequently the main contribution is the conceptual construction of the hypotheses.

Keywords: system thinking skills, tacit knowledge, learning, expertise

Introduction

System Dynamics was developed in order to help decision makers design better policies, based upon an improved understanding of how structure generates behavior. From the outset, it was thought that people's understanding of the system – called mental model – is at the same time the richest source for modeling and meant to change (improve) as a result of the modeling (Forrester, 1961).

Later on it was also tried to foster learning by interacting with simulation models or games rather than modeling, because modeling is more expensive than using a model (Maier and Grössler, 2000). Thus the connection between SD and making-learn became stronger. Also, SD is presented as possible element of inquiry-learning cycles (Sterman, 2000). However, the usual SD publications do not focus on the larger inquiry cycles but rather concentrate on the learning going on during a modeling effort, like for example inside the group model building area (Vennix and Rouwette, 2002).

SD helps in several ways. It provides a language with concepts and a representational system which guide their user to look at situation in terms of stocks and flows, feedback loops, delays, nonlinearities and borders (see Ossimitz, 2000): it is a language for systems thinking. It also allows articulate models to be simulated, in order to validate them before using them to fundament decisions: it is a method for coming to understand a system in a disciplined manner..

Sadly, many studies indicate that adult humans are not intuitive systems thinkers. It has been shown that people misperceive feedback (Sterman, 1989; Moxnes, 2000; Jensen and Brehmer, 2003; Doyle et al., 1998) and other SD building like those involved in the bathtub dynamics (Sweeney and Sterman, 2000; Ossimitz, 2002) and especially distinguishing stocks and flows (Ossimitz, 2002; Kainz and Ossimitz, 2002). However, SD helps evolving metal models (Doyle et al. 1998) and system thinking leads to better control performance (Maani and Maharaj, 2004). Better systems thinking skills would probably help to be a better systems dynamicist as much as modeling skills are needed.

It has to be suspected that the understanding of one system – a conscious mental model - is not the same kind of knowledge as system thinking, which is a skill; accordingly, learning about one system will not be the same as learning to think systemically either. This article assumes that the two mentioned cases of learning are different but strongly connected, as suggested by the theory of logical types of learning (Bateson, 1979). Seen in this light, the studies mentioned above and briefly presented in section 2 investigate different aspects of one underlying theme. The justification for this assumption is given in appendix 1.

Section 3 argues that system thinking skills are well captured by Polanyi's theory of implicit integration or tacit knowing (Polanyi, 1966; Neuberg, 1999). According to this theory the perception of something we recognize in the world is only possible due to the unconscious integration of uncountable sensory stimuli, which is why the things we recognize are always already there, and any conscious knowledge is based on this implicit knowing. This has consequences for how the transformation of a beginner into an experienced systems thinker is represented. Section 4 introduces a five stage model of learning based on Dreyfus (1986), which has been brought into connection with implicit integration (Neuberg, 1999) is presented to conceptually model this progressive transformation.

Section 5 looks at the different studies through the lens of criteria derived from these conceptual models. It appears that the systems thinking tests should be adapted in order to assess the stage-wise construction of system thinking skills. Empirical work in the domain of the first issue is just under way and first elements are presented in appendix 2.

At a secondary level, the influence of these skills on the modeling-for-learning process may become measurable if studies that investigate mental models take into account the stage of their subjects. Third, the fact that in spite of the importance of modeling for learning, none of the studies tested the learning effects of modeling, calls our attention.

Recent empirical studies concerning systems thinking and learning

The concern for the quality of perception of systemic structures and their mental use is not new (for example Sterman, 1989); at the same time, the connection between system dynamics and learning has been a subject ever since "Industrial Dynamics" (Forrester, 1961; also Morecroft and Sterman, 1994). This paper tries to tie together the topics of "learning in SD activities" and "systems thinking"; in recent years, several relevant studies have been published en the SDR or the SD conference, but they seem to concentrate either on "systems thinking" (specially *perceiving*) or on "learning".

Doyle et al. (1998) ask if working with a simulation of a complex system helps to bring about changes in the subjects' mental models. Their case is the Kondratiev economic cycle, built into the Stratagem-2 simulator. Their subjects were undergraduate students without prior exposure to systemic education, who interacted with the simulator during five sessions of one hour each, spread over two weeks. Although they could work together during simulation, the raw material was collected individually. The raw materials were written statements produced by subjects at the beginning and the end of the session. These statements were analyzed as mental models, looking for changes en detail (elements, links) and dynamic complexity (basically feedback loops). This study found subjects to develop more complex mental models (larger models with more feedback loops) but without challenging or changing the model boundary.

Moxnes (2004) investigated if subjects could use the interaction with a simulator to learn not do over-exploit natural resources in the case of reindeer range management. His subjects were graduate students initiating SD studies who had to realize 3 tries with a simulator in the least time possible; they had to work alone. The raw material was their behavior and performance, and mental models or rules were inferred in order to explain the behavior. He finds that result feedback apparently did not lead to go beyond linear thinking, maybe because of the non-linearity involved.

Jensen and Brehmer (2003) asked whether subjects who have to manage a predator-prey population would learn to stabilize the populations in the case of a simulation of foxes and rabbits (a model with feedback loops and non-linearity). Subjects were undergraduate students who could interact with the simulator during one hour (the article does not mention clearly if they worked alone or in teams). The raw material was behavior and performance, but also verbalized reasoning (thinking aloud). About half of the subjects succeeded, but many felt they could use more mathematics skills. The successful groups' reasoning went from closed-loop control to open-loop control. They found that especially higher system thinking activities had a positive influence on performance, and groups that asked for the system's structure before making their plans did achieve higher outcomes.

Sweeney and Sterman (2000) wanted to test stock-flow thinking: would their subjects be able to come to grips with a task that demands relating the net flow into a stock with the stock's changes? The case was a bathtub and a bank account. The subjects were graduate management students beginning SD education. They ware asked to respond to apparently simple questions in an apparently simple format that would not demand higher mathematics skills. The result of the study was that many subjects had substantial difficulties with performing the mental/graphical operations required to properly relate flows and stocks.

Ossimitz (2002) took up the work of Sweeney and Sterman and elaborated a set of tests that would help to distinguish stock-flow thinking problems from issues related with the representation. His subjects were undergraduate students who performed even worse than Sweeney and Sterman's. Ossimitz concludes that a "fundamental aspect is the ability to grasp that in a stock-flow-context the stock with one inflow and one outflow is increasing when the inflow is bigger than the outflow (or the net flow is positive, to put it in another way). Some findings indicate that this might be a key criterion for discriminating between a stock-flow-thinker and a non-stock-flow-thinker". In a following investigation, Kainz and Ossimitz (2002) compared subjects' performance before and after a 90 minute crash-course on stocks and flows, finding a notable improvement.

Maani and Maharaj (2004) tried to find out about if and how systems thinking affects complex decision making; they used a case of an imaginary “computech” firm where subjects have to strive for revenue, profit and market share. Subjects were graduate students in a business school, and had been previously gone through systems thinking education. They could work in teams with a simulator during 2 hours. The raw material was their behavior and performance and the verbalized reasoning. The material was coded following a systems thinking level scheme and a task understanding scheme (which is based on the “correct” understanding of the underlying model).

Learning to think and act systemically

The empirical investigations suggest that few adults are equipped with these thinking skills without having passed through a SD or other systemic education: after all, SD was first proposed as a remedy for the lack of these skills. Also, someone who received this kind of education should have less of a hard time in becoming aware of the SD building blocks when confronted with a system or situation.

This means that there is a progression from beginner to expert, and the beginner uses a different kind of knowledge as the expert. However, it is not clear what the domain of expertise is: does one become an expert systems perceiver (implicit systems thinker) or an expert systems modeler (explicit systems thinker), or both? As stated above, a better systems thinker will have more chances to elaborate a helpful model. However, even the most expert modeler will have to articulate his understanding and undergo formal quantification and validation. So it is assumed as prudent here to think that becoming a system dynamicist is becoming an expert modeler, who masters the modeling skills that prove helpful for elaborating explicit knowledge of a system, and at the same time becoming an expert systems thinker (perceiver). However, the two bodies of knowledge are different (for a brief review, see appendix 1).

We now have to focus on what changes as one transforms oneself into an expert. In order not to duplicate the presented argument, the following discourse is limited to becoming an expert modeler. Does the expert modeler know more (of the same type of knowledge) or differently? Cognitive psychology has been used in SD in order to reflect on the question of knowledge and learning and to fundament the interest for and research on mental models and their change due to SD activities (Doyle and Ford, 1997). This orientation has generated studies about the change in mental models – by definition aware - more than asking for skills. In this paper, it is assumed that indeed skills are a different kind of knowledge that usually will not appear in mental models: the expert is thought to know differently.

Polanyi’s model of implicit integration

Polanyi’s work is proposed to devise an improved model for how a person comes to be experienced and judge and act intuitively. Polanyi elaborated a model of perceiving and acting intelligently based on Gestalt psychology. The basic assumptions are that there is a subject in a world. The external world does exist, and the subject has but his or her own body in order to know this world. So in a way, I know the world through the changes that my encounters with it trigger in my body: electromagnetic waves hit my eyes, the rods and cones trigger a chain of nervous activities up to the point where “I” see an old friend. I know my friend through all of these inner processes. My friend is a *distal* term, and the parts of my body (nervous system included) that worked due to the light waves hitting the retina constitute a *proximal* term. We perceive the world attending *from* proximal terms *to* distal ones. And our knowledge becomes apparent in these terms: we can consciously know grace to our implicit knowing.

Our focal awareness (of the distal term) is directed on *what* we perceive, and *how* we perceive (the proximal term) is not in our awareness, it remains in a subsidiary awareness. We may direct our focal awareness towards our inner processes, but then they cease to be proximal and become distal. For example, a musician performing a Paganini piece is supposed to direct his attention towards the music, not his fingers, and if he redirects his attention to them, his performance will not be a good one.

Naturally, there are many sensory stimuli arriving at each moment, and the subject (each animal) has to steer himself (itself), that is: his movements, in an ever changing and moving world. So there is a need for integration, in order to attend to the most important items. This is done for us by the nervous system without the need for or even the possibility of conscious control. So it is that when I suddenly am aware of my friend’s presence, he is already there; I do not need to transform the sensory stimuli into this conclusion consciously, the integration is implicit from the conscious subject’s point of view. Interestingly, I could not choose not to recognize my friend. It has been experimentally shown that optical illusions persist even though a subject deliberately tries not to fall victim of them (Neuweg, 1999: 170). The subject can choose to doubt his perception, but then the perception – the implicit integration- has already been produced. If for example, one puts on eyeglasses that invert the optical image, one can learn to perform usual activities (like car-driving) within a couple of days; however, this does not mean that the eyes invert the inverted image, but that the rest of the nervous system adapts so that the other relevant parts operate together with the inverted image: it adapts its way to integrate. It was not reflection that brought about the re-integration, but pragmatic attempts to keep on doing usual things of life. Remarkably, subjects tend to forget that they see everything in a inverted manner unless they are asked: the question changes the attending *through* your eyes to attending *to* them.

This model seems well harmonic with recent findings about the brain and its self (Llinas, 2004), that show how the brain organizes complexes of perception (and also of action) in so-called fixed action patterns in order to reduce computational overhead. Llinas believes that the brain’s function is to help the organism move (act) successfully in a ever more dynamic world by making accurate predictions, and that intelligence comes from having to move your body in the world (reflection is but a tool, not an end in itself).

As the example of the inverted image shows, the implicit integration can be learned, and certainly has to be learned from the earliest age on. This goes on all the time. According to Polanyi, our awareness is not only directed outwards in each moment, it also moves on outwards as we learn: as a beginner, a car driver will focus on, say, not directing his car off the road and not becoming too fast or slow; he feels the texture of the steering wheel on his hands: he attends from his hands to the steering wheel. The experienced car driver will feel the road's texture through the car, to him the car is like a part of his body. The same happens with writing on paper with a pencil (you can feel the texture of the paper) and when you walk down the street, you experience your feet hitting the road (and not your socks). We literally *incorporate* our tools and other entities we encounter in the world.

At the side of perception, we develop *connoisseurship* – a capability to intuitively (or implicitly) recognize patterns or situations that require the integration of many elements from the sensory stimuli to the corresponding neural centers, part of which cannot be precisely stated or related to each other. Examples are judging the quality of vine or perfume.

At the side of action, we develop *skills* – the capability to perform complexes of action that require a great deal of implicit integration from the respective neuronal centers to the motor units. One possible example is language, even though it has to be reminded that language also requires *connoisseurship*.

The use of Polanyi's work for System Dynamics

An expert SD practitioner will probably be able to "see" feedback loops and other building blocks in a way similar to the inverted-image case: looking at a case like the bathtub (Seewey and Sterman, 2002, Ossimitz, 2002) or the lichen/grazing case (Moxnes, 2004), he will intuitively see systemic structures: he is a *connoisseur*. He will also intuitively know what to do in order to come to grips with the situation, knowing when to rely on qualitative modeling and when to simulate (and how to): he has the *skills*, he knows the systemic language with all its symbols (Ossimitz) and meanings.

The individuals typically tested in experimental situations (Seewey and Sterman, Doyle et al., 1998; Moxnes, 2000, Maani and Maharaj, 2004; 2004; Jensen and Brehmer, 2003, Ossimitz, 2002) seem to be rather like starters up in systemic terms: they do not have the connoisseur's seeing capability, nor the systemic representation skills. They may have gone through mathematics and sciences education at different levels, but apparently there are some thinks to be learned (in order to become a connoisseur) that are not part of this education. If you have learned German as your mother language, you do not distinguish the separate words your Danish neighbor pronounces, unless you take a Danish course. It becomes understandable how a person who manages his bathtub and bank account (Sweeney and Sterman, 2000) does not manage to perform a task that seems to be the same one in more abstract terms: if managing the bathtub is a skillful activity and the capabilities are proximal (implicit), but the bathtub experiment brings the skill into focal consciousness as distal term, then the conclusion can only be that human adults are not skillful connoisseurs of systemic-dynamic situations unless they become one by learning.

So the question faced by SD and other systemic practitioners is: how can we help them becoming connoisseurs and skillful?

Following Polanyi, we have to learn the proximal term, the elements and subsidiaries that have to do the implicit integration as act of subsidiary awareness. This can be done in different ways:

- the learner can focus on the distal term, leaving the elements needed to produce the integration in the implicit, do not become articulate;

- the learner can focus on the proximal term, trying to make explicit the subsidiary elements and their way of integration.

If the learner can draw on previous personal experience, it can be useful to use explicit learning, but always in combination with activities that use implicit learning. Especially, it becomes important to have a master whom to observe and imitate. This allows the learner to dwell inside the master's mind, thereby producing in him the needed implicit integration. The learner will have to trust his master, and be prepared to execute assigned tasks even though he will not be able to understand them: only by doing so will the have the personal experience required for focusing on the proximal term.

Learning should iterate between the implicit and the explicit mode: the proximal term is a-critical (for un-articulate) and many times, focusing on it me help to improve the process. Afterwards, the improved elements have to be driven back into the realm of the implicit, where it operates as proximal term. This process is like a spiral:

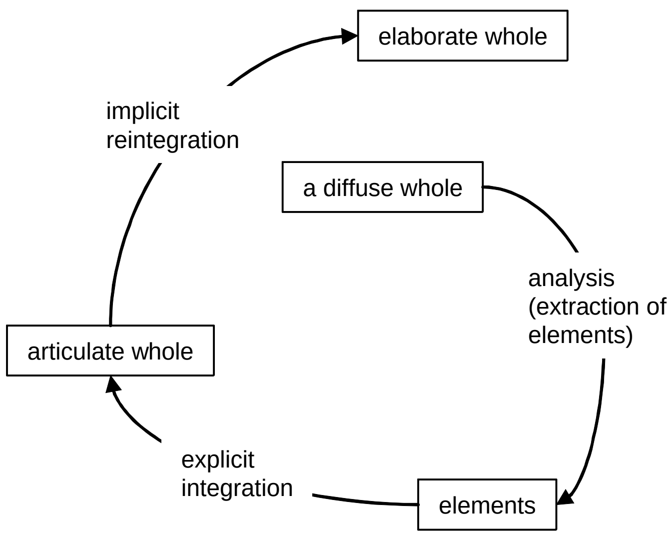

Fig. 1 – learning as a spiral of integrations (translated from Neuweg, 1999:255)

If implicitly perceived situations stay a diffuse whole, but may be analyzed into elements. These can become explicitly integrated into an articulate whole, which is like the revealed mental model. Later, this knowledge may become re-integrated into the implicit realm.

Dreyfus and Dreyfus

While Polanyi's model allows us to understand the meaning of the empirical findings in a way that points at a specific need to foster connoisseurship and skill in a way that honors the need for implicit learning in combination with analysis, it does not show how the learner progressively transforms himself into an experienced or expert modeler. As system dynamicists, we may think of the *learning* as a *delay*: the inflow are beginners, the outflow skilled connoisseurs. The length of the delay depends of didactical and personal factors, but these being equal amongst learners, it is a pipeline delay: it takes time to transform oneself from a beginner into an expert. The question rises if this highly aggregate view is appropriate? Does one turn from beginner into expert in one single step?

Dreyfus and Dreyfus (1986) model of turning from a beginner into an expert suggests that there are indeed several phases one runs through. Since each of the phases is characterized by different and identifiable aspects of the learner, this model can be useful to design a stepwise learning approach for systems thinking and understanding.

Dreyfus and Dreyfus developed a model for the training of aircraft pilots. It tries to make clear how intuitive judgment and action – knowing and acting without previous conscious deliberation- can be developed out of a beginner state where the learner cannot do much but follow previously defined rules. The model has the following phases:

Beginner

The beginner does not have personal experience in the field and depends on the availability of general (context-free) *attributes* and *rules* attached to these attributes. His attention will be absorbed by the analytic search for the attributes and the execution of the rules.

The typical learning activities are instruction, presentation, simple and reduced exercises.

The beginner modeler will typically study a textbook, say "Business Dynamics" (Sterman, 2000) internalize what the SD building blocks are (feedback loops, stocks and flows, delays, nonlinearities and boundaries), and strive to apply the rules extracted from lecture or/and example models in order to do the exercises or resolve the challenges.

Advanced beginner

As he comes to resolve more situations, the learner elaborates a growing set of known situations and comparison between them starts to crystallize situation-specific and holistic *aspects* (rather than formally defined, partial and context-free attributes). These aspects are connected with *directives* (rather than rules).

The typical learning activities are aimed at fostering reflection on the similarities between situations.

The advanced beginner modeler will now try to attack validation tasks, which will demand some interaction with a more experienced modeler or teaching personnel. He may be interested in "best practices" material which helps him to build up his directives.

Competent

Now the learner deals with many details (attributes and aspects) and he starts to develop his own perspective which allows him to order and set priorities and weights; he starts to set goals and plan ahead, taking into account the situational context and also developing an emotional involvement with his knowledge (since it is not based on externally defined rules and directives).

Typical learning activities are mainly simple case studies.

The competent modeler will work on small modeling projects in order to resolve a given case, maybe as part of the book's challenges.

Proficient competent

Now the learner has come to perceive the situation as a whole and in an intuitive (implicit) manner. He does not need to take it apart into attributes in order to know "what the case is". However, since there are more possible action strategies than situations, he still has to consciously reflect upon what to do.

Typical learning activities include more complex case studies and participation in real work situations.

The proficient competent modeler will resolve real modeling tasks and even if he keeps the book like a reference manual, he will only use it to recall how some things are done. He is able to "see" feedback loops and the like –maybe even archetypes- in an effortless manner.

Expert

Finally, the learner has learned to intuitively know what he has to do: "an expert does not have to reflect; he knows" (Frank Lloyd Wright).

The expert modeler may be looked for by some consulting company, since he is able to model productively. He knows when to model qualitatively and when to use quantitative modeling in the situation he meets.

The following table (adapted from Neuberg, 1999, p. 311) summarizes the phases:

	Beginner	*Advanced beginner*	*Competent*	*Proficient*	*Expert*
Elements taken into account	context-free	context-free and **situational**	context-free and situational	context-free and situational	context-free and situational
Sense for what is relevant	no	no	**consciously elaborated**	**immediate** (implicit)	immediate
Perception of situation as a whole	analytical	analytical	analytical	**holistic**	holistic
Selection of action	following rules	interpreting rules and directives	extensive planning	limited planning	**intuitive**

When read from left to right, the boldface words demarcate the transit from conscious to implicit mental processing.

On his way, our modeler will have mastered many –progressively more demanding- leaning 1 situations and he finished a learning 2 itinerary that made him become the expert he now is.

Using the model for System Dynamics

We now turn back to the full question of becoming a system dynamicist, involving skillful systems thinking and modeling.

It is not clear how much time and effort it takes to develop from one level to the next, but most people who have served as subjects in the reported studies (Moxnes, 2000; Sweeney and Sterman, 2000; Ossimitz, 2002) were beginners, and most active workers in the SD community are proficient competent or experts. If so, what should be expected from test subjects is no more than skills that all of us embody implicitly (for example managing not to flood your house just because you wanted to take a bath); being able to avoid hot-cold oscillations in the shower, as well as more complex and "systems"-specific tasks would remain the domain for more advanced learners.

Of cause, it is a rather crude simplification to consider that the learner(s) in phase "beginner" remain beginners until the day the flow into the "advanced beginner" level; we know that each of the learning experiences triggers a small and progressive transformation, and that the flow from one level to the next is going on all the time. Anyway, it takes some time to go through what we distinguish as being a beginner, and some day the learner is considered "advanced beginner".

We may thus represent a class of system dynamics students as a fourth order pipeline delay:

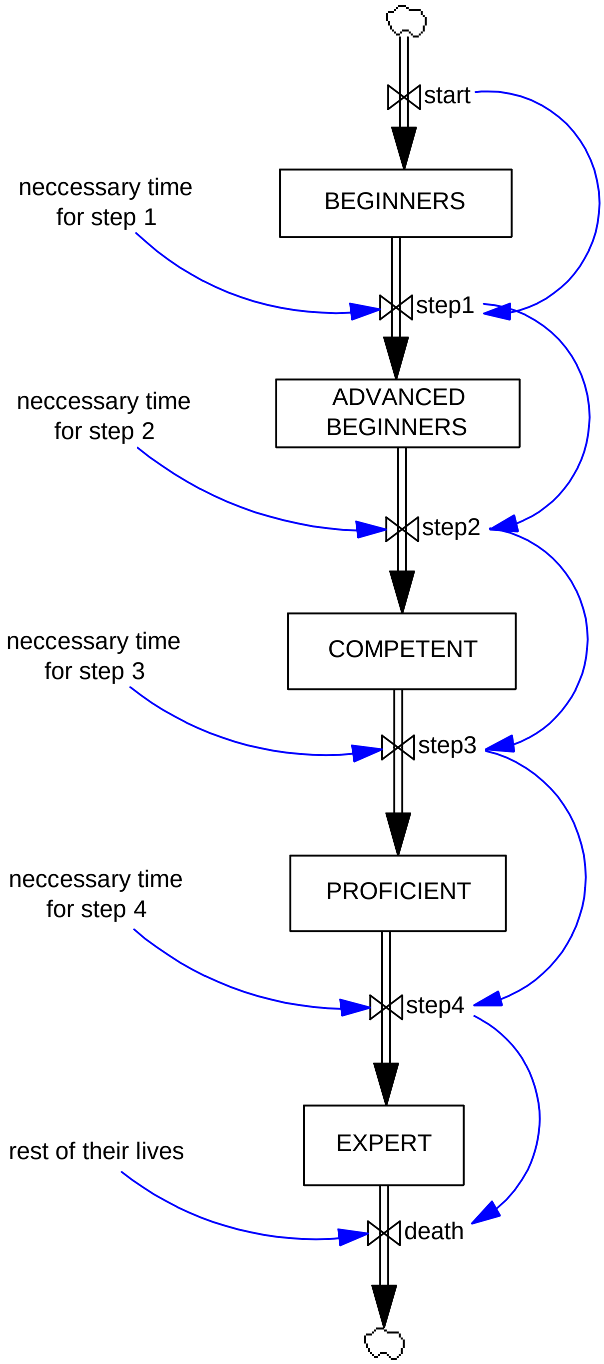

Fig. 2 A model of turning from beginner into expert modeller

This is but a conceptual model, since we do not know how much time it takes to transfer from one stage to the following one. It is plausible to assume that this time varies depending on the didactical context of the learning situation and the personal context of the learner.

In this model, the time it takes to advance from one stage to the following one appears to be constant and not dependent from any variable recognized as part of the system. However, we have said that system thinking skills may influence the becoming of a good modeler. For example, Ossimitz (2002) concludes that a “fundamental aspect is the ability to grasp that in a stock-flow-context the stock with one inflow and one outflow is increasing when the inflow is bigger than the outflow (or the net flow is positive, to put it in another way). Some findings indicate that this might be a key criterion for discriminating between a stock-flow-thinker and a non-stockflow-thinker”. If this specific skill act as enabler, say for turning from beginner into advanced beginner, the chain for systems thinking learning would interact with the one in the above model, and the “necessary time” would change.

This calls for work on the relationship between specific system thinking skills and the specific needs at the respective stages in the learning chain. However, this must wait until the usefulness of this stage-model is established, which would still have to be done.

Empiric studies’ analysis from this viewpoint

Each of the initially synthesized, recently published studies is somehow related to the issue of thinking, knowing and learning, even though in different ways. We will now look at them from the viewpoint of Polanyi’s model of knowing and Dreyfus and Dreyfus’ model of learning. The comparison is based on the following items:

- *t*ype of *su*bjects used according to the learning model used here: TSU
    1. beginner,
    2. advanced,
    3. competent,
    4. proficient,
    5. expert;
- *c*lues *p*rovided according to *s*ubjects: CPS
    1. none
    2. attributes and rules;
    3. aspects and directives;
    4. objective;
- *int*entionality: INT
    1. teaching or
    2. experimentation/research;
- *c*ompetencies *l*ooked *f*or: CLF
    1. control a system,
    2. system thinking;
- *c*ompetence *l*evel *l*ooked *f*or: CLLF
    1. none
    2. beginner,
    3. advanced,
    4. competent,
    5. proficient,
    6. expert;

- *l*earning *r*equired for the *c*ompetencies: LRC
    1. n/a
    2. improve mental model of system,
    3. improve decision policies (learning I; see appendix 1);
    4. improve system thinking skills (learning II);
    5. improve the way complex situations are approached (learning II)
- *s*ystem *d*ynamics *a*ction *s*trategy: SDAS
    1. model
    2. simulate
    3. implicit integration
- *a*ssessment *a*pproach: AS
    1. self-reports,
    2. attitudes,
    3. inference based upon behavior,
    4. mental models from narrative,
    5. mental models from cognitive mapping;

Study	*TSU*	*CPS*	*INT*	*CLF*	*CLLF*	*LRC*	*SDAS*	*AS*
Doyle	1	1	2	1	1	1, 2	2	4
Moxnes	1	1	2	1	1	2 (1)	2	3
Jensen and Brehmer	1	1	2	1	1	2 (1)	2	3
Sweeney and Sterman	1	1	2	2	1	n/a	3	3
Ossimitz	1	1	2	2	1	n/a	3	2
Maani and Maharaj	3	1	2	1, 2	1	1, 2, 4	1	3, 4

Besides from remarking that many of the possible combinations have not been used by the studies used here, we mainly see that

- although subjects almost always were beginners in the field of systems thinking (low TSU), the studies expected them to be (naturally?) skillful, so to say: experts;
- according to this expectation, no clues were provided for beginners (low CPS);
- the majority of the studies used a rather short time horizon; none of the studies looked at the *learning* of systems thinking skills;
- the subjects had either to know or to learn from interacting with a simulation; modeling was not used as learning strategy;
- the focus is usually set on learning I;
- there is diversity as for assessment approaches.

These studies showed that "ordinary" people tend to be systems thinking beginners. The above pipeline – delay model indicates that if nothing in the previous life experience of a subject (including formal education) provides the necessary learning, this had to be this way.

Investigating the transformation from beginner to advanced beginner

It is argued here that studies on the process of learning of systems thinking skills are needed, and it is hypothesized that the proposed model of learning is useful for this purpose. If the stage-model of learning to think systemically is useful, then subjects who are beginners and receive help in form of attributes and rules should outperform other beginners without this help. Kainz and Ossimitz (2002) gave their subjects a 90 minute presentation of stocks and flows where we find a series of items like examples, attributes and some properties, but the presentation does not contain rules comparable to those that underlie the scoring of the test tasks (like "When the inflow exceeds the outflow, the stock is rising"). It would be important to know how subjects would perform if the help given includes these rules. It would also be relevant to assess how much experience (tasks) it takes until they reach the following stage. We can assume that the usual SD-courses do not allow to develop beyond the advanced beginner stage (in one semester's time). So in this section, we focus on this transition. Also, what follows is restricted to the "stocks-and-flow" part of systems thinking.

There are three hypotheses to be corroborated:

1. if beginners need explicit and context-free attributes and rules, then the first series of (adapted) tests should detect superior performance of the subjects.
2. if the beginner stage is a necessary phase in order to become an advanced beginner, then the subjects who participated in the first phase should outperform other subjects in the second series of tasks.
3. subjects who have arrived at the competent stage should be able to elaborate better mental models from interacting with a simulator and from constructing a model.

The tests can be adapted to validate the first two hypotheses (the third one is related to feedback thinking, that is: a different set of rules and directives and has to be done with different test instruments). The first task is the bathtub situation taken from Sweeney and Sterman (2000) with constant flows, and it is presented together with the relevant aspects and rules; rather that limiting time, the time taken by each subject is measured. The other 4 tests are presented without repeating the general rules (that apply to each of the tests); instead, students can ask for a sheet where the rules are given and are also allowed to use personal notes taken (which allows to detect who does not recall the rules) and the task sheet provides a space where subjects are invited to optionally state the rules they use. Again, each subject's response time is taken.

In a first step, this investigation will reveal the dynamics of the use of explicit and context-free attributes and rules. The next step will be to use the diversity of experiences (all 5 tests are different with respect of presentation and specific skills for each type of presentation) in order to make subjects elaborate aspects and directives, followed by a new series of tests that take the form of small modeling tasks, in which each subjects' skills are challenged.

Activities to test the first hypothesis are currently being carried out with undergraduate business students in a Chilean university (during the fall semester from March 15 through June 24) since only the fist test has been absolved so far, the results are only briefly presented in appendix 2 (but will be available by the conference date).

The second hypothesis has to be evaluated once there are subjects who qualify as "advanced beginners", and will take a comparison of one group of beginners with the group of advanced beginners.

The third hypothesis will become meaningful once the first two have passed the examination. Again, its corroboration will require two groups consisting of subjects in different stages to realize the same tasks, in order to compare their performance.

Conclusion and outlook

This paper set out to make a contribution to the domain of the learning of systems thinking skills. This is justified because empirical studies consistently find subjects to lack these skills in a sufficient proportion to raise concerns.

The contribution consisted of the proposition to consider the basic acts of systems thinking to be processes of implicit integration, based of the work of Michael Polanyi. In the framework of this model, the ability to perceive systemically is basically implicit (unconscious), but it can be deliberately learned. This learning process has been suggested to consist of five stages, according to the model developed by Dreyfus and Dreyfus: beginner, advanced beginner, competent, proficient and expert.

Looking at recent studies on the subject of systems thinking and learning, it was found that they did not make an explicit distinction of phases of learning; rather they detect the lack of systems thinking abilities in beginners.

Three hypotheses have been derived from the learning model and it was argued that they make sense in the current situation. The tasks designed by Ossimitz (2002) have been adapted and some more tests have been added in order to test the hypothesis.

The empirical research has just started, which is a limitation for the paper's message, since it has to be understood as the construction hypothesis, and not as their corroboration. However, this construction has opened an interesting possibility for the domain of systems thinking, its learning and its importance for becoming a good modeler or systems dynamicist.

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Appendix 1: Systems thinking and knowledge about a system as complementary types of knowledge

It is not unusual for systems dynamicists to reflect upon learning, which is generally defined as "generating new behavior or the internal possibility to perform new behavior as a product of experience" (Schunk, 1996). For SD use, one can easily translate this into the following:

- "new behavior" refers to new policies and organizational structures;
- "new possibility to perform behavior" means new or improved mental models.

These are two forms of knowledge, and learning is the process of elaborating them. Learning is a process of change in the body of knowledge of someone. It is work to be done by a learner, and if we wish to help someone to learn, we can only provide him with helpful experiences. In this sense, Maier and Grössler (2000: 139) state that "learning objectives are the mediation of declarative knowledge (knowing that) as well as procedural knowledge (knowing how) and structural knowledge (knowing why). […] the meta-purposes of the simulation programs […] are to help users understand the principles of the underlying system and to train users in controlling the system".

These goals are clearly related to structural knowledge (understanding) and procedural knowledge (controlling) in the context of one particular system. It is thought that the interaction with a modeling tool or a simulation model will allow the users to modify their mental model and/or their skills. According to Doyle and Ford (1998:17), "a mental model of a dynamic system is a relatively enduring and *accessible*, but limited, internal conceptual representation of an external system whose structure maintains the perceived structure of that system" (emphasis added). As it is articulated, a mental model is declarative knowledge referring to some combination of procedural and structural knowledge.

What is knowledge that it can be declarative, procedural and structural? Is the capability to control a system - a skill– comparable to understanding? Is procedural knowledge accessible in the sense of a subject being able to articulate it as declarative knowledge? Does mastering one's bathtub draw on the same knowledge as resolving the bathtub tests, or is the declarative knowledge used in reflecting on the test different? And: what is known when one has structural or declarative knowledge? Is it the particular system under study or some more generic knowledge that enables to better study any such system? Doesn't it imply system thinking or system modeling procedural knowledge?

Further, what kind of knowledge is meant when one says "system thinking"? Without being able to discuss different propositions here, Maani and Maharaj (2004: 22) refer to Richmond's (1997) definition: Dynamic thinking -> System-as-cause thinking ->Forest thinking -> Operational thinking -> Closed-loop thinking -> Quantitative thinking -> Scientific thinking. *Thinking* is a process that remains for its main part implicit, as our conscious reflections are only a small part of all the cerebral activity going on. This means that system thinking would be a set of skills rather that declarative knowledge.

Ossimitz (2002) describes systemic thinking as:

- "Thinking in Interrelated Structures;
- Dynamic Thinking, which means a thinking which is not restricted to grasping just snapshots of a situation, but takes into account evolution over time.

- Thinking in Models, which means that any systems thinker should be aware that he or she is always dealing with a model of a complex situation, which is usually massively simplified compared with the "actual" situation.
- Systemic Action, which means the practical ability of steering systems".

The fact that Ossimitz refers to "thinking" is interpreted here as meaning that it is an implicit process of *knowing* more than a conscious knowledge.

Sweeney and Sterman (2000:250) define systems thinking as being able to understand "behavior that arises from the interaction of a system's agents over time", specifically:

- "understand how the behavior of a system arises from the interaction of its agents over time (i.e., dynamic complexity);
- discover and represent feedback processes (both positive and negative) hypothesized to underlie observed patterns of system behavior;
- identify stock and flow relationships;
- recognize delays and understand their impact;
- identify nonlinearities;
- recognize and challenge the boundaries of mental (and formal) models".

This definition is somewhat closed to the SD community; it describes what the systems thinker is able to do: he comes to be aware of feedback loops, stock-and-flow relationships, delays, nonlinearities and model boundaries. These are the building blocks of the system dynamics language. It is not clear to which point "recognize" and "identify" refers to spontaneous recognition/identification of these structures or if they have to be consciously looked for in order to "discover" them (or some of both)

Anyway, systems thinking is always presented as a fluid form of knowledge that enables its owner to perform better learning in front of new situations or systems. In other words, these skills are second order with respect to "understanding a given system X". In the terms of Bateson (1979), there are several types of learning about a system.

- Learning 0: coming to know how such or such a variable behaves. This takes a previously existing model in which this variable makes sense. Many people will feel that this is not really learning, but it is hard to deny that when your company's profits where "high" last year and now they are told they are "low", you just came to know something new: you learned. Also, reading in a SD textbook that there is something called "delay" may be called learning 0. Knowledge at this level would be rather declarative: one knows that there are feedback loops, stocks and flows, delays, nonlinearities and boundaries.
- Learning 1: when confronted with an unknown system or situation, one has to generate a way of dealing with it, calling upon and evolving one's mental model of it. This problem solving performance is clearly a higher form of learning, and it produces the framework inside which learning 0 can go on. SD students will be frequently confronted to this kind of situation, and it is our expectation that they will do better over time. Here, knowledge would be rather procedural in that one knows how to find these building blocks in a given situation (one knows how to

access or articulate a model in terms of these building blocks). The knowledge produced would be structural, as one now understands the studied situation in terms of the same building blocks.

- Learning 2: the building of all the skills that help performing "learning 1" situations using less resources. This may comprise knowing that such things like feedback loops or delays may exist, and certainly knowing how to model step-by-step and also being able to intuitively grasp part of the system's structure or behavioral logic. This learning of a context inside which the situations are alike is the explanation for the observed progresses in learning 1 situations and thus it is called learning 2. The experienced or even expert modeler is one who has passed through a learning 2 process. The knowledge belonging to this level should be thought of as highly procedural, and its articulation would be a declarative reproduction of what is implicitly known.
- Learning 3: there is no guarantee that there can be only one context: there may be several ones, and in some cases a subject would have to learn that a given learning 1 situation no longer belongs to its usual context, but has to be classified as belonging to a new one. This learning of new contexts is called learning 3; since learning 2 gives us our typical way of approaching life and its situation (our personality), Bateson thought learning 3 to be exceptional and rather traumatic for the learner. It has to be suspected that turning from a non-systemic thinker into a systemic thinker is an act of learning 3.

According to Bateson, these types of learning go on at the same time: while working hard to elaborate a model (learning 1), the subject also learns at level 2, and this is how experienced modelers transformed themselves from the beginners they once were into the experts they now are. For example, when a person is prompted to make a statement with respect to some situation (like in the study about mental model changes by Doyle et al., 1998), and the person switches from textual expression to causal loop diagrams, there would have been learning at several levels. Now the person:

0. knows that CLD exist,
1. is able to use it in order to resolve a situation;
2. has a new tool for resolving this type of situation, and maybe even
3. is turning into a systems thinker - according to Ossimitz (2000) the way we can represent something influences the way we know and think about it.

The conclusion from this argument is that what studies like Sweeney and Sterman, Ossimitz or Moxnes investigate is at a meta-level with respect to research on mental models. It follows that the ability to perceive systemically is relevant for (prior to?) being able to develop a helpful model, be it qualitative or quantitative. This in turn leads to ask if the traditional SD activities – modeling or interacting with a simulation – per se would need to be preceded by an intervention in the systemic perception. According to Sweeney and Sterman (2000), this has been the reason why "Business dynamics" (Sterman, 2000) offers extensive treatment of graphic derivation and integration. However, this should also be accounted for when investigating the effectiveness of modeling or “flying” a simulator for learning about a system: what level of system thinking competencies do the subjects have?

Appendix 2: the study concerning the learning of systems thinking skills

This study consists of two phases. The first one applies a modified version of the tests used by Ossimitz (2002) to undergraduate students of business administration in a Chilean university (two groups corresponding to two different courses). The first group is made up of 56 students and it is about information systems development. The second course is about system dynamics and has 20 students.

At the date of march, 18, only one week of courses has passed, so by the time this paper is sent, it is too early to discuss the measured results and compare them with the ones observed by Sweeney and Sterman (2000) and Ossimitz (2002).

Anyway, the first test revealed the following performances:

Task	**S+S**	**O**	**Sch (N=49)**	**ISD (N=34)**	**SD (N=15)**
When the inflow exceeds the outflow, the stock is rising	0,87	0,42	0,55	0,41	0,87
When the outflow exceeds the inflow, the stock is falling	0,86	0,43	0,53	0,41	0,87
The stock should not show any discontinuous jumps (it is piecewise continuous)	0,96	0,64	0,55	0,38	0,93
The peaks and troughs of the stock occur when the net flow crosses zero	0,89	0,56	0,55	0,38	0,87
During each segment the net flow is constant so the stock must rise (fall) linearly	0,84	0,38	0,55	0,38	0,87
The slope of the stock during each segment is +/- 25 units/time period.	0,73	0,26	0,29	0,03	0,87
The quantity added to (removed from) the stock during each segment is 100 units, so the stock peaks at 200 units and falls to a minimum of 100 units.	0,68	0,27	0,31	0,03	0,93
	0,83	0,42	0,47	0,28	0,90

The discrepancy between the two groups is surprising, but not yet explained. The tests will continue over the next 4 weeks.

In phase 2, subjects will be prompted to model a sequence of simple situations; in each, the subject has to make a prediction based on graphical integration / derivation. The sequence is:

- one single positive feedback loop
- one single negative feedback loop
- each of Wolstenholme's totally generic systemic archetypes (Wolstenholme, 2003, 2004), which are all 4 combinations of two interacting feedback loops.

In each of the six tasks, the subject is confronted with a description made from a piece of text and the graph showing the dynamic of one of the variables; the student's task is to decide the type of each identified variable, connect the variables and infer one target variable's dynamic from the model's structure and the available graph. The work sheet prompts the subject to draw an influence diagram (discriminating between stocks and rates; see Wolstenholme, 1990). The following figure (next page) is a translation of the first task from Spanish into English language. To resolve this task, one must be able to tell if a given variable is a stock or a flow, and be able to infer one variable's dynamic from the other one's.

You are the owner of a savings account that rearns a monthly interest corresponding to 2% of the account's balance. This means that the more money there is in your account, the more interests the bank will pay you in one month; and the more interests they pay you, the more money will be on your account.

Draw an influence diagram of this system:

Assume that for opening the account, the bank required you to deposit $10.000. How will the system's variables evolve over the first year?