How much can be learned by exploring an existing model? The concept of guided rediscovery

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Abstract

System dynamics has been developed around the process of modeling and simulation as a means for improving human judgment and decision. Due to the high requirements of the process, interactive learning environments have been developed to allow users to learn in a less time consuming manner. However, there is fear that simplification may precisely take away what makes system dynamics so strong. We have inquired the process of modeling and ants activities in search for the activities particularly relevant for learning; we find that much can be learned from exploring existing models – without creating them. One can rediscover the important insights by asking the important questions to the simulation model, elaborating the responses and interpreting them. The developers of a model can articulate the questions that lead to these insights and thus the model user can be guided to rediscover them. We present a prototypical process for this exploration work. We hypothesize that this process leads to more accurate mental models than exposition to a more traditional transparent-box learning environment; we present the research design to be carried out during the first semester of 2008. We also propose to revisit the current taxonomy of computer based learning support.

Keywords: interactive learning environment, modeling, model exploration

Introduction

Ever since system dynamics and its models have been available together with user-friendly software, there has been a search for building effective "interactive learning environments" (ILE): these would allow their users to gain some essential insights by interacting with a model through an interface. Thus it would be possible to "transfer" some learning from model builders to model users. The obvious advantage would be that "consuming" a model takes much less time than "producing" one. The underlying idea was that one can trigger enduring change in mental models this way (Morecroft, 1994). From early on, it was seen as essential that the model must bee transparent and open to modifications (Davidsen, 1994). Some authors reported from "model-supported case studies (Graham et al., 1994), others spoke of a management-flight-simulator approach (Bakken et al., 1994). Already at this time, problems with computer-based learning environments were acknowledged and mitigation strategies proposed (Isaacs and Senge, 1991). In the following years, there have been attempts to establish a taxonomy (Maier and Grössler, 2002) and to pay attention to the main topics of concern for designing such artifacts (Grössler, 2004).

Ever since this had set on, skeptics have argued that what is learned during the process of modeling cannot be learned by simply interacting with a predetermined model (Forrester, 1985). Firstly, there is no finished model, and any product like a book (or, for our purpose, an ILE) is "only a snapshot in time and catch[es] but a single step in a continuously evolving set of ideas about a social system. [...]The very nature of such a book tends to mislead the reader into feeling that there is greater commitment to the precise structure than is in fact true." Thus, work based upon a model like it is at a given moment in its evolution could never yield more than the understanding the modelers have built up until this moment. Forrester finished stressing that

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"rather than stressing the single-model concept, it appears that we should stress the process of modeling as a continuing companion to, and tool for, the improvement of judgment and human decision making." Much in the same tenor, Sterman (2005) explained why for a system dynamicist, "all models are wrong".

Forrester (2007) maintains that any simplification that takes away the mental effort of modeling – like "systems thinking" only with causal loop diagrams – would make it impossible to experience the "full power of system dynamics" (p.363):

> *"Those who take the road of systems thinking and causal loop diagrams are not practicing system dynamics" "Through an appropriate simulation model, one should know the structure causing the problem, should know how the problem is created, should have discovered a high-leverage policy that will alter behavior, should understand the reasons why the low-leverage policies will fail, should be able to explain how strongly defended policies within the system are actually the cause of troubles, and should be able to argue for better alternative policies. Everything that one says should fit into a totally consistent story, which is possible when built on insightful computer simulations."*

Even if his concern in his reflection concerning the next 50 years seemed to be more with "systems thinking" than with ILEs, one can transfer the message to the latter domain, because users of ILEs do not deploy the system dynamics modeling method to understand the learning environment's underlying model. They may practice "systems thinking" and develop causal loop diagrams of what is going on in the simulation, but in this case, Forrester's reserve applies.

There may be good reasons *not* to engage into modeling, the most obvious being the time required to learn modeling and the time required to develop one model up to being able to "enter a complex dynamic situation and aspire to be the only person present who can talk about the issues for 20 minutes without contradicting oneself" (Forrester, 2007:363).

Still a doubt remains: can there be a third way, somewhere in between these two opposing positions? Here we will argue that there may be a range of possibilities, one of which will be presented. We will first ...

Activities and learning in system dynamics and ILEs

Learning goals

System dynamics aims at improving judgment and decision (Forrester, 1985). Therefore, it aspires to high-staked learning goals. In the words of the field's founder: "Through an appropriate simulation model, one should know the structure causing the problem, should know how the problem is created, should have discovered a high-leverage policy that will alter behavior, should understand the reasons why the low-leverage policies will fail, should be able to explain how strongly defended policies within the system are actually the cause of troubles, and should be able to argue for better alternative policies." (Forrester, 2007:363). Maybe it is mainly the depth of the understanding which one aims for: in order to be able to stand up and explain the whole thing, your mental model of the situation must be very detailed, accurate, coherent and conscious.

First of all, this leaves open the possibility to develop such understanding with *one* appropriate simulation model. Even if the model is bound to evolve over a larger scale of time (which leaves interesting traces of learning; Schaffernicht, 2006), in one specific moment it enables the necessary learning. It follows that modeling is not an aim in itself but rather a tool for triggering change in mental models such as to improve judgment and decision.

It can be argued that at times, there are less ambitious learning goals, especially in terms of depth of understanding. The bounds of time available and the stock of knowledge resources of the problem owner (SD knowledge, previous relevant inquiry into the problem space) may make it necessary to lower the goals. Maybe one wishes to awake a sense of problem in a wide non specialist public by publishing a non technical book. Maybe one wishes to make students of economics understand the economy as a dynamics system without studying system dynamics. Maybe one wishes to help a management team develop an approximate understanding of the problem and one recommendable solution strategy.

The crux seems to lie in the relationship between the available knowledge resources of the target people, the time they are able/willing to invest into inquiry and the time necessary to develop deep understanding.

The sources of learning

Judgment and decision stem from mental models. Let us recall that in system dynamics, a mental model is defined this way (Doyle and Ford, 1998, 1999):

"A mental model of a dynamic system is a relatively enduring and accessible, but limited, internal conceptual representation of an external system (historical, existing or projected) whose structure is analogous to the perceived structure of that system."

The learning challenge is to develop a sufficiently detailed, accurate, coherent and conscious mental model. If there is a problem *P* and an "appropriate simulation model" *M*(*P*) of it, the ones who built it will understand *P* because they understand *M* – they have elaborated a mental model *MM* of *P* by building *M*: *MM*(*M*(*P*)). If *M* becomes the heart of a simulation game of the "black-box" type (for instance for purposes of experimentation), then users cannot directly perceive *M* and many activities that are relevant for learning become impossible to perform. If one builds a "transparent-box" ILE, users will be able to perceive *M*, but they did not elaborate *MM* yet. It should also be clear that an individual who has not yet acquired the mental or cognitive skills needed for properly interacting wit a model *M*, will not be able to perform relevant interaction with the model, which compromises his learning possibilities (if there is no help or guidance offered). If one requires them to build their own model *M*(*P*), this will take previous training in system dynamics modeling and the whole time required for the full modeling process.

For those who develop system dynamics simulation models, the following figure tries to represent a prototypical sequence:

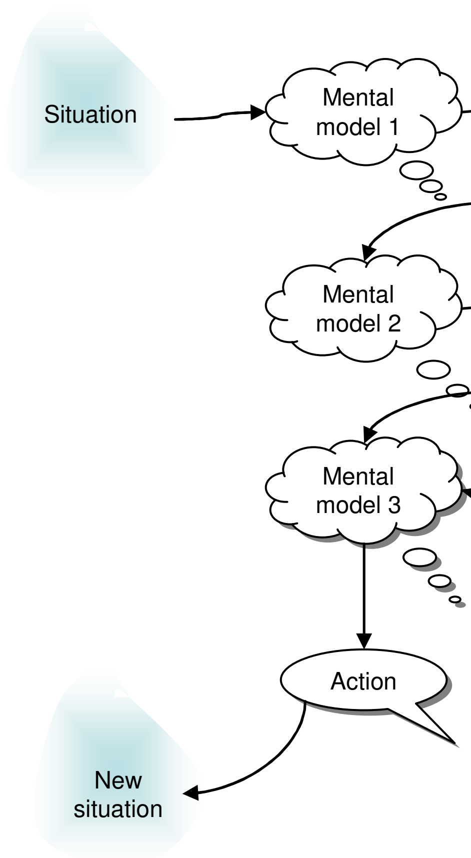

Figure 1: Interaction between mental and simulation model for modelers

The problematic or challenging situation is represented by an initial "mental model 1", much like the "dynamic hypothesis". Now an iterative process of formulating the simulation model begins. Interaction with simulation model 1 leads to mental model 2, which in turn leads to reformulating the simulation model into a second version. In the figure, the process comes to a provisory stop with the respective third versions of the mental and simulation model, some action is derived on base of the now ruling "mental model 3", and this helps transforming the initial situation into a new situation. This in turn may trigger a new round of modeling, but we halt at this point.

The sheer fact of creating the stock-and-flow diagram with tentative equations as "external knowledge representations" has learning effects, mainly "clarification or elaboration of a learner's own conceptual understanding of a problem space" (Stoyanov, 1997, cited in Lee et al., 2005, p. 118). However, in system dynamics, the model is more than a static diagram.

It is common to divide the process of modeling into the conceptualization and then quantification of the model, followed by the validation or testing (Sterman, 2000, p. 86). Surely the limits between the "formulation" and the "testing" phases is rather diffuse in practice: the model developer need simulation to see if their expectations are adequate; usually, there will be "surprise model behavior" and it is not clear if stems from errors in the mental model or in the simulation model. Modelers use specific tactics in order to find out, and many insights arise during these explorations (Mass, 1991). During this work, many questions arise and the modeler has to manipulate the simulation model to answer them. By asking questions and answering them, he arrives at insights. Not all the questions may turn out to produce insights, but this can only be known afterwards, and the modeler do know this after having arrived at am "adequate" simulation model.

So the reason why one can stand up and talk about the situation without running into contradictions is that he has already run into all thinkable contradictions before – which is doubtlessly why the process takes much time and why personal experience is so valuable. For those who do not conceptualize and formulate the simulation model but get into touch with an artifact based upon this simulation model (a book, an ILE), the activities are different.

The question then is if there is some way to incorporate the types of interacting with the model into the process of using a model. We will now look at different learning environments that make their users follow different sequences of activities, trying to show how they relate to the activities of the full modeling process. However, a brief comment on the concept of learning environment is in order before proceeding.

A brief comment on the concept of learning environment

Learning is the consequence of activity: different types of activity lead to different types of learning. Activity is always interaction with some external entities, during which many internal – physical but also mental – entities perform changes. In this sense, any "learning environment" should be understood as an organized set (a *system*) of objects that define an activity space *via* the functionalities they offer (Winograd, 1996).

In this sense, there seems to be no clear frontier separating "interactive learning environments" from "other learning environments": the objects that constitute the "learning environment" always respond do the user's actions in one way or another. As far as some of these objects comprise computer programs, they may have a richer response repertoire, especially allowing for simulation; however, this does not mean that unprogrammable objects are not interactive. Since this is not the main issue of this work, it shall be discussed in a different place.

It is by no means clear that a simulation (a piece of software with a running model and a user interface) would be sufficient.

The concept of an "environment" especially designed to foster learning is not new; it can be traced back at least to Maria Montessori (1995) and her work at the beginning of the 20th century. Also, Piaget taught that by manipulating external objects, the mind puts itself into shape. The work of Papert (1993) proposed the concept of "toys to think with" (toys as special kind of tool or object), which has given rise to a long stream of work from MIT's MediaLab. Jonassen describes "mindtools" as "computer applications that require students to think in meaningful ways in order to use the application to represent what they know" (Jonassen, 2000, cited in Moore, 2006: 402). In is then no surprise that instructional technology is defined as "the theory and practice of design, development, utilization management and evaluation processes and resources for learning" (Seels and Richey, 1994:4, cited in Moore, 2006:401).

Activities in various learning environments

With this in mind, we will now visit various "learning environments" and compare them to the fullest possible system dynamics learning environment, which is the modeling and simulation software itself. In doing so, we will only use "transparent-box" cases, that allow users at least to look at the underlying model.

Let us recall that there are reasons to believe that users of such "transparent-box"-simulators (where in principle one can explore the underlying model and use this information) do not take advantage of this possibility: many rush to action, either because they are just playing or because they prefer acting over thinking. Many times, even if they looked at the model structure, they would not understand the dynamic implications; the cognitive shortcomings in stock-and-flow thinking are well documented (Booth-Sweeny and Sterman, 2000, 2007, Sterman and Booth-Sweeny, 2002, Cronin and Gonzalez, 2007, to mention only the most prominent ones; refer to these articles for more references). A user who does not intuitively know how a stock variable relates to the incoming and outgoing flows may simply not grasp what will be going on when the model runs.

A classical case of system dynamics ILE

Davidson (1994) describes a sequence for working with ILEs consisting of the following steps: make assumptions about the environment (which gives users an initial context for getting started), formulate a strategy, submit it to the computer, let the computer compute the behavioral consequences, evaluate the consequences of the strategy, repeat the previous steps. During the investigation process of finding out what went wrong and formulating strategies, the model itself can be viewed in its behavior, its causal loop representation and as stock-and-flow model, where equations can be seen and modified, as well as variables needed for policy formulation can be added.

The following figure represents the sequence, ready to be compared with the reference sequence of Figure 1:

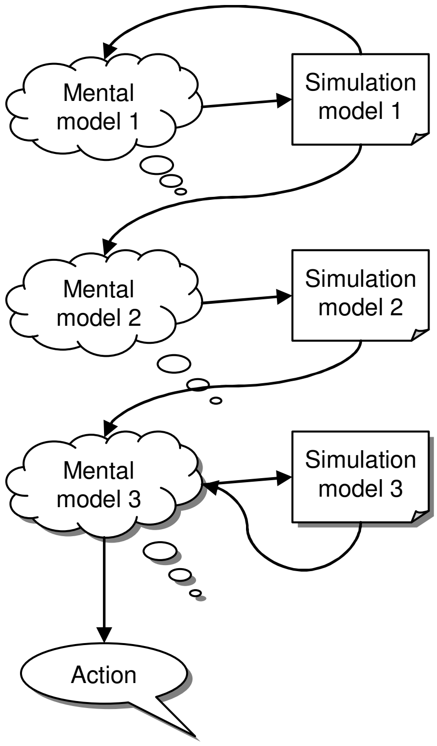

Figure 2: Davidson's 1995 ILE case

For the ILE users, the initial simulation model replaces the "initial situation". The can, in principle, do with the simulation model whatever they need in order to understand the causes of its behavior. They may experience "surprises", which presumably stem from errors in their mental models. By the time they have been able to formulate a strategy without surprising consequences, and are able to explain why this is the case, they can claim to have sufficient judgment and decision capability.

As far as the users of such an ILE do not bring with them the technical skills of the system dynamicist, they may not be able to see the possibility of diagnosing their surprises. This may be overcome by adding a facilitator into the environment.

The World dynamics book and model

The "World dynamics" book (Forrester, 1972) was the book written "around" the first world dynamics simulation model, famously drawn on a napkin. The book presents the stock-and-flow diagram, each of the variables is introduced in word and equation (or graphic function), and each of the important feedback loops is presented and explained. Then the base-run and further scenarios are discussed. The interested individual can re-build the simulation model or download it from the Internet, and engage into active exploration.

Of cause, the model has some more feedback loops than those explained in the initial chapters, and the naive explorer might spend quite a time trying to figure out just what matters in this model. But then, the book's author has already done the exploration and understood what matters. So the "why" of the model formulation can be read in each variable's justification. Each important loop is already identified and can be put to run in isolated manner, to explore its workings. For the base run and scenarios, the key variables are explained in the book and the explorer can trace back from then through the loops of the model. In other words, the modeler's understanding guides the reader/explorer and saves him a lot of time. Still the explorer can have some "surprises" and ask himself some questions. By elaborating the answers, he will develop a mental model that will allow him to stand up and talk about the subject.

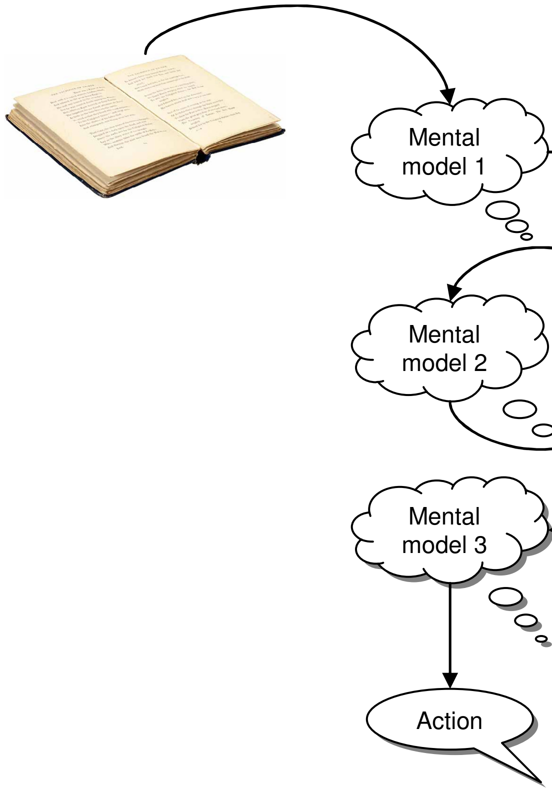

Figure 3: the world dynamics case

Comparing figures 3 and 1, the initial "situation" has been replaced by a book. Also, since the model has been tested and al devices for scenario runs are already built into it, it will probably not change during the process. However, the explorer's mental model will go through changes on this way.

Can we consider this to be an ILE? As mentioned above, each modeling/simulation software package is a most complete ILE: these environments allow their users to see and modify a model and ask it just any question they consider important. However, they come without the model. This book adds the model. And insofar as readers bring with them the dynamicist skills for interacting with this re-built model, the process has all the chances to work.

The possibility of using books like World dynamics as ILE depend on the readers' model exploration skills: those who do not know how to manipulate the model and the software in order to experiment and trace through would need some additional guidance.

The Limits to growth 30 years update with learning environment

"Limits to Growth – the 30 year update" (Meadows et al., 2004) is a book that can be read by any person; those who purchase the additional learning environment for the book can try to go beyond the reading: on top of believing the authors' plausible argumentation, one could build one's own judgment based on exploring the learning environment. However, the learning environment itself shows only scenario buttons and graphs and a results table: the user can switch in between the scenarios discussed in the book and then see how the variables develop on the graph pads. Numeric results can be inquired in the table. The model is hidden away and one cannot explore its structure. On the CD, there is a STELLA version of the "world3" model, where one can indeed make changes to the model and explore the effects; however, its variable names are not understandable without referring to the original book. One can download the "world-3" model from the Internet and avoid the problem with variable names; still it would be necessary to get the additional book. In such a case, the price of going beyond the book reading is high.

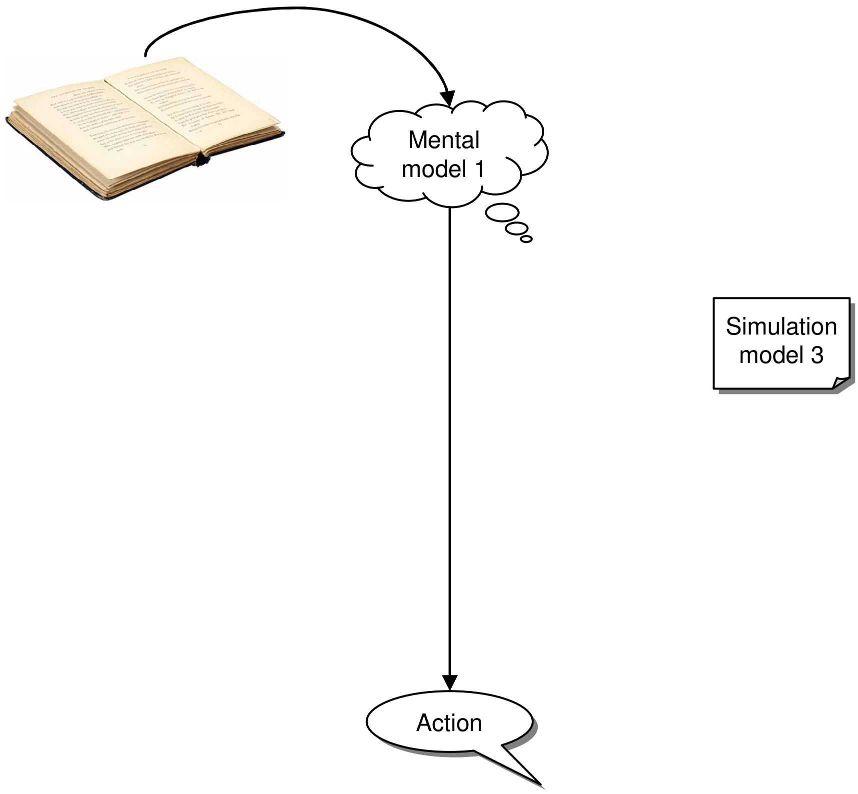

Figure 4: the limits to growth case

In this situation, the reader will still elaborate some mental model of the situation described in the book. But the cognitive load of relating the simulation model to this mental model is rather high. This example shows that a book that is too well-dressed for a public unwilling to read through the detailed explanations of variables and loops is unlikely to be part of a learning environment.

MacroLab

Some ILEs do not intend to involve their users into system dynamics modeling for some relevant reason. One example is the MacroLab environment (Wheat, 2007). This package is used for teaching macroeconomics to students who are not supposed to learn system dynamics. It contains a simulation model of the US economy and the "rest of the world", as well as a set of interaction devices. Students taking this course have to develop understanding of employment and part of their tasks is predicting and problem solving. They can explore the underlying model using STELLA's "storytelling" mode and for each task, causal-loop diagrams are displayed (these users are not previously trained in system dynamics).

MacroLab offers a richer set of interactions than the "world3"- learning environment, and purposefully engages its users in the development of causal loop diagrams. For the reasons mentioned above, the possibilities to interact with the model are limited. MacroLab may thus be used as an example of the state of the art in system dynamics ILEs.

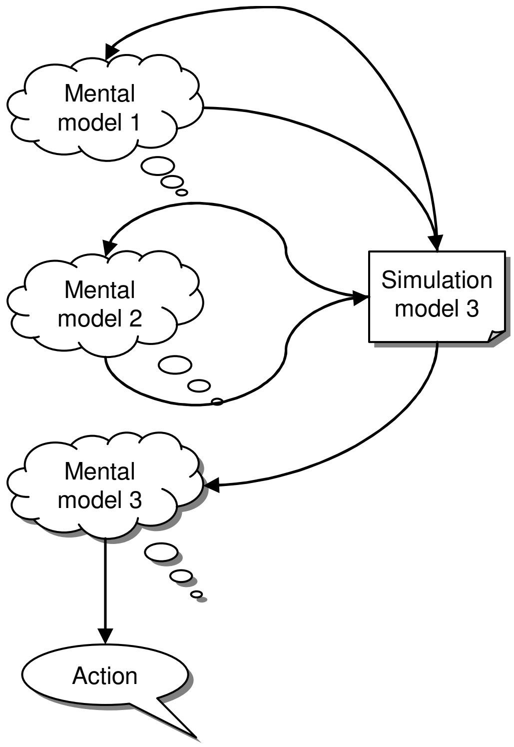

Figure 5: the MacroLab case

The users get into touch with the "situation" in form of the ILE which contains various modes of non-SD presentation. They are challenged by tasks that require the use of causal loop diagrams, representing important parts of the underlying simulation model. The users cannot modify the model's structure by inserting variables or changing equations; however, they can change the operating by deactivating/activating loops and sectors and they can switch between historic and experimental mode.

All this interaction with the underlying model helps them to build mental models hat enable them to outperform peer students that have studied the matter in a traditional manner.

Discussion of the examples

Each of these examples allows to see an aspect that will be important for the rest of the paper. Davidson's case shows that it is not necessary to conceptualize and formulate the simulation model in order to engage in diagnosing activities. It also shows that this, by itself, is not enough to help individuals without model and software manipulation skills to do the explorations.

The World dynamics example shows that the modeler can give a lot of guidance to the users of his work, and that it may not me necessary to build a sophisticated interface between the simulation model and the user. Like the first example, we saw that unprepared readers would need model manipulation guidance. The example also shows that it is useful to walk the user through three different levels of description of a system dynamics model

The Limits to growth example indicates that the material which shall help users to meaningfully connect with the simulation model, must come sufficiently close to the model's components in order to be helpful

The MacroLab example shows that alternative means of representation can constitute a progress over traditional learning environments (in this case, the economics textbook with its typical graphics), but it is plausible to assume that those who dig into the simulation model would go further.

In a system dynamics model, there are several levels of things: at the most elementary level, there are stocks and flows and auxiliary variables; then there are feedback loops, and finally there is the system of interacting feedback loops. In order to understand the global model, it may be advisable to proceed bottom-up: inquire the way each variable is bound to behave (by its equation of graphical function), then study each of the feedback loops and finally the global model.

Since there are so many alternative ways to explore, and many users will not be skilled dynamicists, the will need guidance in several aspects: they do not know which questions to ask and they do not know how to manipulate the model in order to construct the answers; finally they may not be able to see the deeper meaning of the answers.

So somehow, they must be guided into discovering each relevant question, which means that the need to be told to do something with the model, observe the reaction, describe and interpret it. Then they must be told what to do with the model in order to obtain a correct answer. Finally, they must be prompted to construct the meaning of the answer. In each of these steps, they may go wrong, and it is important to assure the errors are corrected before going on.

If we can provide an environment that does this, then we may be able to incorporate the types of interacting with the model into the process of using a model. We refer to this as "guided rediscovery": we wish to guide our users as they elaborate their mental models *MM*(*M*(*P*)) without having to build *M*(*P*) in the first place, but by "rediscovering" it. We use this term because we believe that the original modelers have "discovered" a way to represent *P* in a satisfactory way by an iterative process of "inventing" a candidate model and then trying it against validation criteria.

We are developing a prototypical process for guided rediscovery, which will be introduced together with the architecture of the learning environments in the following section.

A method for making users rediscover a model

Goals and requirements for the learning environment

The users (students) shall develop a successful decision policy in some meaningful, dynamically complex problematic situation. They also shall de able to justify their policy based on a causal-loop diagram of their own elaboration, which will be held for the expression of their mental model.

Several considerations are necessary to transform these goals in functional requirements. The way how one comes to "understand" a dynamic simulation model has to be expressed and organized into a sequence of phases.

Since system dynamics models are a complex of feedback loops, and each one of the loops is a sequence of stock and flow variables, it seems reasonable to distinguish three levels. The most detailed level would be the variables and their connections with neighboring variables: each variable represents some part of the modeled situation; there also is some kind of behavioral rule (equation) that represents how this variable depends on the preceding ones. The next level is the feedback loop, which has a behavior of its own, emerging from the individual variables' behaviors. Usually, there will be several such loops in one model and by understanding each of them on its own, the student prepares his mind for the last level. The highest level is the whole model: its structure is the superposition of all the feedback loops and its behavior emerges from their interactions.

To truly understand a model then means to truly understand each variable individually, each loop and the whole model. Such understanding is the fundament for decision policies (in our case).

At first sight, there are at two ways how one can go through this hierarchy of levels: bottom-up or top-down. To fully understand the entire model, one has to understand each loop; however, the meaning of each loop appears in the context of the whole system. To fully understand a loop, one has to understand each of its variables; however, the meaning of each variable appears in the context of each loop and thus the whole system. Since one cannot study several levels at the same moment, there has to be a sequential itinerary.

Since the first thing to appear –even before modeling sets on - is the entire situation, it may appear reasonable to start at the level of the whole system and to move from the general to the particular, and then go back from the bottom upwards. This is the way taken by *World dynamics* (Forrester, 1972), *Limits to growth* (Meadows et al., 2004) and even Morecroft's textbook (2007). Many educators (like Montessori) believed this to me important if learning has to be meaningful. So there is not a either-or choice to be taken, the best way seems to be to alternate top-down with bottom-up.

We have chosen to make the first contact of our users with the whole model, and then we take then to the level of the individual variables. From there on, we proceed to the individual loops and eventually, we return to the whole model. We believe that this combines the need for context with the need for bottom-up understanding. According to this, it is a functional requirement that the learning environment guides the learners through this itinerary: whole-model context -> individual variables -> individual loops -> whole model.

The modeler comes to insights because he has to find answers to the surprises the model generates; he then knows what the important surprises were and where/how to search for answers in the model. If he can ask these questions to a model user in a way that enables him to replicate the same searches, then the model user can, in principle, gain the same understanding as the modeler himself. Accordingly, another functional requirement is that the user has to be prompted to think on his own, because we want him to develop his mental model. Asking questions is one involving way to prompt thinking; the exercise books by Diane Fisher (2001; 2004) are a good example. This is the way we have chosen; so we develop a workbook where the user is asked questions that will trigger his elaborating a response for each item we want him to understand. Together with this, it is important that each response be corrected before proceeding to the next question: this makes sure we do not continue on a faulty base, and rapid responses ("feedback" not in the system dynamics sense) augments user satisfaction.

One especially important issue is the need to understand the relationship between structure and behavior at each of the levels and with each of its entities. Our users will not be experienced dynamicists, so they will generally not have intuitive understanding of this relationship. We believe that such understanding can be trained by repeatedly passing through a sequence of questions:

- what is the formula?
- what will it do (predict numerically or the shape of the graph) in this or that case?
- simulate.
- what did it do?
- why did it do this?

These are the issues we want a learning environment to take care of in order to guide users towards rediscovery. The discovering itself can only be done by each individual.

Guiding rediscovery

Each workbook is a particular case of a more general method (or "context"), expressed as a sequence of steps:

1. Read through to introduction to the case which includes references to the problematic behavior of key indicators.

2. Inquire at the level of individual variables, based on their introduction in the text. Describe each variable and its links from the viewpoint of its structure (equation or table function), its behavior and its relationship to the linked variables (causal diagram).
3. At the global level: d
    a. Develop a causal diagram indicating the respective equations or table functions of each variable.
    b. Identify the loops and their respective polarities.
4. Identify a key variable and draw its desired behavior over time.
5. Simulate the model. Describe the key variable's behavior and separate it into episodes of distinct behavior (linear, exponential, logarithmic, oscillations). Describe each episode in worlds.
6. Compare the expected and the simulated behavior, for each episode. Ask "why did the variable behave this way?" and "why is it different from my desire?"
7. For each of the individual feedback loops (contained in distinct models), do the following:
    a. Identify an important variable (the key variable or some other variable that calls your attention) and explain your choice.
    b. Simulate the model with different values for the variables on the border (that have been cut off the other loops). Describe the behavioral episodes.
    c. For each episode, ask "how did the variable come to behave this way?" and then:
        i. Develop a causal loop diagram including the behavior graph of each variable and answer the question (in words).
        ii. Write the answer into the loop on the main causal loop diagram.
8. Answer the two questions from point 6 using the main causal loop diagram, in text format.
9. Develop an action plan for having the model generate the desired behavior in the key variable. Justify the plan with reference to the causal loop diagram. Use the gaming version of the model to corroborate the plan.
10. Explain the outcomes of the simulation and how it compares to the desired outcome using the causal loop diagram.

At the time being (march 2008), there is one such exploratory, inspired by the fishery management model in chapter 1 of Morecroft (2007); we are developing exploratories for several other more generic situations: inventory fluctuations in a manufacturing firm, growth from diffusion, growth and investment (Morecroft's textbook has inspired these choices, that go from rather simpler towards more complex cases) and the *world dynamics* model.

The workbooks that implement this procedure are rather lengthy: in the case of the fishery management model which has two feedback loops and 13 variables (3 stocks, 5 flows and 5 converters or auxiliary variables), it makes up about 40 pages.

Does guided rediscovery yield better learning?

We want to know if individuals who work through the procedure perform better than other individuals and if they are able to give better causal explanations. Our hypothesis is double:

Hypothesis 1: users of the rediscovery exploratory perform at least as well as individuals that have to resolve the same task without previous guided rediscovery.

Hypothesis 2: users of the rediscovery exploratory articulate a more accurate mental model in their explanations.

We define "accurate" as being similar in variables and feedback loops to the underlying simulation model.

We are currently starting experimentation with two groups of students. The first group will work through the fishery exploratory and generate performance and explanatory information in their workbooks. A control group has to resolve the task with only the gaming version of the simulator available, and draw a causal diagram in their explanation. Both groups receive the same brief introduction into causal loop diagrams in the introductory part of their respective supporting material.

Their performance will be directly comparable. The analysis of the articulated mental models will use two

The method of mental model comparison developed by Langfield-Smith et al. (1992) and improved by Markovski and Golberg (1995) allows to measure the distance between different mental models [§]. Its extension to group mental models (Langan-Fox at al., 2000; 2001) allows to compare group models. Application of this method allows to discover if there are systematic differences between the models expressed by the individuals in the two groups. We will also measure the distance of the typical model of each group to the underlying simulation model.

However, the above mentioned method does not take into account feedback loops. Since we want to compare our subjects' models also in this domain, we will use the following measure:

Correspondence with underlying simulation model, defined as the percentage of feedback loops of the simulation model appearing in the subject's causal loop diagram. This is decomposed into three indicators:

1. identity of the loop;
2. polarity;
3. variables taken into account.

We can easily compare each subject's causal loop diagram to the reference causal loop diagram and then assess if there are clusters in correspondence to the two groups of subjects.

While today, these assessments have not been carried out yet, results will be published and discussed in these pages before the conference.

Preliminary conclusions

On guided rediscovery

We believe that in the controversy between "modeling" and "model use", it is possible to get to reconciliation. By looking at those modeling activities that are particularly important for learning, one can devise learning environments that allow at least some of these activities, without losing the possibility to ground the environment in one existing simulation model.

We have tried to discuss what these activities are and have found that many times, books play an important role (although they may not appear to be "interactive" at first sight). We have analyzed some pregnant examples and found some indications:

1. make learners cycle through the three levels of a model – variables, isolated loops, whole model;
2. make learners experience "surprises" and help them diagnose them, arousing questions and answering/interpreting them by interacting with the simulation model.

Since the ILE guides and the user rediscovers, we call this a process of guided re-discovery and we think of these learning environments as exploratories.

While it is too early to advance conclusions about the particular exploratories we develop, some reflection concerning the ILE concept and its relationship with the model versus modeling controversy seem to be in order.

[§] The interested reader may refer to Schaffernicht, 2006 for a brief description.

On the ILE taxonomy

Maier and Grössler (2002:139) proposed to condense aspects of previous definitions ‘‘presentations’’, ‘‘user actions’’ and ‘‘system feedback’’ (taken from Alessi, 1988), into “human-computer interaction” (HCI). They then propose a conceptual model of computer simulations consisting of three categories: HCI, functionality and underlying model. Their table 1 (p. 141) lists “trasparency of model” as one aspect, but there is only a categorical distinction: “black-box” or “transparent-box”. As discussed above, the simulation model may be available for a wide range of different “user actions” (Alessi’s term) as they interact with the model:

- looking at a causal loop diagram presentation;
- looking at a stock-and-flow diagram presentation;
- looking at what is shown while being walked through (part of) the model in “story-telling mode”;
- inspect the equations and commentaries of the variables;
- experiment with different values of the variables;
- switching on and off different feedback loops;

Together with deleting the “user actions” term from the taxonomy, we have lost the possibility to state these aspects. As far as users’ actions are necessary for their learning, this may be a choice to be reconsidered.

We also have seen that there may be a new functionality (actions that the learning environment may perform) “guide users to questions, guide users to experiment, guide users to interpret results”. The activities of “modeling as learning” are supported to different degrees by different learning environments, and we suggest that the degree of support be considered in a taxonomy.

The conceptual model that linked together “model”, “functionality” and “HCI” in Maier and Grössler (2002), is so aggregated that it does not help to see how the ILE relates to learning, and there is no place for the designer. The following figure

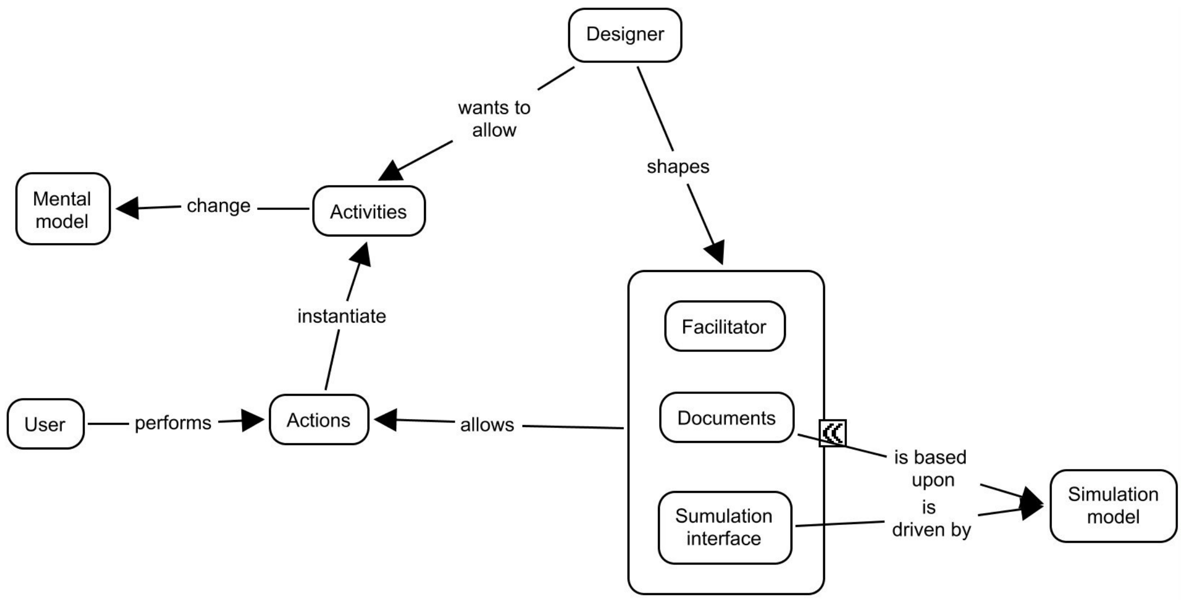

Figure 6: a conceptual model for designing and using learning environments

The designer wants to allow a set of activities (that will make the users change their mental models). So the designer has to shape the learning environment such that it will allow a set of actions that constitute these activities. The environment consists – of cause – of the simulation interface, but also of documents (book, workbook) and maybe there is a human facilitator: users interact with all of these items. The documents are based on the simulation model, and the simulation interface is driven be the model (in this sense, the model developer is a user, too, since we all interact with the simulation model over an interface).

It is thus suggested here that the 2002 conceptual model and taxonomy may be debated and improved upon.

A look into the future

In his outlook over the next 50 years, Forrester (2007) reminds that K-12 education (in system dynamics) is still introductory, that there are no schools of education where teachers receive proper training, and that universities are not designing or running 4-6 years programs in system dynamics.

We dare to imagine that exploratories which implement guided rediscovery may become a step into the following direction:

> "Such a management education will evolve over time, but we might start with the following image. Suppose that we had some 20 generic structures that would cover more than 90 percent of the situations that a manager ever encounters. One example would be a production/distribution system such as dates back to the earliest days of system dynamics. Each such generic structure would require a separate textbook [...]" (Forrester, 2007: 368)

We believe that the type of workbook+ILE we develop, can be inserted into existing business school programs without previous reorganization. The repeated use of such exploratories should have a second-level learning effect on students: repeating the typical sequence of exploring a model shapes a context (Bateson, 2000) or paradigm (Kuhn, 1996)

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