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Teaching System Dynamics and Systems Thinking in Austria and Germany

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Abstract

This paper discusses the emergence of system dynamics/systems thinking (SD/ST) teaching in different countries. A special focus is placed on efforts made to introduce the MODUS *software in Germany and on the introduction of systems-thinking ideas in Austria's mathematics curriculum in the early 1990s. In chapter 4 the fascinating relation between systems thinking and system dynamics is discussed in some detail, followed by my own definition of systems thinking. In the final chapters the main results of four empirical studies concerning the development of systems thinking skills through teaching system dynamics are summarized.*

1 The Emergence of System Dynamics/Systems Thinking Teaching around 1990

In the late 1980s and early 1990s a number of initiatives to establish system dynamics or systems thinking teaching (SD/ST teaching) emerged independently in different countries worldwide.

- In the United States these efforts were focused around the revolutionary STELLA software for Apple Macintosh computers. In several school districts teaching SD modeling with STELLA was established, aiming for the development of systems thinking skills. Among the first were the *Brattleboro Union High School* in Vermont or the *Catalina Foothill School District* in Tucson, Arizona. Projects like STACI (*Systems Thinking and Curriculum Innovation*, Mandinach 1989) or CC-STADUS (*Cross-Curricular Systems Thinking and Dynamics using STELLA*, Waters Foundation 1996) indicate the strong intention to promote systems thinking skills by using SD modeling.
- In the Netherlands Piet van Blokland developed the equation-oriented simulation system VUDYNAMO[1]. Together with Douwe Kok, van Blokland introduced VUDYNAMO-based system dynamics modeling at several Dutch schools in the late 1980s (Blokland/Kok 1989).
- In 1990 a German version of VUDYNAMO was introduced in the Hamburg school district by Friedhelm Schumacher (Blokland/Schumacher 1990a, 1990b).
- In 1988 the *Landesinstitut für Schule und Weiterbildung* (LSW) at Soest (the regional school authority for Nordrhein-Westfalen - Germany) undertook a serious effort to develop and promote MODUS, a graphics oriented software tool for systems modeling and

simulation for secondary schools. Within the MODUS project teaching materials for different subjects have been developed. Moreover extensive empirical research concerning teaching system dynamics with MODUS and the development of systems thinking abilities have been undertaken by Klieme and Maichle (Klieme/Maichle 1991, 1994).

- In Austria an initiative by Gerhart Bruckmann, a member of the Club of Rome, (Bruckmann 1987) led to the implementation of a special section *Untersuchung vernetzter Systeme* ("Investigation of interrelated systems") in the national mathematics curriculum at 11th grade for the Realgymnasium (a special type of high school) in 1991.

All these initiatives (with the exception of the last one) were focused around a specific system dynamics software product. They were typically of the bottom-up style, trying to establish a small nucleus of SD/ST teaching first and extending this later. In most cases enthusiastic individuals or small groups were behind these initiatives.

The only exception was Austria: here SD/ST teaching was implemented as a curri-culum section first, hoping that this would trigger a subsequent teaching. Moreover the Austrian initiative was the only one which did not rely on a single SD software product.

2 The MODUS Modeling Software in Germany

The modeling software MODUS was specially designed for teaching systems oriented modeling and simulation at secondary schools. It was developed under the name MOBILE at the German Institute for Distant Teaching and Research (DIFF) at Tübingen by a group leaded by Werner Walser and Joachim Wedekind. (Walser/Wedekind 1991, Wede-kind/Walser 1992). MODUS was designed for PC computers and introduced a non-standard graphical user interface with mouse and windows technique, emulated in a DOS environment.

The graphical syntax of MODUS was different from the stock-flow-diagram technique invented by Jay Forrester (1961). The MODUS-syntax did not distinguish between inflows and outflows: both were considered as effects upon the stock variable, differing just in the sign. This resulted in an unfamiliar way of representing elementary systems: in MODUS stocks could only be changed by "change variables" (like change_pop in Fig. 1). Both inflows and outflows have to be represented as change variables just with different signs, but always with a logical arrow towards the stock variable.

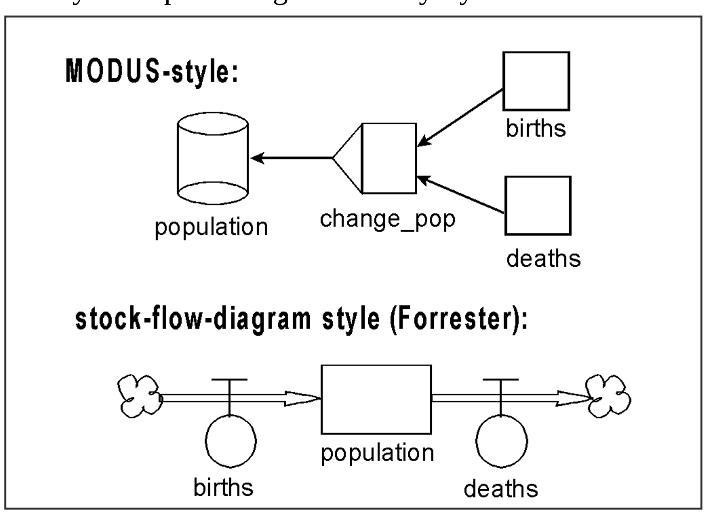

Fig. 1 MODUS vs. stock-flow-diagramming style

Actually the MODUS style of diagramming proved to be counterintuitive and much harder to grasp for students than the Forrester-style stock-flow diagrams. When MODUS was commercially released in 1992 after about four years of development and empirical testing, its DOS-based non-standard graphical user interface was de facto already outdated by the MS-Windows revolution. In those days the first versions of POWERSIM with a standard Windows-interface made it clear that MODUS would never achieve practical status as a teaching tool.

Nevertheless the efforts around MODUS were important. A significant amount of development of teaching materials and empirical research accompanied the MODUS project. The empirical research was done in two big studies by Eckhard Klieme and Ulla Maichle from the Institute for Educational Research (Institut für Bildungsforschug) at Bonn.

In the pilot-study Klieme/Maichle (1991) 180 students in 8 classes at grade 9 and 10 were studied to see the implications of a teaching sequence of about 15 - 20 hours introducing MODUS. The teaching was done using different materials that had been developed at the LSW Soest for mathematics, biology, chemistry and social science classes.

The testing of the students was done in a pre-test – post-test design using written tests which were not known to the teachers. The test covered several themes with a clear focus on modeling and systems thinking abilities. The tasks to be done at the pre-test and post-test corresponded to a very high degree (with the exception of some MODUS-related questions, which were not asked at the pre-test.) One main achievement of Klieme and Maichle was the development of reliable testing tasks that would allow a fair measurement of systems thinking abilities both in the pre-test and post-test. Fig. 2 shows an example.

The Hilu-tribe

The African Hilu tribe breeds cattle. The income of the Hilus depends upon the number of animals they can sell per year. The bigger the herd, the more animals are sold and the higher the annual income of the Hilus becomes. The more money they earn, the more they can invest in their recently built bush hospital for medicines and instruments.
Since rainfalls are rare, the Hilus have drilled a deep-water-well and had installed a water irrigation system. Increasing watering raises the moisture of the grasslands. This has pros and cons: More moisture lets the grass grow better and the cattle can grow, too. On the other hand the moisture supports the propagation of the dangerous tse-tse-fly. This fly spreads the dangerous cattle solemnia disease, which every year infects a part of the herd. With an increasing number of tse-tse fliese more cattle die on this disease. If the irrigation is reduced, both the food supply of the cattle and the propagation of the tse-tse-fly are reduced.

Try to sketch the interrelations described here in a diagram in such a way that one can see the most important aspects at a glance!

Fig. 2 The Hilu scenario in Klieme/Maichle (1994) and Ossimitz (1994)

The Klieme/Maichle studies greatly affected my own empirical research on the development of systems thinking abilities (Ossimitz 1994, 1996, 2000). I adopted most of the tasks for measuring systems thinking abilities that have been developed by Klieme and Maichle for my own investigations.

3 Austria: An Exceptional Curriculum Design

The emergence of system dynamics teaching in Austria around 1990 was quite different from all other initiatives of that time that I know. In Austria teaching system dynamics was not introduced by initiatives at the "teaching front", but in a top-down manner during a revision of the mathematics curriculum for the 9th–12th grade of the Realgymnasium[2]. At grade 11 a section *Untersuchung vernetzter Systeme* (Investigation of interrelated systems) was introduced. This section states explicitly that in the mathematics classes at grade 11 students should gain systems thinking abilities by analyzing systems from different fields like economy, ecology, biology or physics. The curriculum stresses the importance of different modes of denoting or diagramming systems, using causal loop diagrams, stock-flow diagrams or formal equation-style notations. Although intended, the system dynamics method is not mentioned explicitly, so that alternate modeling styles like using a spreadsheet could be used. The curriculum simply emphasizes that the investigations should lead "finally" to a numerical evaluation and simulation, preferably using a computer.

An important intention of the curriculum section is that the underlying assumptions, and limitations of the modeling process and the resulting scenarios should be reflected and discussed – something that is rather uncommon in mathematics classes.

The curriculum section *Investigation of interrelated systems* was not restricted to any specific modeling and simulation technique. This was done to give the teacher some freedom and to help to keep the curriculum section fit for later technological innovations.

In order to make the intentions of the curriculum section more explicit and to support the authors of the mathematics textbooks and the Austrian mathematics teachers with prototype models and practical SD teaching knowledge, the book *Materialien zur Systemdynamik* ("Materials for Teaching System Dynamics" – Ossimitz 1990) was published. This book supports both the "hard" quantitative and the "soft" qualitative modeling paradigm. In the field of quantitative modeling and simulation the system dynamics approach is clearly preferred. Many of the simple discrete models that do not require Runge-Kutta integration are explained both in the VUDYNAMO syntax and as spreadsheet models, so that teachers who are familiar with spreadsheets do not necessarily need a system dynamics software.

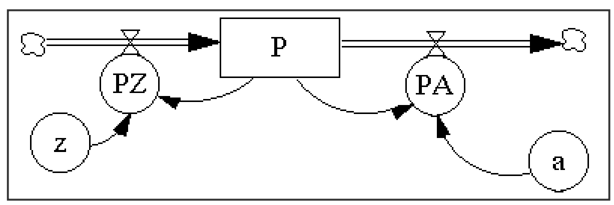

Fig. 3 stock-flow diagram from an Austrian mathematics schoolbook

A disappointing aspect of the Austrian experiment to establish systems thinking in math classes via curriculum innovation was the way in which the new curriculum section *Investigation of interrelated systems* was interpreted by the authors of the three major approved mathematics text books for the 11th grade. Only one of the textbooks made any serious attempt to introduce stock-and-flow diagrams. Fig. 3 shows the result: all variables bear typical mathematical one or two-letter variable names. This reductionism makes it hard to use the models for discussing the design of a particular stock-flow-diagram.

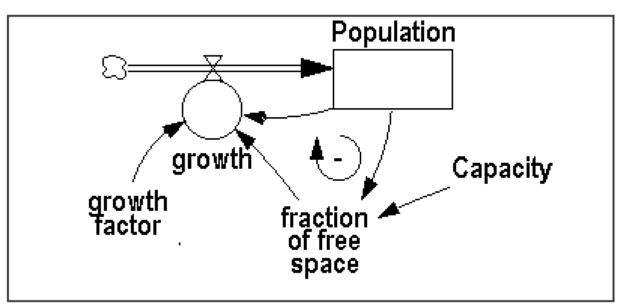

Fig. 4 A reasonable logistic growth model

Moreover the very same stock-flow-diagram in Fig. 3 was used in that textbook for modeling logistic(!) growth. By setting **PA := P² · a** instead of **PA := P · a** Fig. 3 represents a Verhulst-like logistic population model of the type **dP/dt = zP – aP²** (see Richardson 1991, p. 32). Of course no serious SD modeler would take a structure like Fig. 3 for modeling logistic growth.

He or she would argue that such a model should contain explicitly important aspects of the real system, such as its capacity or the fraction of unused capacity. An acceptable stock-flow-diagram might look as the one in Fig. 4, using equations like

growth := growth factor · fraction of free space · Population and
fraction of free space := 1 – population/capacity

The other two mathematics textbooks treated the basic ideas of system dynamics and systems thinking even worse: one of them displayed just a single stock-flow diagram of an elementary capital – interest growth without any explanations. The only commentary was an exercise "Try to find out what this diagram could mean!" The remaining 25 pages of the chapter were focused exclusively on some mathematical theory of difference equations. In the third textbook just a single stock-flow-diagram of population growth like in Fig. 2 is discussed in some detail.

In 1993, two years after the official introduction of the curriculum section *Investigation of interrelated systems*, Franz Schlöglhofer investigated in his doctoral thesis (Schlöglhofer 1993) the extent to which this section has already penetrated mathematics teaching in Austria. The results were mediocre.

The experience made in introducing system dynamics and systems thinking in Austria at the level of teacher-oriented initiatives was by far more encouraging. In-service teacher courses of about one week were held in 1993 and 1994 and had a considerable effect upon the teachers' thinking. Additional empirical research (Ossimitz 1994, 1996) showed that the induced teaching actually had some impact upon certain dimensions of the students' systems thinking abilities.

4 The Relation between System Dynamics and Systems Thinking

In order to clarify this last argument it would be useful to give a short overview about the fascinating relation between system dynamics and systems thinking. In the early writings of Jay Forrester no indication of the term "systems thinking" can be found. The very first occurrence of a connection between system dynamics and systems thinking that I could find was is in a paper by Ellen Mandinach (1989) about the STACIN project. The mere acronym *S*ystems *T*hinking *a*nd *C*urriculum *I*nnovation *N*etwork indicates that the notion of systems thinking plays a core role in this project. Mandinach reports on four courses using STELLA software at Brattleboro Union High school in Vermont. Mandinach (1989, p 222) writes:

> "Systems thinking is a scientific analysis technique given prominence by Jay Forrester and his colleagues at the Massachusetts Institute of Technology. Work on computer modeling of systems thinking started well over 30 years ago with early models focusing on urban growth and development and global patterns of the consumption of natural resources."

A few pages later Mandinach concludes:

> "As defined here the systems thinking approach consists of three individual but interdependent components: system dynamics, STELLA and the Macintosh." (Mandinach 1989, p 225)

It is rather obvious that Mandinach presents an idea of systems thinking which equates systems thinking and system dynamics to a high degree. Actually Jay Forrester himself never had such an intention. On the contrary: in one of his later papers *System Dynamics, Systems*

Thinking, and Soft OR (Forrester 1994) the founder of system dynamics addresses this issue explicitly. First he gives six "System dynamic steps from problem symptoms to improvement", which range from "Step 1: Describe the System" to "Step 6: Implement changes in policies and structure". Then Forrester identifies several procedures which might be helpful for doing Step 1. One of these procedures (among others) is systems thinking. He writes rather critically:

> " “Systems thinking” has no clear definition or usage. ... Some use systems thinking to mean the same as system dynamics. ... “Systems thinking” is coming to mean little more than thinking about systems, talking about systems, and acknowledging that systems are important. In other words, systems thinking implies a rather general and superficial awareness of systems. Systems thinking is in danger of becoming one more of those management fads that come and go. The term is being adopted by consultants in the organization and motivation fields who have no background in a rigorous systems discipline." (Forrester 1994, pp 10-11)

Forrester accepts systems thinking as a kind of "door opener" for rigorous system dynamics modeling; but he refuses the identification of system dynamics with systems thinking. He fears that the formula SD = ST might allow non SD-oriented "systems thinkers" to enter the field and damage the serious reputation of SD modelers.

So what made Ellen Mandinach believe that Jay Forrester is the father of systems thinking? I think that at least a part of the answer can be found in Barry Richmond, the ingenious inventor of the revolutionary STELLA software and the main head behind the great *STELLA Academic User Guide* (Richmond/Peterson/Vescusco 1987). Richmond propagated SD modeling with STELLA from its earliest days quite successfully under the label of "systems thinking". This might have triggered Mandinach's view of Forrester as the father of system dynamics = systems thinking.

In the papers *Systems Thinking: Four Key Questions* (Richmond 1991) and *Systems Thinking: Critical Thinking Skills for the 1990's and Beyond* (Richmond 1993) Richmond addresses the relation between system dynamics and systems thinking extensively. The four key questions in Richmond (1991) are:

1. What is Systems Thinking?
2. Why is Systems Thinking needed?
3. What works against the adoption of Systems Thinking?
4. What can be done to facilitate the adoption of Systems Thinking?

In the introduction Richmond writes:

> "Systems Thinking, A Systems Approach, System Dynamics, Systems Theory, and just plain 'ol "Systems" are but a few of the many names commonly attached to a field of endeavor... As I prefer the term "Systems Thinking", I'll use it as the single descriptor for this field of endeavor." (Richmond 1991, S. 2).

This reads as if Richmond is not very careful to distinguish between system dynamics and systems thinking and that "systems thinking" seems to him as a nice term to coin as a trendy description for system dynamics modeling.

In Richmond (1993) he gives a more explicit definition of systems thinking. Richmond discusses seven basic "systems thinking skills". A closer look at these skills clearly reveals that these are just the skills which are useful for doing successful system dynamics modeling. Of course most of them have some relevance outside SD modeling, too, but taken together these skills are pretty well what I would say that a good SD modeler would need. For some of the skills, like "generic thinking", "operational thinking" or "continuum thinking", it is even somehow hard to see how they would make sense outside an SD modeling context (For details see Ossimitz 2000).

The essence of Richmond's view about the relation between SD and ST can be found in his paper *Systems Thinking – Let's Just Get On With It* (Richmond 1994), which might well be a reply to Forrester (1994). In this paper Richmond cites Forrester's belief that systems thinking is only about 5% of the system dynamics modeling process. "The other 95 percent lies in the rigorous System Dynamics-driven structuring of models and in the simulations based on these models" says Forrester, cited by Richmond. Metaphorically speaking, in Forrester's opinion systems thinking is just a small territory on the system dynamics globe. Richmond gives his own picture by drawing a system dynamics globe with an 'systems thinking atmosphere' around it and writes: "Systems Thinking is 'System Dynamics with an aura'." (Richmond 1994, p 4)

Richmond's way of defining systems thinking has several implications. First it makes systems thinking achievements rather easy: gathering any system dynamics modeling knowledge means *per definitionem* the acquisition of systems thinking skills. The second implication of Richmond's definition is that empirical measuring of systems thinking skills can be boiled down to the measurement of system dynamics modeling skills. Under this assumption it is just a little bit weird to put such a kind of measurement in a pre-test – post-test design with two identical tests: before being taught about SD modeling it can be expected that any student will achieve very poorly in any SD modeling achievement task. At first sight this looks rather trivial: before being taught about SD modeling the students have no idea about SD modeling and systems thinking – so what? On closer inspection the close identification between SD modeling and systems thinking implies that without learning some SD modeling technique there are no (measurable) systems thinking skills at all! We can put it more dramatically: identifying systems thinking and system dynamics as closely as it is done by Richmond would imply that before 1958, when Jay Forrester invented the SD modeling method, there were no systems thinkers at all in the whole world! I am sure that such an implication would be considered a little bit too heavy, even by Barry Richmond himself.

5 What is Systems Thinking?

Pondering the consequences of Richmond's ideas brings us to the point that there is a need for a definition of systems thinking which is somehow independent of the system dynamics modeling approach.

When looking in the literature for such a definition, it is surprising how little is to be found, although the term *systems thinking* ("systemisches Denken", "vernetztes Denken" etc.) is a widely used phrase both in international and in German literature. Yet it is hard to find a concise definition of "systems thinking". Let me give some examples of my findings. Klir (1991, p 19) writes in his monumental book *Facets of Systems Science*:

> “Systems movement emerged from three principal roots: *mathematics, computer technology*, and a host of ideas that are well captured by the general term *systems thinking*.”

Although this citation suggests that systems thinking is something very fundamental for Klir, this single sentence is all that Klir says explicitly about systems thinking. Klir gives no closer hint about what he means by “systems thinking”.

The German cognitive psychologist Dietrich Dörner (1989, p 308ff) says in his book *The Logic of Failure* (*Die Logik des Mißlingens*):

> "I hope I could clarify the fact that we cannot grasp what is often generally called «systems thinking» as a simple entity, as an individual, distinguishable ability. It is a bundle of abilities, and essentially it is the ability to use our normal, sound reasoning according to the circumstances of the individual situation." Dörner (1989, p 308ff, *translated by G.O.*)

Here Dörner essentially reduces systems thinking to the formula:

systems thinking = complex situation + a thinking mode adequate to the situation.

6 A Definition for Systems Thinking

I would like to define four essential dimensions of systems thinking:

1) **thinking in models**: explicitly comprehended modeling
2) **closed loop thinking**: thinking in interrelated, systemic structures
3) **dynamic thinking**: thinking in dynamic processes (e.g. delays, oscillations)
4) **steering systems**: the ability for practical system management

6.1 Thinking in Models

From the viewpoint of Radical Constructivism (cf. eg. Glasersfeld 1995) thinking in models is inevitable. Constructivism says that we can only think according to our pictures and views of the world, which are necessarily models of the world itself. Now my point is that systems thinking requires the **consciousness** of the fact that we deal with models of our reality and not with the reality itself.

Thinking in models also comprises the ability of model-building. Models have to be constructed, validated and developed further. The possibilities of model-building and model analysis depend to a large degree on the tools available for describing the models. Choosing an appropriate form of representation (e.g. causal loop diagram, stock-flow diagram, equations) is a crucial point of systems thinking. The invention of powerful, flexible and yet standardized descriptive tools was one of the main achievements of Jay Forrester. For school purposes the representation forms of the System Dynamics approach have proven to be successful. The causal loop diagram allows qualitative modeling, the stock-and-flow diagram already gives key hints about the structure of the quantitative simulation model.

6.2 Closed Loop Thinking

People of the western hemisphere are usually very good in causal reasoning. If-then relations are basic building blocks of our mind and our understanding of things. A foundation of this kind of thinking is a strict distinction between cause and effect. In order to explain a phenomenon we have to find its (probably single) "cause". It is supposed that this cause does exist and that the effect always can be observed whenever the cause is valid. Words and phrases like "because", "therefore", "if – then" denote such thinking concepts in everyday language. The mathematical analogon is the function-concept with one independent variable (="cause") and one dependent variable (="effect"). Accordingly the thinking in simple cause-effect relationships might be called **functional** or **linear** thinking - in contrast to **closed loop thinking**.

In interrelated systems we have not only direct, but also indirect effects. This may lead to **feedback loops**. Feedback loops might be reinforcing (*positive*) or balancing (*negative*). The arms race between the superpowers was an example of a reinforcing feedback loop. Americans said: Because of the armament of the Soviets we have to build 1000 new missiles". The Soviets said: "We have to increase our strategic arms force, because the Americans have built 1000 new missiles." This increase in the Soviet Army Forces led to further armament on the American side... and so on. Each side viewed the other side as the cause. In a global perspective a distinction between cause and effect is no longer possible. Once you have entered a vicious circle, you can no longer identify a single cause for the whole process, since any effect also affects the cause. A proper understanding of feedback loops requires a dynamic perspective, in order to see how things emerge over time.

Interrelated thinking is a kind of thinking which takes into account indirect effects, networks of causes and effects, feedback loops and the development of such structures over time. Interrelated thinking also requires adequate representations: the causal loop diagram is the simplest and most versatile tool for denoting interrelated issues.

6.3 Dynamic Thinking

Systems have a certain behavior over time. Time delays and oscillations are typical features of systems, which cannot be observed without the time dimension. Even the simple task of keeping the temperature constant in a (simulated) cooling house is for many subjects a difficult task, because changes in the temperature would require some time before they became effective (see Dörner 1989, pp 200ff). Considering only the present state of the temperature as a guideline for adjustment might lead to serious overreaction, which might take even a rather inert system like a refrigerated warehouse out of control.

Dynamic thinking also means foreseeing (possible) future developments. A mere retro-spective view of past developments is insufficient for the practical steering of systems - or would you trust a car driver who makes exclusive use of the rear mirror in order to determine where to steer the car? Often simulation models are helpful or even necessary in order to foresee future developments - especially when reality emerges rather slowly.

6.4 Steering a System

This brings us to the fourth core aspect of systems thinking: the practical steering of systems. Systems thinking also always has a pragmatic component: it deals not just with contem-plating the system, it also is interested in system-oriented action.

One of the most fundamental and most important questions of practical systems management is: *Which of the systems components are subject to direct change?* In a social system it is often impossible to change the behavior of others directly, one can only change one's own behavior. In an economic system the producer usually has no direct control over the market. Marketing activities are usually actions on the supply side in order to induce the desired reaction on the demand side.

7 How can Systems Thinking Skills be Developed?

This is a very hard question. There are a number of different approaches (or claims), how "it" could be done. Let me give an overview of some possible answers:

- **Sensibilization for systems aspects** by information campaigns for the general public (see F. Vester's exposition *Unsere Welt - ein vernetztes System* (our world - an interrelated system, Vester 1986) or the works of D. & D. Meadows concerning *The Limits to Growth* (Meadows 1972).
- Dörner (1989, p 307ff) suggests **computer-simulation games** (like *Tanaland* or *Lohhausen*), in order to learn systemic thinking and action.
- **Group-dynamics** oriented approaches try to develop systemic skills as holistic encounters in special seminars (e.g. the Tavistock concept for the development of systemic management abilities).
- Some **curricular concepts** try to develop systems thinking skills via explicit teaching at schools. Examples of this are the Austrian Schools Mathematics Curriculum section *Investigation of interrelated systems* (*Untersuchung vernetzter Systeme*) or, on a more comprehensive scale, curricular projects like CC-STADUS (Cross Curricular Systems Thinking and Dynamics Using Stella or STACI (Systems Thinking and Curriculum Innovation Network) in the USA.

For the rest of this paper I will confine my considerations to the curricular-oriented efforts. I will try to summarize several empirical studies devoted to this subject.

8 Can Teaching System Dynamics trigger Systems Thinking Abilities?

This has been a core question of a number of empirical studies undertaken by Klieme/-Maichle and by myself. I will give an overview about the design and the main results of the following studies:

(1) **Klieme/Maichle (1991):** ***Erprobung eines Modellbildungssystems im Unterricht*** *(Evaluation of a Model Building System in the Classroom*).

(2) **Klieme/Maichle (1994):** ***Modellbildung und Simulation im Unterricht der Sekundarstufe I*** (*Modeling and Simulation in Grades 9 and 10*)

(3) **Ossimitz (1994):** ***Systemdynamiksoftware im Unterricht*** (*System Dynamics Software in the Classroom*)

(4) **Ossimitz (1996):** ***Entwicklung vernetzten Denkens*** (*Development of Systems Thinking*)

The design of these studies is summarized in Table 1. All studies addressed the following questions: Can systems thinking be taught in an ordinary school environment? To what extent can the System Dynamics method facilitate the development of systems thinking and action skills?

In each study the students were tested before and after a System Dynamics teaching module of about 10 - 25 hours. The tests were in writing and not known to the teachers. The tasks of the post-tests were closely similar to the corresponding pre-tests. In both studies of Klieme/Maichle and in the Ossimitz (1994) study the graphical simulation software MODUS was used. (Since in Germany and Austria almost all schools were equipped only with DOS-PC's at the beginning of the 90ies, STELLA or some other Windows-oriented software could not be used).

Study	Students/ Classes	Grades	Teaching Subjects	Software	Research Method
K/M91	180 / 8	9; 10	math, biology, chemistry, soc. stud.	Modus	pre- & post-test
K/M94	240 / 10	9; 10	economy, biology, information sci.	Modus	pre- & post-test, selected videos
Oss 94	7 / 2	9; 11	mathematics	Modus	pre- & mid- & post-test + interviews
Oss 96	130 / 7	9 to 12	mathematics, inform. sci., physics	Powersim	pre- & post-test

Table 1: Design of the Klieme/Maichle (1991, 1994) and Ossimitz (1994, 1996) studies

The general results of all these studies were:

- Most students and teachers considered the system dynamics teaching modules very interesting. (In some classes it was the first attempt both for teachers and students of computer-assisted teaching).
- The way in which a systemic situation given as a text was sketched graphically changed considerably between pre- and post-test. Most of the students who learned about causal loop diagrams used them in the post-test; whereas in the pre-test most students used pictorial images or verbal summaries to sketch the systemic situation. Students who did not see causal loop diagrams, but structural or stock-flow diagrams, often used this type in the post-test.
- The ability to understand a systemic situation given as a text was very good even for the youngest students (aged about 14-15) in the pre-test. Thus in the Ossimitz (1996) study a rather complicated text was used for the pre- and post-test.
- To teach systems thinking requires a great deal of engagement on the part of the teacher. The students' advances in systems thinking skills depended basically on the teachers' own motivation and mental models about systems. The students of open-minded, systems oriented teachers achieved significantly better improvements in all the SD-related measures we applied.
- The modeling style of MODUS is much harder to understand than the style of POWERSIM. POWERSIM was also considered to be far superior to non-graphical modeling options like VUDYNAMO or spreadsheet modeling by all those teachers who have seen all these variants.
- Measurement of systems thinking skills and their improvement is very difficult. "Systems thinking is no general ability. To understand the dynamics of Modus-models is something different than predicting effects in verbally described models." (Klieme/Maichle 1994, p 76)

Particularly important results of the Klieme/Maichle (1991) pilot study were:

- The interest of the students depended upon their readiness to work on the computer. This readiness differed greatly. (For the majority of the students it was the first contact with a computer).

- The software product MODUS had a considerable impact upon the teaching and the way of modeling. Some of the students' problems in the modeling process seemed to depend upon the specific way that systems are modeled in MODUS. The logic of MODUS seemed to be counter-intuitive and a hurdle for many students to understand structural diagrams.

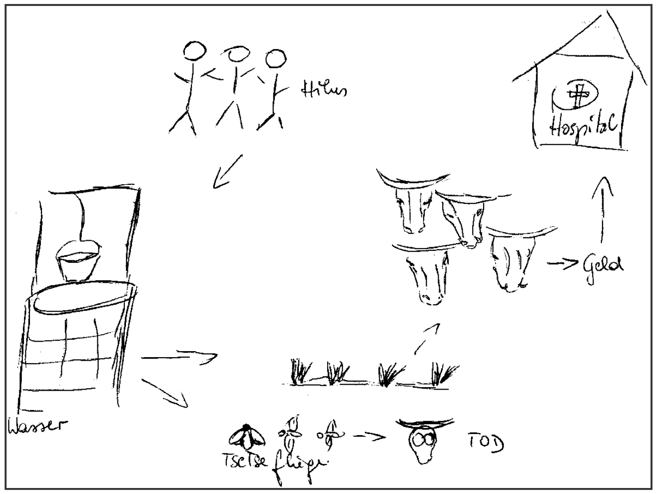

Fig. 5 Typical sketch of the Hilu – scenario (pre-test)

The Klieme/Maichle (1994 pp 73ff) study yielded the following special results:

- The students of teachers using a highly directive teaching style got better results concerning the achievement of model building in the post-test.
- The achievement of the students depends more upon their motivation and prior experience with computers.
- Through the work with MODUS the ability of model building could be significantly improved. The ability to think systemically within the MODUS-models could be improved only marginally.
- The readiness of the students for experimental work and cooperation was significantly improved by the software-supported teaching compared with the "usual" non-computer-oriented education.

In the pilot-study of Ossimitz (1994) only a few students of each class were tested before and after a System Dynamics module of about 10 hours (grades 9 and 11), using a part of the Klieme/Maichle (1994) test. After each test the students were interviewed about their answers. The test + interview combination was more successful in the determination of thinking processes than a design without interviews.

The Ossimitz (1994) study also showed that the use of causal loop diagrams (CLD's)can be taught to ninth-graders astonishingly fast. In one class the "pre-test" accidentally took place after the first hour of SD – teaching. In this lesson the students had been shown just two very simple causal loop diagrams. They spontaneously used causal loop diagrams to describe Hilu-scenario (Fig. 2) in their pre-test. An example is shown in Fig. 6. Without prior teaching most students just used pictorial diagrams to describe the Hilu-situation. Fig. 5 gives a typical example.

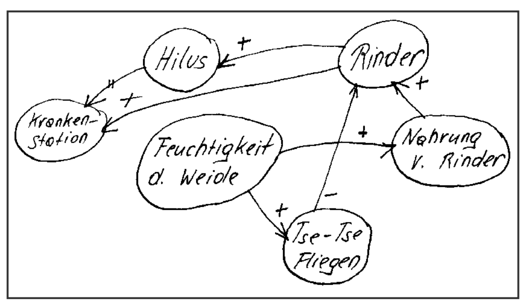

Fig. 6 causal loop diagram of the Hilu-scenario (after seeing 2 CLD's)

9 The *Development of Systems Thinking* – Study (Ossimitz 1996)

The project *Development of Systems Thinking* ("Entwicklung vernetzten Denkens") was undertaken in cooperation with six volunteering teachers of Austrian (mostly business-oriented) high schools. First the teachers got a one-week introductory course about the principal ideas of System Dynamics, systems thinking and systemic modeling and simulation using the simulation software POWERSIM. Then the teachers were free to design a teaching unit of approximately 20 hours on system dynamics modeling and simulation. They were only required to document the unit and to use POWERSIM in some way. For a detailed documentation see Ossimitz (2000).

The students were tested with a written test (of about 45 minutes) before and after the teaching (the test was not known to the teachers). The test design was similar to the study of Klieme/Maichle (1994). The pre- and post-tests consisted of two main tasks with some additional questions.

The first task in the pre-test was to depict a variant of the "Hilu"-scenario in a picture or diagram; in the post-test a similar "Mori"-scenario was presented. On a formal level, the complexity and inter-relatedness of both scenarios were (almost) identical. Both scenarios had been given additional complexity (several closed loops) compared with the text in Fig. 2, because the Hilu-text Fig. 2 turned out to be no real challenge for almost all students aged 14 – 16 in the pre-tests of the Klieme/Maichle (1994) and in the Ossimitz (1994) studies.

In addition, students were asked about indirect consequences of some actions (like *"What effect does using more grass-fertilizer have upon the abundance of the "tse-tse-fly?"*). In the evaluation of this task, mainly the type and the systemic complexity of the resulting diagram and the quality of the additional answers were evaluated.

The second task, called **arguments and counter-arguments** ("Argumente und Gegenargumente"), was taken without change from the Klieme/Maichle (1994) study. Following a given example, students should write down chains of arguments (like *more tourists / more hotels / more traffic problems / less attractivity of the resort*) for traffic problems in a small rural town (pre-test) and tourist problems in a sea-side holiday resort (post-test).

For the evaluation of both tasks the number of items (Elements in the graphs) and relations (arrows, logical if-then relations) being stated by the students were counted. These basic measures were used to calculate an index of complexity and an index of inter-relatedness. These indices were used as indicators to measure the skill of designing interrelated systems.

The measured items were also correlated with basic variables like gender, age, grade in mathematics, computer experience. About 40% of the students owned a private computer; about 10% of all students worked more than 6 hours per week on a computer.

9.1 Results of the Pre-Test

The students used a wide variety of diagram-types to depict the Hilu-scenario (see table 2). There was no significant correlation between the type of diagram and the age, gender or mathematics grade of the students. The results for the arguments-and-counterarguments task were similar: I could not observe any correlation between the complexity-index or the interrelatedness-index with age, gender or mathematics-grade.

9.2 Results of the Post-Test

The diagrams the students used for sketching the Mori-scenario at the post-test were in most cases considerably different from the pictures they used in the pre-test. Generally pictorial and verbal descriptions decreased and the number of causal loop diagrams increased significantly. In some classes (Table 2, teacher T3 and teacher T6), almost all students used causal loop diagrams. An extreme to the opposite side was the class of teacher T1: One third of the students of teacher T1 used pictorial descriptions even at the post-test. Moreover they were the only who drew pictorials in the post-test. However, the circumstances in the class of teacher T1 were disastrous: in this class the "project" lasted for just 6 hours. Half of this time was spent with very general discussions about medical health care, reasons for early deaths, the belief in astrology and the like. Only about 1½ hours were spent in the computer room. The rest of the time the teacher discussed a drug addiction model using transition matrices (no system dynamics), which led to the mathematical interesting issue of fixed points in iterated vector equations.

Type of picture/diagram used for Hilu / Mori-scenarios	pre-test: Hilu-sc.	post-test: Mori-scenario (teachers T1 ... T6)						
	all teachers	all teachers	T1	T2	T3	T4	T5	T6
pictorial or verbal descriptions	22%	6%	**33%**			6%		
function charts (mostly Cartesian style)	5%	3%					8%	6%
chain diagrams (lin. seq. of arguments)	15%	3%	11%	8%				
tree diagrams (mostly 2 branches)	7%	7%	11%	16%		6%	4%	
causal diagrams without loops	29%	19%	28%	33%	5%	12%	21%	11%
causal diagrams with loops	17%	61%	11%	42%	**95%**	**71%**	67%	**83%**
Total	100%	100%	100%	100%	100%	100%	100%	100%

Table 2 Types of diagrams used to denote the Hilu/Mori scenarios

For the first task (Hilu/Mori-scenarios) most indicators for systems thinking in the post-test were significantly higher (on the 95%-level) than in the pre-test. E.g. the average index of interrelatedness of the Mori-diagrams was at about 2.29±0.12 (double standard error of the mean) compared with 1.47±0.14 in the pre-test. Table 3 shows that this average result over all students differs significantly for both tests according to the teacher. The students of teacher 1 had the worst result at the pre-test (1.01) and almost no increase between pre- and post-test (1.18). The students of teacher 3 were below the average in the pre-test (1.39), but they got the best result (2.83) in the post-test.

Index of interrelatedness	**T 1**	**T 2**	**T 3**	**T 4**	**T 5**	**T 6**	**Total avg.**
Pre-Test: Hilu-scenario (avg.)	1.01	1.67	**1.39**	1.70	1.45	1.73	**1.47**
Post-Test: Mori-scenario (avg.)	1.18	2.00	**2.83**	2.15	2.11	2.50	**2.29**

Table 3: Average index of interrelatedness by teachers T1 – T6

For the arguments-counterarguments task several of the indices to measure the level of systems orientation (complexity, interrelatedness, number of items and number of causal arrows) were significantly higher in the post-test than in the pre-test. Again there was no correlation with age, mathematics grade or computer experience, but a great influence of the variable "teacher". I observed that the index of interrelatedness was slightly higher for the boys than for the girls (for both pre- and post-test); but this might be just a side-effect of the fact that the best teachers had a higher percentage of boys in their class.

Some other interesting results of the Ossimitz (1996) study were:

- Two other classes (at different schools) were also tested as control groups (without SD teaching between pre- and post-tests). There was no significant difference in the students' behavior between pre- and post-tests. A test-retest effect (that the students learn from the pretest and thus achieve better results in the posttest) could not be observed.
- The teachers reported very positively on their teaching projects. They said that the Windows-oriented software POWERSIM was (unlike MODUS) very easy to learn - despite the fact that only an English version of POWERSIM was available and that POWERSIM has many features far beyond the elementary needs of teaching.
- The teachers had few problems in giving homework and written tests for the system dynamics module.
- Most students had no prior experience in project-oriented teaching, which caused some insecurity at the beginning. In the final review of the teaching project most students gave very positive comments about project-oriented teaching and the simulation software POWERSIM. Here are two statements by students (from their written feedback about the project):

  "This kind of teaching was new for me, but somehow I appreciated it. I would not like all teaching to be like this, but now and then it would be fine; especially so that one can understand the connections between certain things."

  "I liked the project. It was fun that we could work on our own. I like it better when we can summarize the items ourselves than when the teacher talks for an hour or so."

10 Conclusions and Summary

The project *Development of Systems Thinking* showed that it is possible to construct indicators for the development of systems thinking skills and to measure some progress through a teaching unit of about 20 hours. **The central result of our study is that the variable "teacher" has by far the greatest influence upon explaining the differences between the pre-test and post-test achievements.** The impact of the teacher proved more important by far than the variables "age", "gender", "computer experience" or "mathematics grade". Even the style of teaching (conventional vs. project-oriented) did not affect the outcome. In retrospect this might not be so surprising, but in the design-phase I definitely did not expect the teacher's impact to be so strong.

Let me conclude with a remark about "learner-centered-learning", as proposed by Forrester (1992) for teaching and learning System Dynamics. I do not think that learner-centered-learning lessens the importance of the teacher. In my opinion the teacher is **the** key factor for introducing and maintaining learner-centered-learning at school. We cannot expect that most students automatically have the same motivation and excitement as researchers in their laboratory; thus it is the teachers' role to induce and to guide the motivation of his or her students.

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[1] VUDYNAMO is an easy-to use DYNAMO-clone for PC computers, suitable for the early XT and AT generations with primitive CGA-Graphics. VUDYNAMO accepts the original DYNAMO syntax, but does not require the (j, k, l) time indices of the original DYNAMO.

[2] The Gymnasium is a non-business-oriented type of secondary school with a lower school from grade 5-8 and an upper school from grade 9 - 12. It is finished with the Matura/Abitur leaving examination, which permits general University access in Austria. The Realgymnasium is a branch of the Gymnasium with a somewhat higher natural science orientation.

Systems thinking requires a shift in mindset, away from linear to circular. The fundamental principle of this shift is that everything is interconnected.Â But all systems are dynamic and often complex; thus, we need a more holistic approach to understanding phenomena. Synthesis is about understanding the whole and the parts at the same time, along with the relationships and the connections that make up the dynamics of the whole. Essentially, synthesis is the ability to see interconnectedness. 3. Emergence.Â Working and teaching systems thinking for years has led me to develop additional new tools, as well as employ these time-honored concepts from the pioneers. What stands out to me as critical in order to make a positive impact, is the ability to develop your own individual agency and actions. 1. SYSTEMS AND SYSTEMS THINKING One of the main aims of teaching System Dynamics is to promote the ability to develop something called systems thinking (or systemic thinking). In the mathematics curriculum of Austrian natural-science orientedÂ System borders are important for several reasons: - Borders ensure (and even may determine) the identity of the system. - The relations between a system and its environment take place mainly at the borders.It. is at the borders, where it is determined, what can enter or leave a system (input and output). d) Systems often have a dynamic behaviour over time. This behaviour is often related to the aim of the system. Biological systems (living beings) are determined to ensure their self