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THE DEVELOPMENT OF SYSTEMS THINKING SKILLS USING SYSTEM DYNAMICS MODELLING TOOLS

Abstract:

According to the author’s conviction, systems thinking and the modelling of System Dynamics are of great importance for the field of mathematics education; but for the moment I do not want to put forward specific ideas on the ways they should be applied to and made productive in this field. However, I want to stimulate discussion on this topic and, therefore, gives a survey of research into the education of System Dynamics and systems thinking. In the first section basic ideas of systems and systems thinking are discussed. In section 2 some issues of System Dynamics modelling and simulation software are addressed. In section 3 I give a survey of the empirical research on teaching System Dynamics and the development of systems thinking skills. In the last section the main preliminary results of my study “Entwicklung vernetzten Denkens” (Development of systems thinking) are presented. This study showed very clearly that the key factor for teaching and developing systems thinking skills is the teacher.

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 oriented highschools (*Realgymnasium*, 11th grade), the section *Investigation of interrelated Systems* (Untersuchung vernetzer Systeme) begins with the following preamble: “Through the analysis of systems (consisting of components, which influence each other) interrelated thinking (systems thinking), which has become necessary in many areas, should be promoted. Especially the ability for grasping more complex situations, which go beyond simple cause-effect-relationships, should be improved.” (BÜRGER et al. 1991, p 152ff)

1.1 What is a System?

The term “system” is being used in different fields in a variety of meanings (see KLIR 1991, p 4). Yet we can state some general characteristics of systems:

a) Systems consist of (definable) *elements* - just as a mathematical set consists of certain, distinguishable elements.
b) Between these elements there exist (mostly functional) interrelations. A system is more than a mere accumulation of elements; there has to be also a certain structure of relations among these elements.
c) Every system has a boundary to the surrounding “environment”, which is more or less permeable. This boundary might be material (like the skin of a human body) or immaterial (like the membership to a certain social group). 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-

preservation (essentially via homeostasis); production systems are made for a certain output; transport systems are designed for a certain throughput etc.

e) On a closer perspective, individual system elements might be considered as whole subsystems or a system might be a single element of a larger system. A motor might be a subsystem of a car, which is again an element of a more complex transport system. Thus whole hierarchies of systems may emerge.

RAPOPORT (1986, p 30ff) names *identity*, *organisation* and *goal-orientation* as three fundamental features of systems. By identity he means "stability within change"; by organisation he means the design and the handling of complexity; by goal-orientation he means the destiny of a system.

1.2 System-Approaches in Different Fields of Science

Different fields of science have developed different system approaches. I would like to mention some important system approaches and mention founders or important representatives of each approach:

- The *approach of mathematics and physics* (Isaac Newton) deals mainly with systems of equations, especially differential equations. "Classical dynamics is essentially the theory of differential equations". (RAPOPORT 1988, p 38)
- The *approach of General Systems Theory or Systems Science(*VAN BERTALANFFY, RAPOPORT) considers systems like mathematical entities and uses mainly mathematical methods to describe and classify systems. "It follows from this *common-sense definition* that the term "system" stands, in general, for a set of some things and a relation among things. Formally, we have

  $$\mathbf{S} = (T,R)$$

  where **S**, *T*, *R* denote, respectively, a *system*, a *set of things*, distinguished within **S**, and a *relation* (or, possibly, a set of relations) defined on *T*." (KLIR 1991, p 4)
- The *Cybernetics approach* was founded by WIENER with his book "Cybernetics: or Control and Communication in the Animal and the Machine" (1948). WIENER dealt primarily with control and information systems. It is important maintain certain system parameters by means like homeostasis or adaptation and the interrelation between system and environment.
- The *System Dynamics-approach* was founded by FORRESTER at MIT at about 1960. He developed a powerful method for describing interrelated systems (using causal loop diagrams, stock-and-flow diagrams) and the simulation language DYNAMO for the numerical simulation of dynamic systems. The main issue of stock-and-flow diagrams and of the System Dynamics simulation style is a clear distinction between *stock* and *flow* variables (or *levels* and *rates* in the original terminology of FORRESTER). Other than in the classical approach of systems of differential equations, in the System Dynamics approach closed solutions do not play a considerable role. The focus of interest is concentrated upon a certain subject field. Other than in the world of continuous differential equations discrete time steps are used for describing and simulating the dynamic development. Stocks are time-point related and flows are time-interval related system variables. The first publication in System Dynamics was the classic "Industrial Dynamics" (FORRESTER 1961). Among all the system approaches mentioned here the system dynamics approach is highly standardised and has a number of advantages for being taught at school.

- The *ecological-biological approach* deals primarily with ecosystems. Main proponents are ODUM (1994: systems ecology) or VESTER. VESTER proposes ideas for systems thinking via the exposition „*Unsere Welt - ein vernetztes System*“ (1986) or via the game “Ökolopoly”, which is available both as a board game and as a computer game. The system view of ecologists is often more qualitative than the system dynamics view of system.
- *Systemic communication theory* deals with human relationship systems, based upon communication. WATZLAWICK formulated in his classic work “Pragmatics of Human Communication” (WATZLAWICK 1967) principles of systemic-oriented communication theory. This theory gives insight into human interactions and offers a systems oriented explanation for psychic disorders like schizophrenia as a result of paradox communication structures.

Most of these approaches use ideas and concepts of mathematical tools for describing and analyzing systems; some are even incomprehensible without the aid of mathematical tools.

1.3 Systems Thinking and Systemic Behaviour

“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 what “systems thinking” is like. KLIR (1991, p 19) writes in his encyclopedic work “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*.” That is all that KLIR says explicitly about systems thinking. KLIR gives no closer hint about what is meant by “systems thinking”.

The German cognitive psychologist DÖRNER says in his book „*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.” (1989, p 308ff) DÖRNER reduces systems thinking to the formula: systems thinking = systemic, complex situation + situation-adequate thinking.

In an online paper (http://www.hps-inc.com/st/st.html) RICHMOND gives the following definition of “systems thinking”: “systems thinking is the art and science of linking structure to performance, and performance to structure – often for purposes of changing structure (relationships) so as to improve performance.“ In his paper “Systems thinking: critical thinking skills for the 1990s and beyond” RICHMOND writes that “doing good systems thinking means operating on at least seven thinking tracks simultaneously.” (1993, p 121) These tracks are: *dynamic thinking*, *closed-loop-thinking*, *generic thinking*, *structural thinking*, *operational thinking*, *continuum thinking* and *scientific thinking*.

Richmond’s seven tracks of systems thinking are closely related to system dynamics Modelling. (RICHMOND is one of the creators of Stella software). I would like to specify and discuss four characteristic dimensions, which are essential for my definition of “systems thinking”:

a) *thinking in models*: explicitly comprehended modelling
b) *interrelated thinking*: a thinking in interrelated, systemic structures
c) *dynamic thinking*: a thinking in dynamic processes (delays, feedback loops, oscillations).
d) *steering systems*: the ability for practical system management and system control.

a) Thinking in Models

From the viewpoint of Radical Constructivism (cf. GLASERSFELD 1995) thinking in models is necessary. Constructivism says that we can only think according to our pictures and views of the world, which are necessarily models of the world itself. My point is now 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 comprehends 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. To choose an appropriate form of representation (e.g. causal loop diagram, stock-and-flow diagram, equations) is a crucial point of systems thinking. The invention of powerful, flexible and yet standardised 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 modelling, the stock-and-flow diagram already gives key hints about the structure of the quantitative simulation model.

b) Interrelated thinking

People of the western hemisphere are usually very good in causal reasoning. If - then relations are basic building blocks of our mind and understanding of things. A foundation of this kind of thinking is a strict delineation 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 analogy is the function-concept with one independent variable (=”cause”) and one dependent (=”effect”) variable. Accordingly the thinking in simple cause-effect relationships might be called *functional* or *linear* thinking - in contrast to *interrelated 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 Ami’s have built 1000 new missiles.” This increase of the Soviet Army Force lead 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 no longer is possible. If 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.

c) Dynamic thinking

Systems have a certain behaviour 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 of the temperature would require some time until they become

effective (cf. 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 cooling-house out of control.
Dynamic thinking also means to foresee (possible) future developments. A mere retrospective view of past developments is insufficient for the practical steering of systems - or would you trust a car driver who uses exclusively 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.

d) Steering a System

This brings us to the fourth core aspect of systems thinking: the practical steering of systems. Systems thinking has always also a pragmatic component: it deals not just with contemplating about 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 behaviour of others directly, one can only change one's own behaviour. In an economic system the producer usually has no direct control over the market. Marketing activities are usually actions of the supplier side in order to induce the desired reaction on the demand side.

1.4 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 VESTER'S exposition "Unsere Welt - ein vernetztes System" (Our world - an interrelated system, Vester 1986) or the works of MEADOWS concerning "The Limits to Growth" (1972).
– DÖRNER (1989, p 307ff) suggests *computer-simulation games* (like *Tanaland* or *Lohhausen*), in order to learn systemic thinking and action.
– Some curricular concepts try to develop systems thinking skills via explicit teaching at schools. Examples 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 *http://www.teleport.com/~sguthrie/cc-stadus.html* or STACIN (systems thinking and Curriculum Innovation Network; see *http://etsis1.ets.org/research/tacin.html* or MANDINACH 1989) in the USA.
– 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).

2. SYSTEMIC MODELLING AND SYSTEM DYNAMICS SOFTWARE

2.1 Qualitative vs. Quantitative Modelling

Systems can be modelled in a qualitative or quantitative manner (cf. OSSIMITZ 1991a). The difference applies even at the level of descriptive tools being used: verbal descriptions and causal loop diagrams are more qualitative, stock-and-flow diagrams and equations more quantitative ways to describe dynamic systems. Although there is a structural similarity between causal loop diagrams and stock-and-flow diagrams, they belong to different modelling paradigms. In quantitative modelling the model elements are quantifiable entities with functional relations between them. In a quantitative predator-prey model of hares and lynx the "hares" are not animals, but the number of animals. To kill some hares means in the quantitative model that their number decreases. We have to take into account that there is a significant difference between the hares as animals and the numbers of hares. The lynx can kill hares, but the number of lynx cannot kill anything, it can just have an influence upon the number of hares. Quantitative Models are usually designed and simulated on a computer, qualitative models are less computer-oriented.

SENGE's famous book "The Fifth Discipline" (1990) about learning organisations is an excellent example of how system models can be developed and analysed in a completely qualitative manner. SENGE uses extensively verbal descriptions and causal loop diagrams to describe (mostly economic and managerial) systems and their behaviour, but you cannot find a single stock-and-flow diagram or equation in his book.

For System Dynamics modelling at school level the quantitative approach (using some graphics-oriented simulation software) seems to be far ahead of qualitative modelling. Teachers and students often show a strong tendency to start immediately with the work at the computer. According to my experience, however, it is very useful to present first some basic aspects of systems thinking and modelling without the computer, using just loop diagrams. Then one can proceed to the realms of quantitative modelling, using stock-and-flow diagrams and equations. The sequence *verbal description causal loop diagram stock-and-flow diagram equations* proved also a very natural and step-by-step progression when developing a single quantitative model (cf. also RICHMOND 1991, p. 2).

2.2 Self-Made-Models vs. Ready-Made-Models

Students can either develop their own models or explore ready-made models, which are designed by some experts. Both methods have their pros and cons. If students make their own models, they usually know more about the inner structure of the model and have to think more about the design of the model for themselves. The modelling process, however, takes a lot of time and success is not guaranteed in all cases (especially in more complex contexts). This means in practice, that self-made-modelling often ends at a level of rather simple models. The development of more realistic, (and thus more complex) system dynamics models often goes beyond the scope of time available at school.

Ready-made models might help here. If they are rather complex, their inner structure will usually be adopted only partially by the students. Most of the system remains a black box (cf. MAAß & SCHLÖGLMANN 1994). The students often just learn about the system by varying parameters. The user/learner/player has no direct access to the inner model structure; one can learn about the inner structure only by changing input parameters and watching the development of the output parameters. Although complex System Dynamics models (like World3, MEADOWS 1972) in principle allow the study of the inner structure of the model in detail, it will be used more like a black box simulation software in practical teaching.

Predesigned, complex models should only be used with a teaching guide. This helps teachers and students from getting lost in the awesome number of parameter-selections and things that can be explored. Without a guide the work with a complex model might soon become boring or frustrating.

When making self-made-models, it is very important to begin with a basic model which is as simple as possible, then to test this model and then to add more features to the model. The first model should contain only one (or very few) stock variable(s). The appropriate flow and auxiliary variables can be defined around this variable. This yields typical sequences of models, starting with a very primitive basic model, which will be refined in several steps. In a more complex context it is advisable first to construct independent partial models for each sector and to test and calibrate these models. Only then can these sub-models be put together to form the more complex model. (cf. OSSIMITZ 1990). It is also advisable to choose the model parameters first in such a way that all model variables stay constant (stationary) over time. This helps to identify the kind of influence of each input parameter.

2.3 Simulation Software

System Dynamics modelling needs appropriate computer software. Software for modelling and simulation can be classified according to different dimensions:

– according to the *kind of model-representation* we can differentiate between model oriented software and black-box-oriented software products;
– according to the *spread of the software*: prototypes, special application software, standard software;
– according to the *purpose of the software*: research-oriented software, teaching-oriented software, application-oriented software.

In *model-oriented software* products, the model structure is explicitly available to the user (like in Dynamo, Stella, Powersim, Vensim, Modus...). In the System Dynamics approach only model-oriented software products are used. *Black-box oriented simulation software* usually has a fixed and mostly very complex model-structure, which is not directly accessible and cannot be changed by the user. The model behaviour can be studied by changing input parameters. Most commercial entertainment simulation games (like SimCity or Ökolopoly), many management flight simulators (business planning games), and also the prototypes (like "Lohhausen" or "Tanaland", cf. DÖRNER 1989), which were used in German psychological research (see 3.1) are black-box oriented simulation software products.

Prototypes are software products, which are available only to a small group of specialists. By *Standard Software* I mean products like word processors or spreadsheet software. All System Dynamics software products belong to the middle category of *special application software*. Spreadsheets are the only kind of standard software, which can be used for some simple System Dynamics modelling issues (e.g. see OSSIMITZ 1990).

2.4 Software-related Educational Research

When discussing software-related research results, e.g. about systems thinking skills, it is crucial to be aware of the type of software the results are based upon. It is questionable, to what extent results which were gained with black-box-oriented software also apply to model-oriented software. There is also a fundamental discrepancy between experimental prototypes and standard application software products. For research reasons it is often desirable to develop and use special software prototypes. In actual modelling at schools and firms, however, these prototypes are usually not used and mostly not even available. Often not even special System Dynamics software is available, but a spreadsheet program like Excel. For practical reasons it might be a very important question to ask: *what kind of system dynamics / systems thinking education can be done just with a spreadsheet program*?

Another serious problem of simulation software related research is the fast innovation cycle of simulation software products. If the research is bound too closely to a single software product, the results of such a study might be worthless within a few years. Thus it is advisable to design empirical research independent of specific software products.

3. EMPIRICAL INVESTIGATIONS ABOUT THE DEVELOPMENT OF SYSTEMS THINKING

3.1 How can Systems Thinking be measured?

Under the title “Complex Problem Solving” (*Komplexes Problemlösen*), a group of German cognitive psychologists undertook considerable efforts to measure the ability of subjects to act in complex, systemic situations (cf. DÖRNER 1989), using computer simulation scenarios. The inner model structure of these scenarios was not known to the subjects (black-box-concept); they just could guess about the system structure according to sound reasoning and system behaviour. This research gave some insight into the (often poor) abilities of the subjects to manage complex situations, but issues of the development of systems thinking (or complex problem solving) skills were hardly mentioned.

Attempts to measure the development of systems thinking have only been undertaken in System Dynamics related studies. One of the first of these studies was undertaken in the “Systems Thinking and Curriculum Innovation Project” (STACI, MANDINACH 1989). Mandinach essentially defines systems thinking as the System Dynamics modelling ability: “Systems thinking is a scientific analysis technique given prominence by Jay Forrester and his colleagues at the Massachusetts Institute of Technology. ... As defined here, the systems thinking approach consists of three individual but interdependent components: system dynamics, STELLA, and the Macintosh.” (MANDINACH 1989, pp 222; 225).

3.2 German Studies about teaching System Dynamics and Systems Thinking

In German-speaking countries efforts to measure the development of systems thinking abilities were undertaken by Eckhard Klieme and Ulla Maichle of the Institut für Bildungsforschung (Institute of educational research, Bonn) and by myself. I will give an overview of the design and the main results of the following studies:

- KLIEME/MAICHLE (1991): “Erprobung eines Modellbildungssystems im Unterricht” *(Evaluation of a Model Building System in the Classroom*).
- KLIEME/MAICHLE (1994): Modellbildung und Simulation im Unterricht der Sekundarstufe I (*Modelling and Simulation in Grades 9 and 10*)
- OSSIMITZ (1994): Systemdynamiksoftware im Unterricht (*System Dynamics Software in the Classroom*)
- OSSIMITZ (1996): Entwicklung vernetzten Denkens (*Development of Systems Thinking*)

The design of these studies is summarised 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 make the development of systems thinking and action skills easier?

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 1991 study the graphical simulation software Modus (developed at the Deutsches Institut für Fernstudien (DIFF) in Tübingen by Werner Walser and Joachim Wedeking for DOS Computers) 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	mathematics, biology, chemistry, social studies	Modus	pre- & post-test
K/M94	240 / 10	9; 10	economics, biology, informatics	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, informatics, physics	Powersim	pre- & post-test + interviews (4/class)

Table 1

The main results of these four studies were:

- Students and teachers considered the System Dynamics teaching modules very interesting. (In some classes it was the first attempt of computer-oriented teaching both for teachers and students
- The way to sketch a verbally described systemic situation changed considerably during the teaching. 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 diagrams (like stock-and-flow diagrams in Stella), 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 more complicated text was used for the pre- and post-test.
- 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 different from predicting effects in verbally described models." (KLIEME & MAICHLE 1994, p 76)

The main results of the KLIEME & MAICHLE (1991) pilot study were:

- The interest of the students depended upon their readiness to work on the computer.
- The software product Modus had a considerable impact upon the teaching and the way of modelling. Some of the students' problems in the modelling process seemed to depend upon the specific way that systems are modelled in Modus. (In Modus, both inflows and outflows of stock variables are modelled as effects from the flow variable to the stock variable. Other than in the standard System Dynamics modelling paradigm, arrows of outflows are (like inflows) oriented from the flow variable to the stock. This should indicate that the flow variable causes an effect upon the stock in any case; inflows and outflows have only different signs in Modus).

The KLIEME & MAICHLE (1994 pp 73ff) study yielded the following results:

- Students of teachers who used 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 than on their 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 co-operation was significantly improved.

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 merely test-oriented design without interviews. The OSSIMITZ 1994 study also showed that the use of flow diagrams can be taught to ninth-graders astonishingly fast. In one class the pupils were tested after having seen just two simple flow diagrams. They instantly used flow diagrams to describe a far more difficult situation.

4. THE STUDY "ENTWICKLUNG VERNETZTEN DENKENS"

The project "Entwicklung vernetzten Denkens" (*Development of Systems Thinking*) was undertaken in co-operation with six volunteering teachers of Austrian (mostly business-oriented) high schools. First the teachers got a four-day introductory seminar about the principal ideas of System Dynamics, systems thinking and systemic modelling and simulation using the simulation software Powersim. Then the teachers were free to design a module of approximately 20 teaching units about System Dynamics modelling and simulation. They were only required to document the teaching units and to use Powersim in some manner. In the test-phase 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. Pre- and post-test consisted of two main tasks with some additional questions.

The first task was to depict a verbally given systemic situation (the "Hilu"-scenario at the pre-test; the "Mori"-scenario at the post-test) in a kind of picture or diagram. Both scenarios described the highly interrelated hypothetical economy of a tribe in a third world environment. On a formal level, the complexity and interrelatedness of both scenarios were (almost) identical. In addition, students were asked about indirect consequences of some actions (like *"What effect does using more grass-fertiliser 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 "Argumente und Gegenargumente" (*arguments and counter-arguments*) 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 town (pre-test) and tourist problems in a sea-side holiday resort (post-test).

In each class four students were interviewed about their answers to the Hilu- and Mori-task respectively. For the evaluation of both tasks the number of items and relations being stated by the students were counted. These basic measures were used to calculate an index of complexity and an index of interrelatedness. These indices were used as indicators of interrelated system design skills.

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.

4.1 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-counter-arguments-task were similar: I could not observe any correlation between the complexity-index or the interrelatedness-index with age, gender or mathematics-grade.

4.2 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 3 and Teacher 6), almost all students used causal loop diagrams. One third of the students of teacher 1 used pictorial descriptions even at the post-test.

Type of picture/diagram used for Hilu / Mori-scenarios	pre-test	post-test						
	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. sequ. 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

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 these average results differ 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 average
Pre-Test: Hilu-scenario (average)	1.01	1.67	1.39	1.70	1.45	1.73	**1.47**
Post-Test: Mori-scenario (average)	1.18	2.00	2.83	2.15	2.11	2.50	**2.29**

Table 3

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 the variable "teacher" had a great influence. 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 System Dynamics teaching between pre- and post-tests). There was no significant difference in the students' behaviour between pre- and post-tests. A test-retest effect (that the students learn from the pre-test and thus achieve better results in the post-test) could not be observed.
- The teachers reported very positively about their teaching projects. They said, that the Windows-oriented software Powersim was (unlike Modus) very easy to learn - despite the many extra features of Powersim.
- The teachers had few problems in setting homework and written tests for the System Dynamics module.
- Most students had no prior experience in project-oriented teaching, which caused some insecurities 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 summarise the items ourselves than when the teacher talks for an hour or so.*"

4.3 Summary and Conclusion

The Project "Development of Systems Thinking" showed that it is possible to construct indicators for the development of systems thinking skills and to measure certain progress through a teaching module of about 20 units. *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 by far more important than the variables "age", "gender", "computer experience" or "mathematics grade" In retrospect this might not be so surprising, but in the design-phase I definitely did not expect such a strong impact of the teacher.

'Traditional empirical educational research often tries to eliminate or minimise the "teacher" as an influential factor. My study showed that this is rather questionable, if the results of educational studies are to be of any relevance for actual school teaching. Yet I must admit that it is far more difficult to design and undertake scientifically founded studies about learning, which include the teacher as a key factor of learning.

Let me conclude with a remark about "learner-centred-learning", as proposed by FORRESTER (1992) for teaching and learning System Dynamics. I do not think that learner-centred-learning lessens the importance of the teacher. In my opinion the teacher is *the* key factor for introducing and maintaining learner-centred-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.

REFERENCES

BERTALANFFY, L. v. (1969): General system theory. New York: Braziller

BÜRGER, H. u.a. (Hg) (1991): Mathematik Oberstufe: Lehrplankommentar. Wien: Österreichischer Bundesverlag

DÖRNER, D. (1989): Die Logik des Mißlingens. Reinbek: Rowohlt *Engl: The logic of failure. London: Philosophical Transactions of the Royal Society of London, Vol. B 327. (1990)*

FORRESTER, J. W. (1961): Industrial Dynamics. Cambridge, Mass: MIT Press

FORRESTER, J. W. (1992): System Dynamics and Learner-Centered-Learning in Kindergarten through 12th Grade Education. Paper D-4337, Cambridge, Mass.: MIT

GLASERSFELD, E. (1995): Radical constructivism: a way of knowing and learning London: Falmer *Dt. Radikaler Konstruktivismus: Ideen, Ergebnisse, Probleme. Frankfurt/Main: Suhrkamp (1996)*

KLIEME, E. & MAICHLE, U. (1994): Modellbildung und Simulation im Unterricht der Sekundarstufe I. Bonn: Institut für Bildungsforschung

KLIEME, E. & MAICHLE, U. (1991): Erprobung eines Systems zur Modellbildung und Simulation im Unterricht. In: Gorny (Hg): Informatik und Schule 1991. Berlin: Springer

KLIR, G. (1991): Facets of Systems Science. New York: Plenum Press

MAAß, W. & SCHLÖGLMANN, W. (1994): Black Boxes im Mathematikunterricht. JMD 15 (94), 123-147

MANDINACH, E. (1989): Model Building and the Use of Computer Simulation of Dynamic Systems. In: J. Educational Computing Research, Vol. 5(2) 221-243, 1989.

MEADOWS, D. et al (1972): The limits to growth: a report for the Club of Rome's project on the predicament of mankind. New York: Universe Books *Dt: Die Grenzen des Wachstums: Bericht des Club of Rome zur Lage der Menschheit. Reinbek: Rowohlt (1973)*

ODUM, H. T. (1994): Ecological and general systems: an introduction to systems ecology. Niwot, Colorado: Univ. of Niwot

OSSIMITZ, G. (1990): Materialien zur Systemdynamik. Wien: Hölder-Pichler-Tempsky

OSSIMITZ, G. (1991a): Darstellungsformen in der Systemdynamik. In: Kautschitsch (Hg): Anschauliche und Experimentelle Mathematik I; Wien: Hölder-Pichler-Tempsky

OSSIMITZ, G. (1991b): Systemdynamische Modelle aus Biologie und Ökologie. ZDM 1991/6, 221-228

OSSIMITZ, G. (1994): Systemdynamiksoftware und Mathematikunterricht. Endbericht zum gleichnamigen Projekt. Universität Klagenfurt

OSSIMITZ, G. (1996): Entwicklung vernetzten Denkens. Universität Klagenfurt: Projekt-Endbericht

RAPOPORT, A. (1986): General system theory: essential concepts & applications. Tunbridge Wells,

KENT: Abacus Press. *Dt: Allgemeine Systemtheorie: wesentliche Begriffe und Anwendungen. Darmstadt: Verlag Darmstädter Blätter (1988)*

RICHMOND, B. (1991): Systems Thinking: Four Key Questions. Lyme: High Performance Systems Inc.

RICHMOND, B. & Peterson, S. (1992): Stella II. An Introduction to Systems Thinking. Lyme: High Performance Systems Inc.

RICHMOND, B. (1993): Systems thinking: critical thinking skills for the 1990s and beyond. In: System Dynamics Review, Vol. 9, no. 2 (Summer 1993), 113-133.

SENGE, P. (1990): The fifth Discipline. New York: Doubleday

VESTER, F. (1986): Unsere Welt - ein vernetztes System (3. Auflage). München: DTV

WATZLAWICK, P. & BEAVIN, J. & JACKSON, D. (1967): Pragmatics of human communication: a study of interactional patterns, pathologies, and paradoxes. New York: Norton. *Dt: Menschliche Kommunikation. Bern: Huber (1969)*

WIENER, N. (1948): Cybernetics: or control and communication in the animal and the machine.

New York: Technology Press *Dt: Kybernetik: Regelung und Nachrichtenübertragung im Lebewesen und in der Maschine. Düsseldorf; Wien: Econ-Verlag (1963)*

WINKELMANN, B. (1992b): Modellbildung im Mathematikunterricht. Dynamische Modellbildung als Mathematisierung. Computer und Unterricht 8/1992, S 46-50

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