Systems for Modelling and Simulating in Schools

Hans-Ulrich Dönhoff
The North-Rhine Westphalian State Institute for School and Adult Education
Paradieser Weg 64
D-59494 Soest, Germany
Tel: 02921 693 267
Fax: 02921 683 228
E-mail: doenhoff@lsw.soest.nw.schule.de

Abstract

This paper wants to report about an approach to make German pupils familiar with the problem of system dynamics, to promote the comprehension of complex systems, to teach them something like "thinking in networks".

To reach this aim we employed a tool for modelling and simulating, comparable with well-known systems as ITHINK or POWERSIM, but able to run on simple PCs under MS-DOS.

Using this tool we have developed the following four units (the subject in parentheses):

- Ecosystem forest (ecological balance, biology)
- Flows of carbon dioxide (chemistry)
- Growth (mathematics)
- "Tycoon" (economy)

Two of these units, "forest" and "economy" are the basis of our research. In 11 groups with 238 pupils we made pre-tests, video recording and final tests.

The results in the field "model thinking" were remarkably better than in a pilot study, initiated two years ago, the semantic and the syntactic correctness of the models have increased as well.

This will be shown by evaluation of several items, regarding the aspects of

- prediction of behaviour,
- forms of presentation, and
- level of net structure.

Systems for Modelling and Simulating in Schools

1. Introduction

Since the publications of the "Club of Rome" 20 years ago the world has recognised the problem and the necessity of knowing more about the behaviour of complex systems.
Although those complex systems like traffic-systems, global communication-systems and world-wide economic systems are created by man, you more and more recognise, that these systems are not surveyable, even the smallest mistakes can cause immense damage.
Obviously we have great problems in understanding these processes. The German philosopher and physicist G. VOLLMER speaks about a "meso-cosmos", a fraction of the cosmos, we can understand only. Things like exponential growth and complex networks don't belong to this fraction. That is why I think it will be more and more necessary to try to understand them, to get them under control.
The problem is how to reach this aim. We should start to do so at school. We want pupils to learn more than only one-dimensional chains of causation. Our scientific approach centres around the problem: is it possible that pupils can learn something like "thinking in networks".

2. The Tool

To do so we used a tool for modelling and simulating. Together with software engineers [KLÜVER, WEDEKIND, WALSER] and a publisher [CORNELSEN SOFTWARE] we have developed the product, called MODUS. The characteristic feature of this product lies in the fact, that the whole process of modelling is done on a graphical screen: For the user it is not necessary to know anything about higher mathematics (e.g. differential equations).
On the screen we discriminate between four elements:
symbols, which describe a state (or level, stock)
symbols, which describe a rate (or converter, flow)
symbols, which describe a function and
symbols, which describe a constant;
these symbols will be linked with functional arrows.
After the input of the starting values and the rates the simulation can "run".
The graphical structure of MODUS is shown in the example in picture 1.

The tool MODUS differs from the well-known systems ITHINK and POWERSIM mainly in the fact, that MODUS runs on a MS-DOS-PC without any special devices - except a mouse. Moreover the graphical form of the objects is a special one. Following the recommendation of HERING et.al., there is only one kind of an arrow, which is used for rates and information. So in our system no "valves" or "clouds" are necessary.
Another difference is the possibility of integrating several models to one main model: thus a very great amount of rates and levels can be used to form one model.

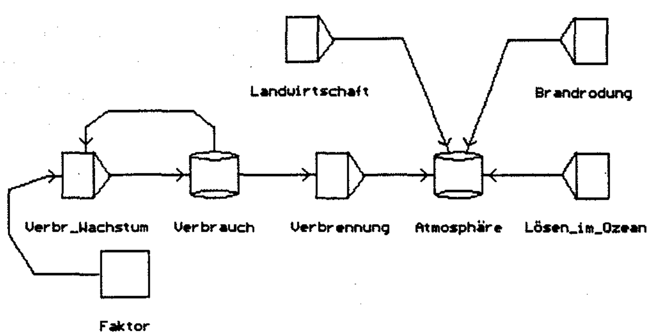
3. The educational units

With the help of this tool for modelling and simulating we have developed the following four units (subject in parentheses):

Ecosystem forest (ecological balance, biology)
Flows of carbon dioxide (chemistry)
Growth (mathematics)
"Tycoon"(economy)

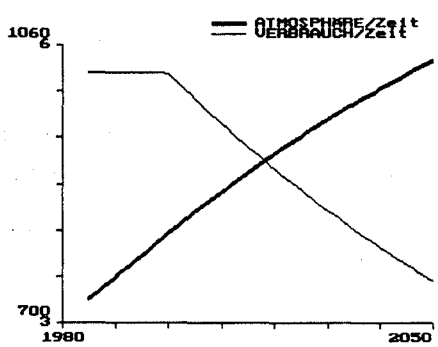
In the unit "ecosystem forest" - abbreviated in the following "ecosystem" - important anthropological influences on ecological systems will be discussed, e.g. interrelations between ants, woodpeckers and hawks. Out of the complex relationship between animals in the forest, at first only one population will be looked at: the woodpecker. The first model which is built with our tool describes the increase and decrease of the woodpecker population. Next the mutual dependence of several populations is considered, a first "food chain" is built. Later on certain chains are linked to a "food-network", wherein other populations, like titmouse, jay and pine-trees, are taken into amount additionally. Parameters can be changed and the consequences can be made visible on the screen.

The unit "Flows of Carbon-dioxide" intends to make the pupils familiar with the menacing problem of the climatic changes. At first a linear growth of CO_2 in the atmosphere, caused by burning fossil fuel, is modelled. The comparison with authentic measurements will lead to a model of exponential growth. After that all possible sources and drains of the CO_2-flows will expand the model, the links within the model will be shown. Political demands for the decrease of fossil fuel combustion can be checked by changing the special parameters, the pupils can immediately recognise the consequences graphically. A more detailed report is given by the author at another place [DÖNHOFF, WEIGEND]. Picture 1 shows the reduced model, the result of the simulation is shown in picture 2a, given a a decrease of 1 % per year, beginning in the year 2000; picture 2b shows the same changes, given 15 % decrease.

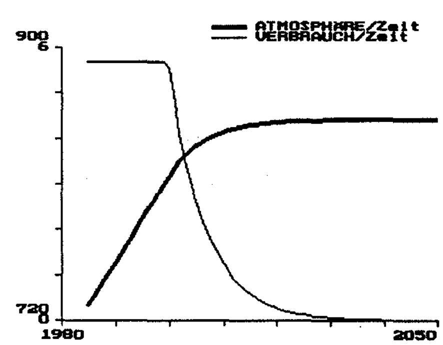


translations:
Landwirtschaft: agriculture
Brandrodung: slasg-and-burn
Verbr_Wachstum: Growth of consumption
Verbrauch: consumption
Verbrennung: combustion
Atmosphäre: atmosphere
Lösen_im _Ozean: dissolving in ocean
Faktor: factor
Zeit: time

Picture 1: A reduced model of carbon-dioxide-flows



Picture 2a: decrease 1% per year



Picture 2b: decrease 15% per year

"Growth" is the title of the third unit, in which some fundamental aspects of growth are treated. Furthermore a special view of mathematics will be presented, which focuses to a higher degree on applications: not reading texts or the insertion of certain values in fixed formulas are the main aims of this model unit, but the discussion and reflection of the process of modelling, qualitative reasoning, numerical simulating and comparison with authentic measurements.

The fourth unit, called "tycoon" - abbreviated in the following "economy" - tries to create more understanding in both, micro and macro economics; in other words: to give the pupils an insight into the whole system of supply and demand, of the role of money and interest rates play.

Whereas our main aim is to train pupils to "think in networks", in these four units we offer them an introduction into learning basic facts of the behaviour of complex systems:

1. The initial conditions of a complex system are very important for its following behaviour
2. Initial conditions are continuously changing through feed-back
3. Marginal conditions strongly influence the development of the system and can change themselves.
4. Non-linear systems depend on simple rules, but they are not predictable, because the initial conditions influence the development of the system to a much stronger extent.
5. Systems can - dependent on the above conditions - oscillate periodically, change or grow exponentially or logistically.

4. The empirical research

4.1 The design of the examination

This research was carried out by U. MAICHLE and E. KLIEME from the Bonn Institute for educational research. The pilot-study two years ago was published by the above mentioned psychologists.

Table 1 shows the composition of the whole sample, partitioned in kind of schools and units of instruction.

forest	economy	growth	flows	comparison groups	kind of school
3 groups 9/10 119 pupils 49 % girls	2 groups 9/10 70 pupils 39 % girls	2 groups 9/10 28 pupils	1 group 9 20 pupils 30 % girls	3 groups 9/10 50 pupils 60 % girls	Realschule
3 groups 9 79 pupils 54 % girls	3 groups 10 66 pupils 35 % girls	3 groups 10 64 pupils		1 group 9 18 pupils 39 % girls	Gymnasium
	1 group 9 15 pupils 27 % girls				Hauptschule

Table 1: Survey of the whole sample

The kernel is shown in the bold frame: Altogether there are 238 pupils in the classes 9 or 10, separated in 11 groups; 41 % of the pupils are girls.

An survey of the design of the whole examination is shown on table 2.

The Design of the Examination
- pupils -

presuppositions of learning	**learning process**	**success of learning**
thinking in systems - building systems - presenting systems and evaluating of interfering into systems (subject: breeding cattle or fish)	video-recording and analysis of teamwork at the computer (2 groups, 3 x 30 min)	**thinking in systems** - building systems - presenting systems and evaluating of interfering into systems (new subjects)
quantitative building of models (subject: power generation)	co-operation, reasoning on the point, system of dealing with the tasks, explorative learning, handling of MODUS	**building models** - presenting models - interpretation of a MODUS-model (subject: growth of population)
existing knowledge, related to a special subject conceptions, relations, mode of actions and coherence, ordinary models	recording the lessons evaluation by the teachers	**success of learning, related to a special subject**
points of interest computer-related experiences and attitudes; expectations from the project		**experiences with handling MODUS**
		attitudes towards computers satisfaction - with MODUS - with team-work - with the project
computer-aided problem-solving learning structuring and steering a dynamic system (12 pupils)		

Table 2: The research design

4.2 The items

To show the way, the items are built, some of them are translated in the appendix.
Pre-test and final test both contain one item about "Thinking in systems", an example is given by item no. 1 (traffic situation, appendix A).
The problem of building models is treated in the pre-test by a qualitative item about power-generation; in the final test by two items; one about the presentation of a model, here: water-reservoir (appendix B), another one about interpretation of a special MODUS-model, coping with "growth of population". In both tests there are subject-related questions included, requiring a certain knowledge, e.g. about forests.
Moreover both tests demand answers about experiences with the computers; some questions in the final test deal with satisfaction with the project.
During the whole process there are some video-recordings of the team-work at the computer, two groups , 3 times 30 minutes.

4.3 The results

Many detailed results will be given orally, e.g. about the activities of the pupils before starting the lessons (what are their expectations) and after finishing (retrospective view). Here are some details of the answers on the questionnaire, which are remarkable:

- the strong interest, specially of the pupils of the unit "forest" before starting the lessons, but the low participation in the course of the lesson.
- the pupils of the "forest"-lessons have a more positive engagement, compared with those of the "economy"-group.
- the comparatively low interest - especially of the girls in the lesson "economy" - in the announced instructions.

Also the expectations of the teachers are evaluated, separated in three parts concerning

- the educational process
- the units
- working with the tool MODUS

Table 3 a and b show the development of the performance between pre- and final test, for the both units separately. On the tables the mean values and the standard deviation in pre- and final test are presented. The significance is readable in the right column: " ** " means very significant; $p < 0.001$, " * " means significant, $p < 0.01$.

unit "forest"	pre-test	final test	significance
Interest in computers	mw 25.7 s (6.0)	26.2 (6.7)	n.s.
Systems: - prediction of behaviour	mw 6.7 s (2.5)	7.0 (2.2)	n.s.
- form of presentation	mw 3.5 s (1.0)	3.7 (0.9)	**
- level of net structure	mw 0.95 s (0.3)	1.17 (0.3)	**
Expert knowledge	mw 12.8 s (2.7)	13.5 (2.1)	*

Table 3 a: Comparison of the results of pre-test and final test (mean value and standard deviation) of the identical measured variables, related to the unit "forest"

unit "economy"	pre-test	final test	significance
Interest in computers	mw 25.8 s (5.1)	25.9 (6.3)	n.s.
Systems: - prediction of behaviour	mw 6.4 s (2.9)	6.8 (2.6)	n.s.
- form of presentation	mw 3.5 s (1.0)	3.5 (1.0)	n.s.
- level of net structure	mw 0.99 s (0.4)	1.10 (0.7)	n.s.
Expert knowledge	mw 13.3 s (2.1)	13.4 (1.9)	n.s.

Table 3 b: Comparison of the results of pre-test and final test (mean value and standard deviation) of the identical measured variables, related to the unit "economy"

Our special interests - related to something as "thinking in systems" - are the following variables:

a. prediction of behaviour
that means the ability to predict the effect of a defined intervention in a described system.

b. forms of presentation
this is the result of the evaluation of the free drawings of the structure of a system by the pupils. Therefore drawings are listed in a special way - according to their approach to the causal networks:

pictures of a scene - pictures of a stadium - tree-structures - causal networks.

c: level of net structure (German: *Vernetztheitsgrad)*
this variable refers to the evaluation of item 1: the number of the relations is divided through the number of elements of the causal chain, which the pupils had written down.

You can see that the "forest"-group with two variables show a very significant increase in performance; this is also true for their expert knowledge. Similar effects can not to be proved in the other group (economy).

One of the most interesting questions is: What are the reasons, that in one case an increase in performance could be observed, but not in the other one?
In order to approach an explanation, you can connect the most important variables (for performance and engagement) by arrows. The arrows represent the significance between pre- and final test. In this case you can see a tight network of arrows in the region of interest and engagement; hence it follows, that interest in computers and engagement with the subject have an influence on satisfaction and handling the tool. "Thinking in systems" is not touched by this.
If we regard the relations separately for both units, there is another conclusion: the expert knowledge has - in both cases - an effect on the ability of thinking in models, related to the unit (economy) an effect on the ability of thinking in systems too.

Results of the final test in the field: "model-thinking", applied to the items "growth of population" and "water-reservoir"

The results in the field "model-Thinking" were remarkably better than in a pilot-study (two years before with other pupils).
Only 14 % of the pupils were not able to give any model of the water-reservoir scenario (two years before 50 % couldn't do this).

The semantic and the syntactic correctness of the models has improved, compared with the pilot-study.

The further results can be divided into three aspects:

a. **how to deal with MODUS-symbols**
that means, whether the symbols and the syntactic rules are used correctly.

b. **formalism**
that means, whether the subject of the model with the regard to the contents is correct; e.g.:
Are the directions of the arrows correct? (in comparison to the flowing direction of the water);
Is the feed-back-loop drawn at the right place?
Are the levels treated as time-dependent variables?

c. **Understanding system dynamics**
Here are the questions about the "population-model", part a and b, summarised, in which statements about the development of population or growth should be given.

To a: how to deal with MODUS-symbols
The following table shows the results, divided in the two units (biology/economics). All numbers describe the frequency of correct results in percent.

kind of symbol	symbol correct in the sense of the given subject	symbol syntactically correct
level	56/58	72/65
rate	57/57	75/67
constant	48/37	75/49
function	19/8	29/20

An analysis shows that not all symbols are equally well-known, the members of the unit "forest" are able to deal better with the difficult symbols than those of the unit "economy".

To b. formalism
The following table shows the frequency (in percent) of the correct answers in both units:

feed-back in the population-model correctly drawn	27/0
feed-back in the water-reservoir-model, - drawn, somehow - positively correct	58/17 14/16
directions of the arrows (water-reservoir-model) correct	65/53
levels assumed as **not** time-dependent	35/15

Now as before deficiencies are very frequently and the unit "forest" has better results than the other one. (Exception: time-dependence of the variable. But this problem could be due to the ideas pupils have about variables)

To c. Understanding system dynamics
The following table shows the results of the item "growth of population":

a)	question 1 (boundless growth)	34/52
	question 2 (simulation of infection)	38/17
	question 5 (zero growth)	74/74
	question 7 (doubling)	46/26
b)	number of population (exponential)	67/59
	birth rate (constant value)	30/11

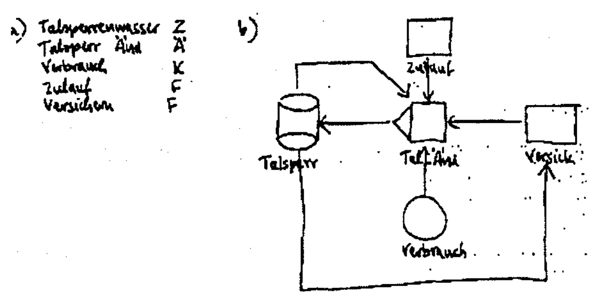
Again the "economic-pupils" show less performance. Exception: question a 1 about boundless growth. Perhaps the pupils could compare this problem with their well-known interest-rate-model; here the question of bounds could be discussed with the teacher!

Further results:

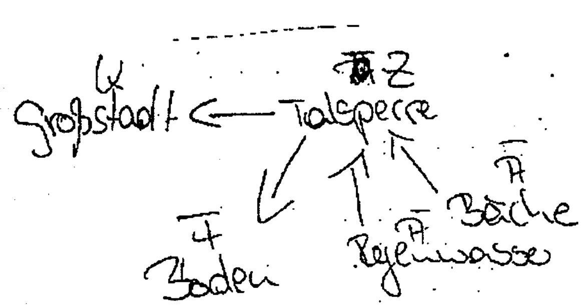
The differences between the two groups (biology/economics) are statistically significant. Between the different types of schools there are no significant differences.
The results in the array "understanding system dynamics" correlate with our items about the MORIS and HILUS (Both are tribes in Africa, living in ecological balance, and the pupils had to interfere with actions like increasing fertiliser, selling more products, improving water-supply and so on).

The ability of correct use of MODUS-symbols correlate with computer related interests and is better with those pupils, which had have high expectations of the lessons. Perhaps a question of motivation?

At the end a positive and a negative example of the result model about the water-reservoir, first the positive:



Talsperre:	water reservoire
Zulauf:	feed
Tal_Änd:	Changing of the reservoire
Versickern:	to ooze away



Großstadt:	city
Boden:	ground
Regenwasser:	rain fall
Bäche:	brookes

6. References

CORNELSEN SOFTWARE: MODUS, Grafisch interaktives Modellbildungssystem

DÖNHOFF, H.-U., WEIGEND, M.:Kohlenstoffhaushalt, Treibhauseffekt und Politik, Modellbildung und Simulation im Chemieunterricht, Computer und Unterricht 3/91, S. 33

HERING et. al.: Neue grafische Darstellungsmethode für Simulationsmodelle. Angewandte Informatik (1988), H. 2, S. 90-93

KLIEME, E., MAICHLE, U. : Erprobung eines Systems zur Modellbildung und Simulation im Unterricht. Informatik und Schule 1991, Informatik-Fachberichte, S. 251-258

VOLLMER, Gerhard: Hauptvortrag auf der Jahrestagung der Gesellschaft für die Didaktik der Chemie und Physik (GDCP) 1989 in Kassel, erschienen im Tagungsband

KLÜSER, J., WALSER; W., WEDEKIND, J.: Hierarchisches Modellieren komplexer Systeme. Informatik und Schule 1991, Informatik.Fachberichte, S. 244-250

7. Appendix

A.
Pre-test:
System thinking; building systems; here the translation of the text:

The number of the pupils at the Albert-Einstein-school decreases from year to year. One day the director invites teachers, pupils and parents to a hearing about the problem: "What is the reason why less pupils attend our school and what can we do against this?"
The director chairs the discussion and writes down the suggestions, arguments and counter-arguments, and writes them on the blackboard. In brackets he makes a note about the initiator of the argument (TE for teachers, PU for pupils and PA for parents).
The notes could look like this:

buying more computers - lessons are more attractive - more pupils (TE)
better marks - better chances to get a job - more pupils (PU)
better marks - lower reputation of the school - less pupils (PA)
more pupils - greater groups - lessons less attractive - less pupils (PA)

This was only an example. Here is the item:

In the town-hall of a small city the mayor invites to a hearing about the subject: **"What are the reasons for the increasingly chaotic traffic situation and what can we do against this?"**
Write down some arguments as in the above example.

B.
Final test:
model water reservoire

A water reservoir provides a city with drinking-water. The reservoir will be filled - more in winter, less in summer - by several brooks and by rainfall. The consumption of the city is nearly the same each month. In addition some water oozes away: about 0.1 % of the content of the water reservoir in a month is lost.
A model is to be built, which describes how the content of the water reservoir will change from month to month.

a) Please give all elements, which the model should contain! Note down, whether it is a rate, a level, a function or a constant.

b) Draw a model, which describes the relationship (by arrows); use the symbols of MODUS.