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# Students modelling environmental issues

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**Abstract** This work is based on a Brazilian project that aims to promote the use of a semi-quantitative tool with students (11 - 18 years old) in topics about local environmental problems. The paper presents the *VISQ* program, a network to analyse models, a set of tasks and three examples of models made by students. Results suggest that the *VISQ* program is suitable for use in Environmental Education as while working with the proposed tasks students thought at a system level becoming aware of some local environmental issues.

*Keywords*: Environmental education; Modelling; Semi-quantitative models

## Introduction

Teachers and students of the Physics Department at FURG (Fundação Universidade do Rio Grande) are developing a project that aims to improve the standard of science education in primary public schools through computer assisted learning. This paper reports part of the activities developed by the group. The paper presents the semi-quantitative tool *VISQ*, a network for data analysis and a set of real-world tasks for work by primary students. Also, it points out the potential of computational semi-quantitative modelling for environmental education to promote responsible citizenship.

## The context in Brazil

The school where the work was developed was created by a government project for teaching primary school children and is located in a very poor area of Rio Grande. The students are of a very low social class and, at the time this work was carried out, did not have access to a computer. In general, there are no classes with computers in Brazilian primary public schools and nowadays there is no place for the computer in the official curriculum.

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In most science classes there are no discussions about real local issues and science teachers usually work with static texts about specific topics. For example, they work with texts describing what insects are, but they do not consider insects in interaction with other living creatures and with the environment. They do not treat the environment systematically and do not promote thinking about environmental issues in the normal curriculum.

The city is located near the sea and fishing takes an important role in the local economy. Unfortunately the city has many sources of industrial pollution that have caused environmental and health problems of which students seem unaware.

Environmental education must relate to the main environmental issues, focussing on current situations which can motivate an intense awareness of citizenship. Children can get critical about their status as citizens, whilst using the computer animation as a tool to explore their local ecosystem, filtering and organizing knowledge from their mental models, heading towards more responsible citizenship.

The work presented in this paper has three dimensions:

- introducing students to the use of computers;
- promote local environmental system thinking;
- promote responsible citizenship through environmental education.

## *VISQ*

*VISQ* is the Portuguese acronym for 'Variáveis que Interagem de modo Semi-Quantitativo'*. It allows the creation of semi-quantitative models in both the human and natural sciences. *VISQ* uses the mathematics of neural networks to run causal diagrams on the computer screen. It gives a systematic interpretation to any causal diagram (see Miller *et al.*, 1990). It has been developed in *cT* (see Sherwood & Sherwood, 1989) and can be used with IBM-486 compatible computers and Macintosh Quadra 605.

The function of *VISQ* is to animate causal diagrams containing boxes (which represent variables) with vertical levels inside (which represent qualitative values) and to produce coloured simultaneous graphical output of variable qualitative values over time when the model is run.

According to Forrester (1973) the human mind seems able to formulate a structure (causal diagram) to fit separate pieces of information together. But when the pieces of the system have been assembled, the mind is nearly useless for anticipating the dynamic (that is, the time-varying) behaviour that the system implies. It is here that a computational tool like *VISQ* is invaluable.

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* It is an extended and adapted Brazilian version of IQON (Ogborn & Miller, 1994) which originated in the ESRC Tools for Exploratory Learning Project. It was programmed by Marcelo Resende Thielo. The translation of VISQ in English would be 'variables that interact in a semi-quantitative way'.

*VISQ tools*

The main window of the program, in Fig. 1. shows the icons that are the program functions.

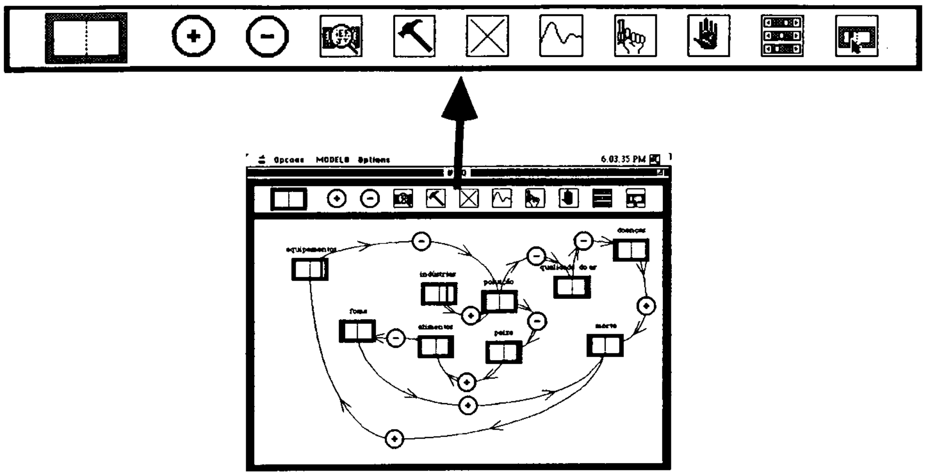

**Fig. 1.** *VISQ* main screen with the tools and a model

To make a model the student uses these icons as explained below.

From left to right, the *box* icon represents a variable or a constant; as many boxes as necessary can be build into the model.

*Positive* and *negative* icons represent the (causal) links that connect the boxes. A positive link means that if the first box increases its qualitative state, moving the vertical level to the right, or decreases it, moving to the left, the second box will present the same behaviour. A negative link means that the behaviour of the second box will be opposed to the behaviour of the first. If the first moves its level to the right, the second will move it to the left and vice-versa. The links also allow different weights to be applied, as indicated in Fig. 2.

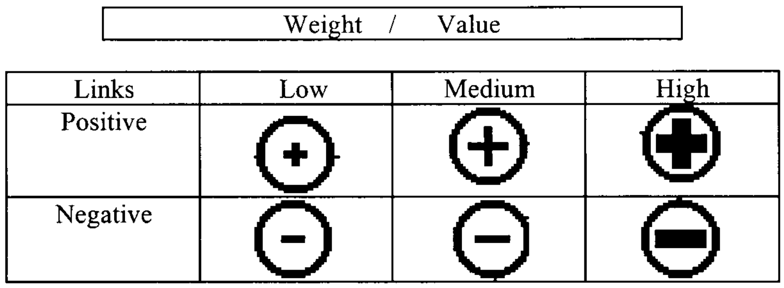


**Fig. 2.** Weights of positive and negative links

The *lens* icon makes possible to change the name of a selected variable and hypertext, with hot words, can be written inside any box.

The *hammer* icon can be used to isolate one variable and observe what happens without it.

The *X* icon has two functions: to delete a box or a link and to reset the model.
The *graph* icon is to observe graphs of temporal change of any variable and a phase diagram of one variable against another. It is possible to get up to six coloured simultaneous graphs of variables in a model.
The *gun* icon is to run a model and the graphical window.
The *hand* stops the model and the graphs.
The icon with *sliders* makes it possible to change speed, damping, time interval and scales of graphs.
The *box and pointer* icon gives semi-quantitative initial values of dependent and independent variables of a model.

## Networks for data analysis

The networks presented here are related to the ones reported by Kurtz dos Santos and Ogborn (1994). The network, Fig. 3, describes aspects of students' models on three dimensions and shows how *VISQ* models can be interpreted and analysed:

- the nature of the entities invoked;
- the nature and status of the links used and
- the final structure of the *VISQ* model.

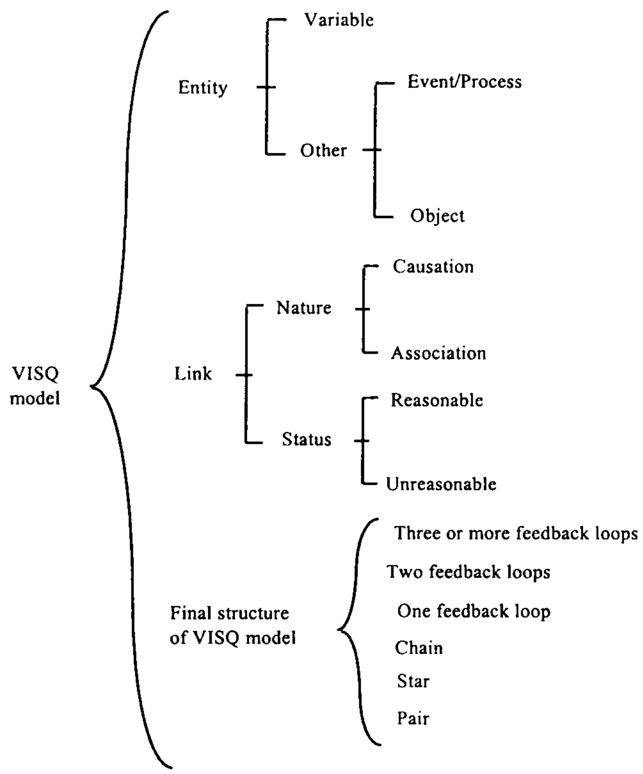


**Fig. 3.** Framework for a *VISQ* model in terms of entities, links and final structure of the model

The network, Fig. 4, describes aspects of students' models in which concerns the models' coherence and the process of model building. The networks in Figs. 3 and 4 follow the systemic network conventions in Bliss, Monk and Ogborn (1983).

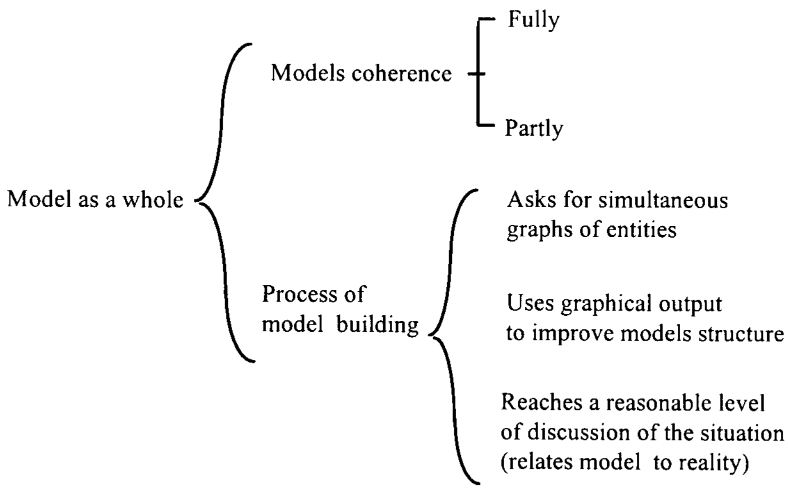


**Fig. 4.** Framework for a *VISQ* model as a whole in terms of models coherence and the model building process

*Classification of entities used*
The network describes entities as *variables* or *other*. A variable is a box that represents a level or a rate of change. For example, population and number of cars are variables. Foxes, representing the number or population of foxes is also a variable. Velocity, which is a rate of change, is a variable.

As 'other' there can be an event/process or object. A *process* is an action of some kind. For example, 'eating' is a process and it can be more or less intense or active, in other words, there is more or less of an action. Other examples are: burning fuel, eating grass and reproduction. An *event* is something that just happens, for example, starting eating or stopping eating. It is localised in time and is not considered in terms of any sort of quantity. Examples of events are: car moves away, foxes die and rabbits survive. It is not always possible to distinguish an entity as an event or process, in which case entities that could be considered as an event or process are grouped in one category named '*event/process*'.

There is an *object* when the 'variable' is seen as a thing or a person. Examples of objects are: Bob (name representing a person), Earth and Man.

*Kinds of links*
As an indicator of whether a link is reasonable or not in a *VISQ* model its *nature* and *status* are considered. The framework uses Bunge's (1963) ideas of directional/non directional and productivity, for analyzing the nature of the link as Causation or Association. The status of the link is also assessed as reasonable or unreasonable.

A link is reasonable if it shows the correct direction (production) or association between two entities and if it is correctly signed. A link is unreasonable if it shows a wrong direction or association between two entities. It is unreasonable, as well, if it has got at least one unsuitable entity or has the wrong sign. The judgment about what should be considered a correct/wrong direction/association, a wrong sign and an unsuitable entity will depend on the situation being modelled.

Reasonable links can be composed of variables, events/processes and objects as well, but have to make sense. For example, both the links

**rabbits ---------> + foxes**

and

**number of rabbits --------> + number of foxes**

could be considered reasonable, though the first link might be interpreted as composed only of objects, and the second of variables.

*Final structure of VISQ models*

The structures of the models produced, Fig. 5, were analyzed in terms of the number of feedback loops, chains and pairs. Amongst the models that lacked a feedback loop, it was possible to order structures as *one pair,* mainly *star* and *at least one chain.*

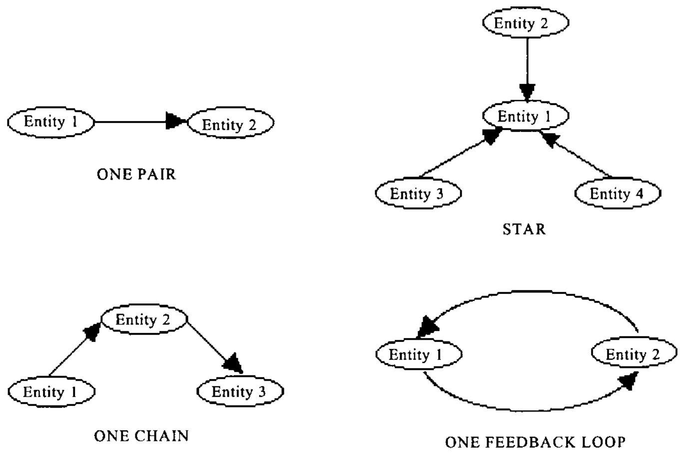


**Fig. 5.** Possible structures of *VISQ* models

*The model as a whole*

Models were also analyzed as a whole in terms of coherence and are classified as fully or partly coherent. A model is considered fully coherent when it shows the correct qualitative values of all its variables as expected in science and life. For example, it is expected that when 'pollution' gets high it will decrease the qualitative value of 'air quality'.

A schedule for systematic observation has been developed and during a session a grid was filled in showing the main aspects of the framework. The model building process was analyzed through observation of the student-computer interaction mainly in terms of use of simultaneous graphs of entities and use of graphical output to improve the model's structure. The level of discussion reached by the student was analysed by observation of the student-student interaction. A 'reasonable' level of discussion means that the students discussed correctly the interactions shown in the model, giving opinions and exchanging ideas about the model, relating verbally and spontaneously the model to reality. This aspect is related to the promotion of responsible citizenship.

### System thinking

The description of any large system will necessarily involve the interaction of several variables. The understanding of a model is related to the ability to manage all the relevant facets of a system, such as the dominant feedback loop.

Forrester (1990) considers that the feedback loop is the basic structural element in a system. He adds that the more complex systems are assemblies of interacting feedback loops. System level thinking relates to the understanding of causal feedback loops which represent reality. The perception of feedback indicates the match between people's mental models and the complexity of the environment.

It is suggested that the students are able to engage in system thinking:

- when they use variables in reasonable causal links, in fully coherent models with at least one feedback loop;
- when, during the building of the model, they ask for simultaneous graphs of variables, use the graphical outputs to improve the model structure, reach a reasonable level of discussion of the situation studied, and relate the model to reality.

In this work, besides introducing students to computing, their ability to engage in system thinking when working with topics related to their reality was studied. Students who think at a system level can be considered as having a higher level of perception of the situation (Kurtz dos Santos, 1992).

### The sample

The project has been working with 11 to 18 years old students, with an average age of 14.3 years old. These students had never worked with a computer before. The sample was biased in age and gender. There is a noticeably larger fraction of young females (11 to 15 years old, $p = 0.06$ - Fisher). Since the school is located in a very poor area of Rio Grande it contains, in the same classroom, students ranging from 11 to 18 years old. Differences in gender and age were not treated in this study and only the average pattern for the group as a whole are presented.

## The tasks

Instructional material was developed and tested with school students in various topics. The modelling tasks were preceded by comic strips and texts strongly related to the students' world.

The first task was presented by a comic strip of a child who did not like to take a daily shower and keep clean. The second was also a comic strip of a little Indian (Brazilian native) that is trying to fish in a polluted river without fish because of a polluter monster that is a plant. This comic strip is followed by a text about 'pollution in Rio Grande our industrial city' taken from a local newspaper. There are also two activities one presented by an 'ecological poem' and the other about 'bats'. The final activities were presented by texts also taken from local newspapers about 'recycling litter', 'rats' population explosion in Pelotas' and 'fishing of irregular sized prawns in Southern Brazil'.

After learning about the *VISQ* tool, the students were asked to think about the real situations, and express themselves with the tool. Each student worked, using the computer, once a week, in four sessions of 3 hours each.

## Main results

*Examples of models developed by students*

Figures 6, 8 and 9 show three examples of models developed by students for the proposed tasks which will be called: 'fishing', 'pollution' and 'rats'.

When the model runs it is possible to see the vertical level moving continually inside the boxes, and a coloured simultaneous graph of up to six variables against time. Although it is not possible to represent this dynamicism in a paper, an attempt will be made to discuss briefly the *dynamic behaviour* implied.

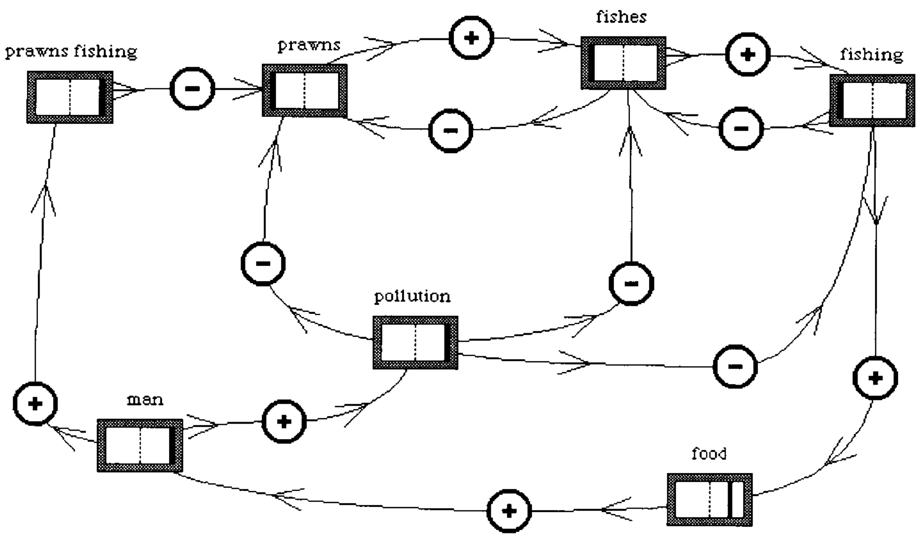


**Fig. 6.** A model for 'fishing of irregular size prawn in Southern Brazil'

The causal diagram was very well designed by the son of a fisherman. It has more than three feedback loops.

Figure 7 shows, in pairs, examples of the six possible dynamic behaviours for the task.

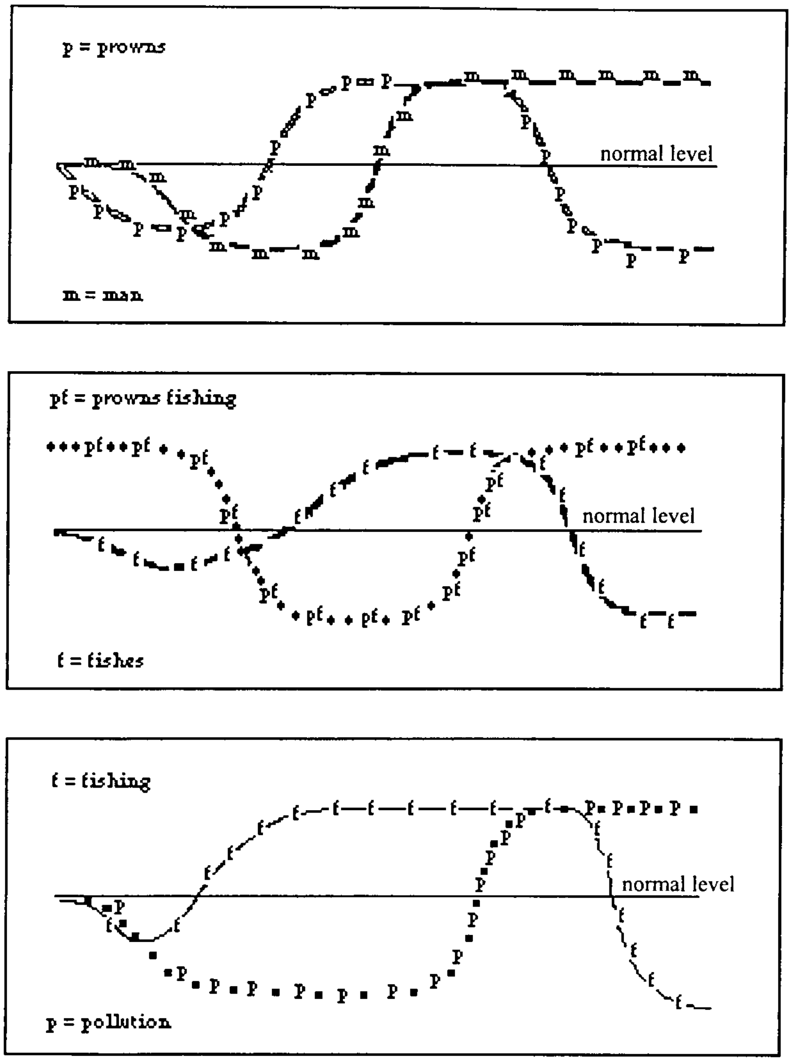


**Fig. 7.** Dynamic behaviours in *VISQ* for 'Fishing of irregular size prawn in Southern Brazil'.

Whilst fishing for prwans is high, because pollution is low, all the other entities are low, but increasing. When the prawn density start to go up, fish also go up and, consequently, fishing goes up. Because fish go up also the population (man) goes up. In the next cycle, when pollution starts to grow, fishes, prawns and fishing all go down.

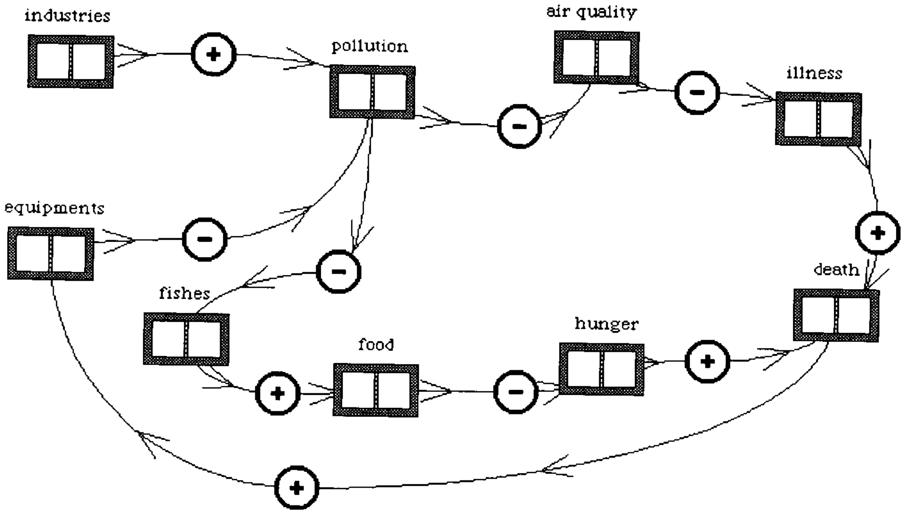


**Fig. 8.** A model for the 'comic strip about pollution' followed by a text about 'pollution in Rio Grande our industrial city'.
The entity 'Equipments' means the tools used to control pollution.

The model in Fig. 8 has two negative feedback loops and the pair *industries-pollution*. When the number of industries is above the normal level, pollution starts to increase, also increasing hunger, death and 'equipments for control'. Whilst pollution increases, fishes and food decrease. When pollution goes down, food and fishes start to increase what will decrease hunger and death.

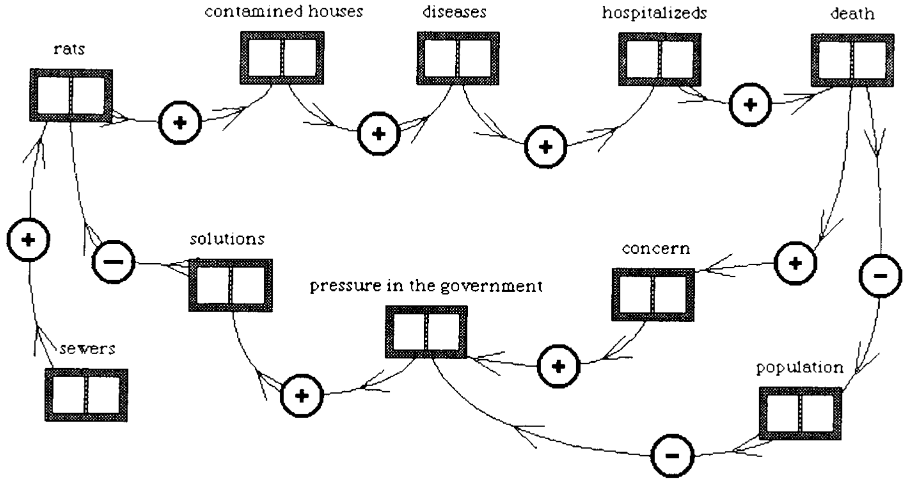


**Fig. 9.** A model for 'Rats population explosion' in Pelotas.

The model in Fig. 9 has two negative feedback loops and the pair *sewers-rats*. When the number of rats increases, diseases, death and pressure also increase, making the population (of people) go down.

*Entities used*

In general students developed models composed mainly of variables (average number ranging from four to seven per model) with less than one 'other' (events/processes and doubtful) per model. There is an average maximum number of about two objects for the comic strip task concerning environment. Examples of other (events/processes and doubtful) and objects are, respectively, 'planting' and 'river'.

*Nature and status of the links used*

The causal links used were mainly reasonable (average number between 3.6 and 7.2 per model), being followed by a low number of reasonable associations (maximum average number about 2.7 per model). Unreasonable causal links and unreasonable associations were rare (average number about one per model).

Examples of unreasonable causal link, reasonable association and unreasonable association are, respectively, 'litter decreases rats', 'recycling increases money' and 'seas decreases prawns'.

*Final structure of VISQ model*

In general students have used at least one feedback loop in any of the tasks, which is considered a positive aspect. The total average number of feedback loops was noticeable, since there is a minimum average number of 1.5 for the 'child that did not like to take a daily shower and keep clean' task and a maximum average number of 6.5 for the 'ecological poem' task. The 'fishing' task had an average number of 4.0 feedback loops. The average number of chains was maximum (2.0) for the 'child that did not like to take a daily shower and keep clean' task, maybe because it was placed as the first one in the instructional material. The 'pollution' task had 1.5 chains. Chains were rare for the other tasks.

*Coherence*

Models in general tended to be coherent for all tasks, with more than half of the students building fully coherent models. They tended to be fully coherent for the 'ecological poem' and 'fishing' tasks, with more than 70% of the students. About half of the students developed coherent models for the comic strip situations and for the 'bats' task.

*Model building*

During the model building process 90% of the students asked for simultaneous graphs of entities and more than 60% tended to use the graphical output to improve the models' structure. Also, more than 50% reached a reasonable level of discussion of the situations, in which concerns explaining the interactions showed in the model, giving opinions and exchanging ideas about the model and relating verbally and spontaneously the model to reality. Results suggest that the students reached an argumentation level that they did not have before.

*Teacher's opinion*

The science teacher thought that using *VISQ* to think about environmental issues was more effective than the conventional teaching based on written materials. According to the teacher, after the tasks with *VISQ*, when studying a topic students tended to point out every dynamic interaction possible to be modelled with the tool. Due to the use of *VISQ* students started to look in a different way at interactions presented in science classes.

It was a surprise for the teacher that students who usually did not take part in discussions in conventional classes had been very active, giving opinions and exchanging ideas, during the proposed tasks.

## Conclusion

Results suggest that the *VISQ* program is suitable for introducing students to the use of computers. After their first exposure to the program, poor students, who had never worked with a computer before, could demonstrate competence in some abilities related to modern computational systems. *VISQ* allowed students to be introduced to some 'Principles of Systems' such as the idea of cause-effect pairs, negative and positive feedback loops and the corresponding dynamic behaviour.

*Results suggest that in general the instructional material could promote system thinking.*

Students were presented with situations for modelling which related strongly to their reality. The results presented above can be summarised by saying that the models the students constructed had entities which were mainly variables, connected through reasonable causal links and that the models were coherent having at least one feedback loop. Besides, whilst constructing these models, students asked for simultaneous graphs of entities and used the graphical output to improve the model's structure. They related the model to reality and reached a reasonable level of discussion of the situations. Related to what was defined before, it can be said that these students probably engaged in system thinking.

*Results suggest that the VISQ program is suitable for use in environmental education.*

It seems that *VISQ* makes it possible for students to work with many variables that represent biological, social and economic aspects of a situation. This is why the program is suitable for working with complex systems in a semi-quantitative way.

After working with the set of tasks, students started to become aware of some environmental issues. It is hoped that they make use of this knowledge to understand their roles as agents that can transform society, heading for more responsible citizenship.

While observing the model running on the computer screen, students discussed and came to their conclusions. Such interactions promoted a better understanding of the situations studied, also showed critical thinking about environmental issues.

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