An Experiment Using The Hexagon Technique With Semiquantitative Computer Modelling[1]

Arion de Castro Kurtz dos Santos
Departamento de Física - Projeto PROFECOMP
Fundação Universidade Federal do Rio Grande – FURG - Brazil
arion@calvin.ocfis.furg.br

Fabio Ferrentini Sampaio
Núcleo de Computação Eletrônica
Universidade Federal do Rio de Janeiro – UFRJ - Brazil
ffs@nce.ufrj.br

Laércio Ferracioli
Laboratório de Tecnologias Interativas Aplicadas à Modelagem Cognitiva
Departamento de Física
Universidade Federal do Espírito Santo – UFES - Brazil
laercio@npd.ufes.br - laercio@cce.ufes.br

ABSTRACT
This paper reports a small experiment carried out with Master's degree students about the development of semiquantitative models first using the VISQ modelling system and STELLA afterwards. The conception, elaboration and representation of the models included a conceptual phase using the hexagon technique (idons – combination of idea and icon). A classical model, for coupled non-linear feedback loops, presented by Forrester (1990), was used as a parameter to define the activity and as a validation criteria. Results suggest that it seems recommendable to take students through a phase of developing the conceptual model with idons, before working with the computer (VISQ). Despite the fact that the model developed with STELLA is very simple when compared to Forrester's, results show that the students were able to construct a flux diagram taking into account the VISQ model which was previously developed.

KEY WORDS: Computer, Modelling, Model, Semiquantitative, Idons, Hexagon,VISQ, STELLA.

INTRODUCTION

This work is about the use of computer modelling systems in Science Education (Kurtz Dos Santos, C., 1992). Each of the authors of this article is carrying out work in this area with their research groups in different Brazilian Public Universities. In the end of 1998 there was a Research Seminar (II Seminar about Modelling and Representations in the Teaching-Learning Process) at the Laboratory of Applied Interactive Technologies to the Cognitive Modelling, at the Federal University of Espirito Santo (Brazil). Amongst the different activities of the Seminar, there was a short course on Principles of Systems in which the students had the opportunity to work with semiquantitative modelling using VISQ modelling system (Kurtz Dos Santos, C., 1995; Kurtz Dos Santos. C. et al., 1997) and (later) STELLA environment (Richmond, B. et al., 1987). The conception, elaboration and representation of the models had a conceptual phase using the technique of hexagons (Hodgson, A.m., 1994).

The association of Computer Science and Education has generated new strategies for teaching and learning, making headway with teachers, students and school. A relatively recent strategy of working with computers in education has been through Dynamic System that is based on the representation of ideas with causal diagrams (Roberts, N. et al., 1983) and its conversion to flow diagrams (Roberts, N. et al., 1983; Forrester, J. W., 1990; Kurtz dos Santos, A. C., 1995) to be used in quantitative computer modelling system such as STELLA. A semiquantitative computer modelling system called VISQ was developed based on the same principles. It uses the mathematics of neural networks to allow the animation of causal diagrams directly on the computer screen, with no need of using numbers.

VISQ programme can be considered as a tool for learning, making new ways of interaction with school contents possible, such as learning through the interpretation of simultaneous graphs, or through the discussion about the dynamic behavior of the elements during simulation, which would be - perhaps - impossible with pencil and paper.

There are two possible ways of working with modelling systems that are based on System Dynamics. The first one is through *exploratory* activities where the user explores a model or a representation of a teacher or researcher previously placed in the modelling system. In this case, the user interacts with simulations and is limited to the manipulation of parameters. According to Mandinach, and B. & Cline, H. F. (1994) the manipulation of parameters in existing models promotes basic research abilities such as the understanding of causality and variations, and can directly influence the acquisition of content knowledge, demanding a lower level of knowledge of the user. The other way is through *expressive* activities, where the user presents or exposes her/his vision or mental model of the situation that is being modelled. According to Mandinach, and B. & Cline, H. F. (1994) model building promotes more general problem solving abilities and transference of these abilities to other research areas.

This article presents results of a small introductory expressive actvity, where a small group of students develop models, using three tools: the hexagons, for the systemic thought, VISQ, for semiquantitative modelling and STELLA for the quantitative modelling for a situation already presented in the literature (Forrester' s one). In this study our intention was to find some evidences about the effect of the use of a tool over its predecessor and about the modelling process facilitation. The results presented here are certainly modest, not generalizable, but they point to possible enlargement of the research in future works.

2. VISQ – A SEMIQUANTITATIVE MODELLING SYSTEM

In this section we will make a brief introduction to the VISQ environment and its functions. VISQ is a semiquantitative modelling system in which the mathematics is hidden from the user, with no need of entering numbers, which means, it is suitable to be used by students of elementary levels.

VISQ - an acronym for Interacting variables in a semiquantitative way - (Kurtz Dos Santos, C., 1995; Kurtz Dos Santos. C. et al., 1997) was developed in cT (Sherwood, B. & the Sherwood, J. N., 1989) and can be used in IBM 486 (and superior) PC compatible and ' Macintosh Quadra 605 '. It uses the mathematics of neural networks to animate causal diagrams on the computer screen. The system supplies a systematic interpretation to any causal diagram, allowing the creation of semiquantitative models without taking into consideration the content, in natural as well as human sciences.

The neural network mathematics of VISQ works considering that each pair $X \rightarrow {}^{+}Y$ (X affects Y positively. See Figure 01) means that a change in the vertical level of Y is caused by the semiquantitative state or vertical level of X. In other words, X is the rate of change in Y.
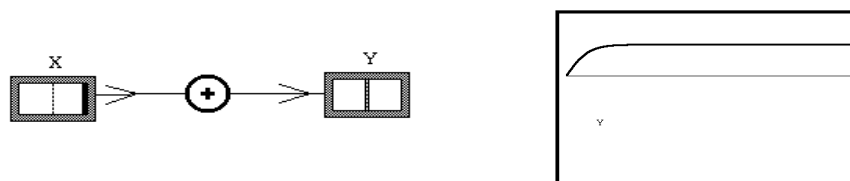

Figura 01 – X affects Y in a positive way, in VISQ, with its corresponding graphical output of Y against time. Note that Y increases until it stabilizes due to the squashing function used by the system. The horizontal line corresponds to the normal (resting) level and coincides with the time axis.

A positive pair as presented in Figure 1 would be described by the following equation

$$\frac{dY}{dt} = k*\left(1 - Y^2\right)*X - \left(p*Y\right)$$

where *k* and *p* are constants, limiting the levels of the involved variables to a variation between -1 and 1. Notice that the level of Y will eventually damp with the time. Thus, the causal diagrams or networks, will always evolve for a stationary state - equilibrium. A person analyzing a causal diagram made with pencil and paper will be able to foresee diverse dynamic behaviours as possible (viable) solutions. In VISQ, a causal diagram, will have a unique interpretation.

Although, a model in VISQ will be able to contain many boxes representing variables with negative and positive links between them, the mathematics is hidden from the user.

2.1 VISQ Functions

Through a direct manipulation interface, users can construct and simulate models that represent causal relations between entities of the world to be modelled. The result of the simulation is presented to the user in an interactive way (step by step) through the animation of objects presented on the computer screen. The main window of VISQ presents a tool bar that shows a set of all basic functions of the programme through icons (Figure 02).
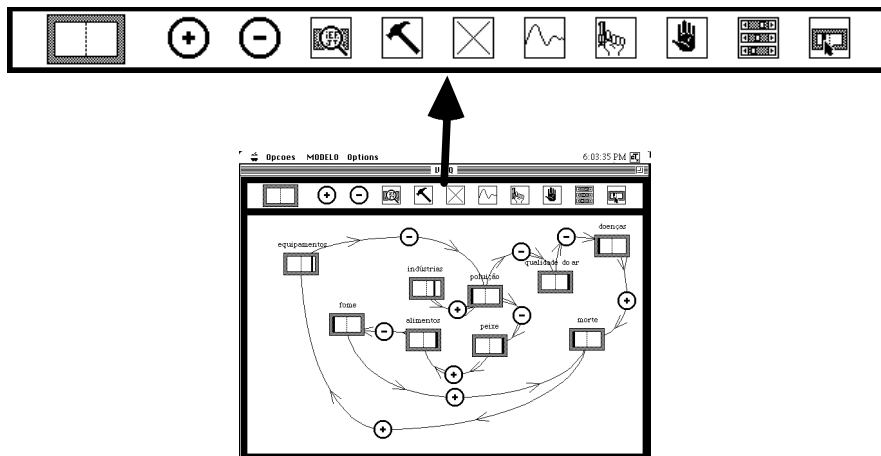

Figura 02 – VISQ main window showing the tool bar and a model

- Represents a variable or a constant in the model.

$\oplus$ $\ominus$ - They represent the types of causal links (positive and negative) that connect the boxes. The links can have different weights as shown in table 01. A link can be more intense than others in the same model.

Links	Low	Medium	High
Positive	⊕	⊕	⊕
Negative	⊖	⊖	⊖

Table 01 - Positive and minus weights of the links.

⊞ - The *lens* icon allows the change of names of a selected variable, as well as the writing of a hypertext document containing information about the variables and "hot words" to other variables.

🔨 - The *hammer* is used when it is desired to isolate a variable, allowing the observation of the model without it.

⊠ - Icon *X* has two functions: to delete a box or a link and to reset the model values.

∿ - The *Graph* icon allows the observation of time evolution of any variable and its phase diagram against another one. It is also possible to obtain up to six graphical outputs of different variables at the same time using different colors for each variable.

☝ - The *pistol* icon allows to simulate the model and to present the graphical window.

✋ - The *hand* icon stops the simulation of a model and a graph presentation.

▦ - The *Sliders* icon allows to change the speed, the damping, the time interval and the scales of the graphs.

▦ - The *box and arrow* icon supplies the semiquantitative initial values of dependent and independent variables of a model. This function can be used by placing the pointer directly on the vertical bar of the boxes and dragging it to the desired position.

Boxes and links can be dragged and rearranged on the screen, according to the user discretion, using the pointer and pressing mouse down.

3- THE TECHNIQUE OF HEXAGONS APPLIED TO SYSTEMS THINKING

In this section we briefly present the Hexagon technique which has been used for modellers working with enterprise modelling. In the present work, this technique was used by students in a training phase, previous to the semiquantitative modelling phase with VISQ.

Hodgson (1994) proposes a bridge between the generalistic thinking of decision makers and the specialized thinking of modellers, using the grouping of hexagons that allows the combination of an idea and an icon - what he called *idon*. The core idea of this method would be the semantic unit - the atomic object of thought. According to some authors, the construction of conceptual maps with idons (Novak & Gowin, 1984) is the process of making tacit models visible and available for the analysis of any person. The hexagons add dimensions of flexibility and speed to the constant rearranging that happens when the creative thought is made visible. The method proposed by Hodgson focuses on the development of the conceptual model, during the modelling process. Although the

hexagons originally proposed are magnetic and plastic, the hexagons used in this study were made of cardboard paper fixed on a flannel board for the development of the conceptual model.

The method makes it possible to think about new hexagons representing events, processes, objects or groups of concepts corresponding to variables that would be lacking to make the conceptual model more complete.
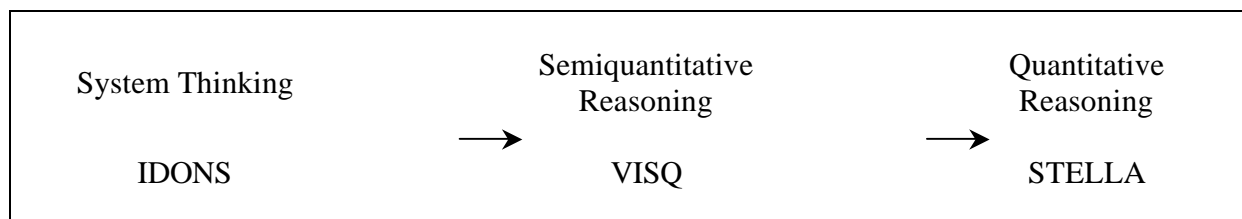The use of the hexagon technique can be questioned by more experienced modellers (Hodgson, 1994). However, it is being used by people who do not have any experience on modelling, but only an expertise in his/her field of work or a naive knowledge he/she wants to elicitate.

In the present study, a particular situation was presented through a short text to the students (See Section 6). Based on the content of the text and their own knowledge about the situation the students were asked to develop their models with idons. The class was divided into groups which worked for about 30 minutes. Afterwards, each group was invited to present and comment the final model developed with the hexagons to the large group.

4. The Problem

In this section we present the situation used for the development of the models and the sequence of modelling proposed in the study.
A situation governed by coupled non linear feedback links, studied by Forrester (1990, originally 1971) and presented in figure 03 was used in order to test the hypothesis of the use of the hexagrams grouping as a method to facilitate the construction of models in the computational modelling environment VISQ and STELLA. For doing so, we proposed the sequence of modelling presented below:

System Thinking	Semiquantitative Reasoning	Quantitative Reasoning
IDONS	$\rightarrow$ VISQ	$\rightarrow$ STELLA

In this case, the method of the hexagons – considered static when compared to computational animations - would be the first step for the construction of the computational

model before using VISQ and STELLA which are dynamic. Thus, in this design, VISQ is seen as a predecessor of the quantitative modelling with STELLA. The association of the idons with VISQ would appear as facilitator of the modelling process and it would allow a better knowledge on the system/process that will be modelled in a quantitative way. It is important to point out that there has been no systematic study about the bridge between the SEMIQUANTITATIVE REASONING and QUANTITATIVE REASONING regarding computational modelling so far.

Thus, such methodology was applied in the proposed activity, enabling each group of students to develop a conceptual model with idons for the same situation, which was followed by the construction of a model in VISQ and the construction of a model in STELLA.

The situation chosen to be modelled was very intuitive, consisting of the idea of a company that possesses its team of salesmen and, eventually, expands it depending on its production, that is, on the solicitation of its products by the customers. However, there is a delay between the solicitation and the delivery of the product, which is noticed by the customer. Depending on the delay, the customer can seek for another company, an attitude that would reflect in the salesmen recruiting.

The computational model developed by Forrester (1990) (Figure 03), here adapted for the computational modelling environment STELLA corresponding to the situation, was completely unknown to the students.
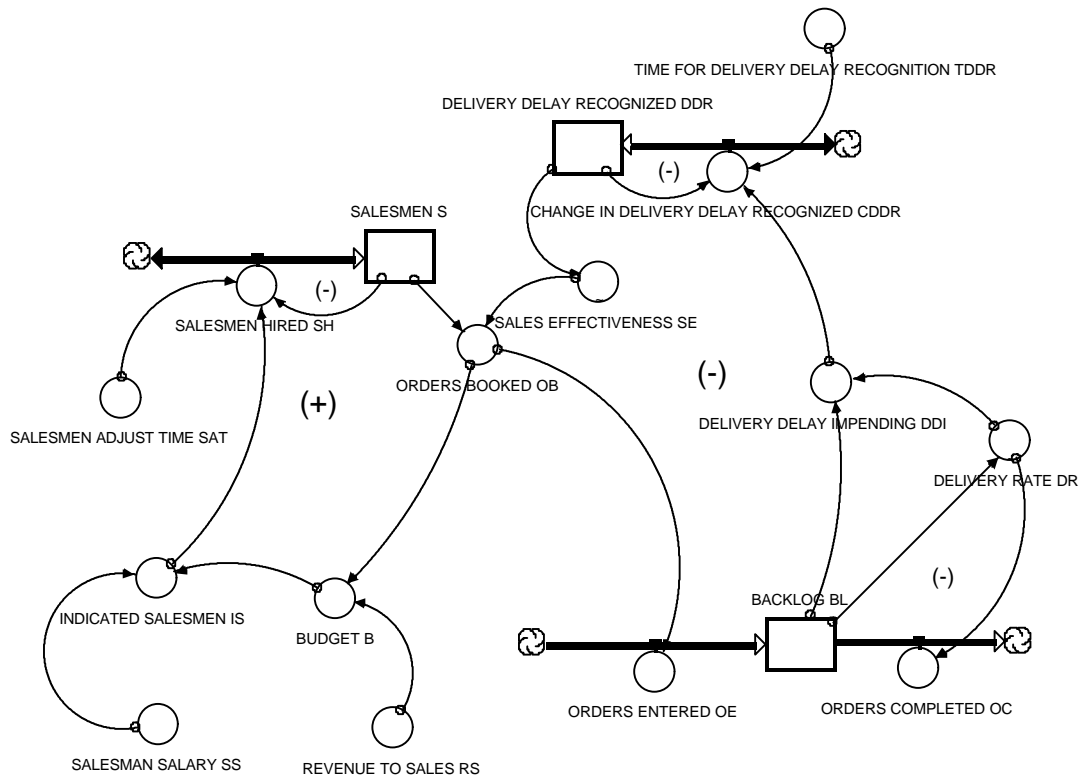
Figure 03 - *STELLA version of the model presented by Forrester (1971)*

As shown in the model of Figure 03 the growth of the sales that is eventually suppressed by the saturation of the production frequently happens through a system of relationships. In this model, the positive link of the left controls the number of salesmen. The link on the right is a second order negative one. The two levels in the largest negative link are ***Backlog (BL)*** (not yet attended) and ***Delivery Delay Recognized (DDR)***, that is related to the custumer's perception of the delay. Inside both links on the left and on the right, there are negative subordinate first order feedback link. The system consists of five feedback links - a larger positive, a larger negative, and three smaller negative. The loops represented with large (+) and (-), in Figure 03, correspond, respectively, to the larger positive and negative links.

A detailed description of the model can be obtained in Forrester (1990). In the present article, we will just present a qualitative description of the links, though in the Appendix a complete version of the models equations in STELLA can be found.

Next, we present some information for a better understanding of the Forrester 's model presented in Figure 03.

5. Understanding A Little More About the Forrester's Model

In this section we briefly present the description of the main larger positive and negative feedback links, aiming at the best understanding of the model in Figure 03, which is being used as reference in this study.

5. 1. The Positive Link

In the positive link, a fraction **RS** of the capital of the solicitations is available in the budget to pay expenses with the Salesmen. The suitable Salesmen are those that could be sustained by the budget. **Salesmen (S)** are contracted (or dismissed) to adjust the current value of the number of Salesmen in direction to the number of **Indicated Salesmen (IS)**. When the salesman sells more than enough to pay its own expenses, an expansion of the force of sales takes place.

The orders booked depend on the number of salesmen and of the sales effectiveness. The effectiveness of sales is a variable that depends on the time that the customer has to wait for the delivery of the product.

The budget for the salesman's monthly expenses is computed of the Orders Booked multiplied by the effective monetary units by unit of the product.

The Indicated salesmen are computed by the division of the monthly budget by the monthly expense with each salesman.

Salesmen and **Salesmen hired** form a small negative feedback link. The Salesmen hired rate adjusts the Salesmen in direction of the number of **Indicated Salesmen (IS)** that can be sustained by the budget. The goal **Indicated Salesmen (IS)** comes from outside of the negative link but it is a variable created by the positive link. It is the difference between Indicated Salesmen and Salesmen (current), that motivates the hiring of more Salesmen.

5. 2. The Negative Link

In the largest negative link of the right, the orders that enter are placed in a group of not filled solicitations that is decreased by the completed solicitations. The division between the **Backlog (BL)** and the **Delivery Rate (DR)** supplies the **Delivery Delay Impending (DDI)**. Delivery delay here means that there was not time enough of such delay being recognized and interfering in the market desire of purchase. A temporary delay intervenes before the delivery delay is recognized. The sales effectiveness depends on the recognition of the delay in the delivery of the product in such a way that a small delay will facilitate the sale of the product while a larger delay will make it difficult.

The delivery rate depends on the group of solicitations to represent the fact that the production capacity is limited.

The negative link as a whole tends to adjust the order rate to the maximum delivery rate (production capacity), whenever the force of sales is large enough to support the total production. If the order rate is larger than the maximum delivery rate, the group of solicitations will increase.

Inasmuch as the work demanded in each machine tends not to increase anymore, the delivery rate does not increase in proportion with the group of solicitations. An order rate larger than the delivery rate will only cause an increase in the group of solicitations without any growth in the delivery rate.

Out of the group of solicitations and of the delivery rate it is possible to deduce the "true" delay in the solicitations. But this is not generally known by the customer. Even after being aware of the delay in the delivery, the customer usually takes some time to redirect the search for other company. However, there is a time delay between the delay of factory delivery and the moment in that this affects the customer's readiness to request. The **Delivery Delay Recognized (DDR)** is represented as a delayed version of the **Delivery Delay Impending (DDI)**. The delay is created in two steps, first the rate in which the Change in Delivery Delay is Recognized **(CDDR)**, and then the Delivery Delay Recognition **(DDR)**. Notice that the way Forrester works with delay is not intuitive and demands a great modelling expertise.

If the goods were available for immediate delivery, each salesman in one month would manage to sell, on the average, an amount that would be determined by characteristics such as price, quality, readiness, adaptation to the customer's need, the maker's reputation, and sales ability. But when the customer realizes that he/she should wait for the delivery, more and more customers refuse to buy the goods, then reducing the average of the sales effectiveness.

6. Research Methodology

In this section we present the research methodology showing how the activities were carried out and making clear the data collection dynamics.

Physics and Computer Education Post-graduate students of Espirito Santo and Rio de Janeiro Federal Universities, respectively, were asked to split themselves naturally into four working groups. This paper focuses on the results of one of the groups only, describing the development of a conceptual model using hexagons, and the modelling with VISQ followed by STELLA. Our aim was to observe possible effects of using one tool compared to the one used before in terms of facilitating the modelling process.

The following text (original in Portuguese) was used to present a situation to be modelled with hexagons:

" A company has a number of Salesmen which is increased according to production, or demand of products made by clients. Nevertheless, there is a delay between the order of the product and its delivery, noticed by the client. Depending on the delay, the client may even look for another supplier, jeopardizing the hiring of new Salesmen".

The development of a conceptual model makes it possible to think about the main events, objects, processes, concepts to be translated into variables and then establish the possible interactions present in the studied situation. The translation of the conceptual model into a semiquantitative one makes it possible, through simulation, to intuit about tendencies of expected dynamic behaviours and possible mathematical relations among variables. The construction of a quantitative model, with STELLA, presupposes a rigorous study which will be based on an iterative process involving the conceptual and semiquantitative representations to the understanding of the passage which moves from semiquantitative to quantitative reasoning.

The groups were asked to work during a certain time and try to reach an agreement on their conceptual model with hexagons. Afterwards, the models were presented with the help of a flannel board on which cardboard paper hexagons were fixed. Each group explained the structure and entities of the conceptual model to the large group. All the detailed recordos about the models presented were kept.

In the following activity, students were asked to develop a semiquantitative model using VISQ corresponding to the previous model with hexagons, which had just been presented to the large group. Students worked during a certain period of time, discussing within small groups and saving computer versions of their models in VISQ which were given to the researchers.

During VISQ model construction process, all groups were encouraged, in every developmental phase, to ask for coloured superposed graphs of the main variables of the model. It is important to point out that VISQ allows the simultaneous observation of up to six variables of a model at the same graphical window. Based on the graphical analysis students improved the structure of the model.

We believe that the superposition of coloured graphs of variables and the consequent improvement of the model structure, as shown in the graphical analysis, as well as the fact that no mathematical knowledge is needed to use VISQ, are aspects that add support to the use of computers in Education, in our case the VISQ programme, and show advantages over the use of hexagons or other static methods of representation.

Following the activities with idons and VISQ, students were asked to develop a model in STELLA corresponding to the one constructed with VISQ. The groups spent some time mapping in STELLA. The attribution of numbers and algebraic equations for running models, giving back numerical and graphical output, showed to be extremely difficult in STELLA. According to Kurtz dos Santos, A. C. (1992) STELLA metaphor is very

demanding in terms of world conceptions, which influences the idea students have about variables. Differently from VISQ, that allows students to freely choose entities, STELLA structure works like a straight jacket, forcing students to use the idea or conception of *rates of change*, which means that in order to model with STELLA an entity must be thought as a rate or a level. When the student is not familiar with such conceptions, he/she is not able to express himself/herself successfully with the tool. Aware of the difficulties in using STELLA, we searched for some evidences on the process of moving from modelling in VISQ to modelling in STELLA, considering the coherence of STELLA diagram in relation to models developed before with idons and VISQ. The computer versions of models developed in STELLA were saved and given to the researchers.

7. Results of the Modelling Research Methodology to the Proposed Situation

In this section we present the models developed by students and the corresponding discussion about its characteristics.

7. 1. Development of conceptual model with hexagons

The studied group was composed of three students and spent about 30 minutes for reaching an agreement about the conceptual model which would be translated into idons and whose representation by hexagons is showed in figure 04.
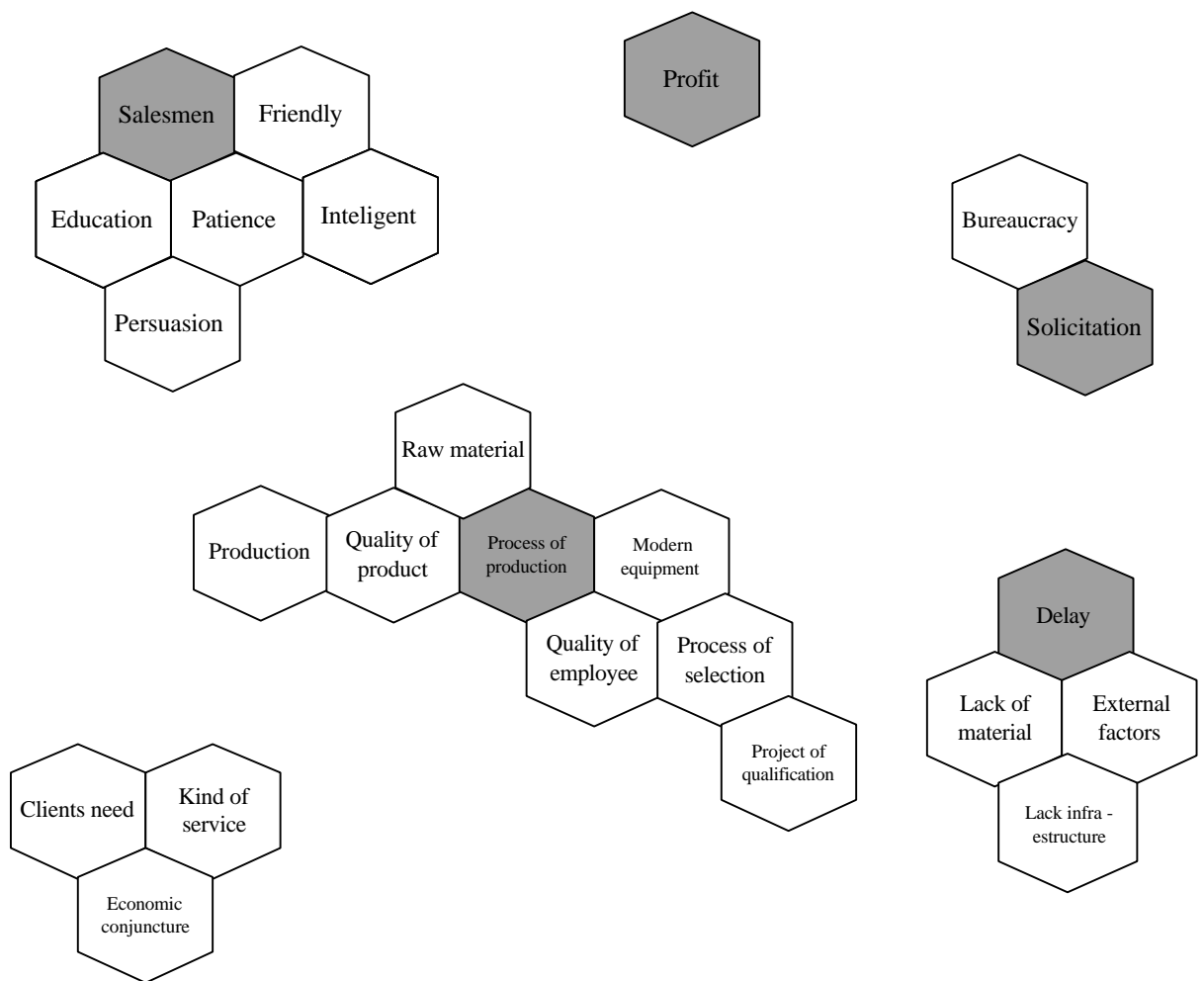
Figure 04 – Conceptual Model with Hexagons made by a Group of Students.

The conceptual model is composed of six blocks of hexagrams or hives that represent the groups of related concepts. We can identify groups related to six concepts:

1. Group representing the Salesmen;
2. Group composed by a single hexagon representing the profit;
3. Group related to solicitations;
4. Group of the largest hive which represents the product or process of production;
5. Group representing the delay, to the right of the largest hive and
6. Group related to the external world, on the left of the largest hive.

According to the discussion about Forrester's model presented in figure 03, STELLA

model has the following fundamental blocks: one related to the Salesmen, one to the group of solicitations and another more sophisticated one representing the delay. Thus, it can be noticed that the intuitive conceptual model developed by the students includes a range of concepts needed for a later quantitative modelling with STELLA.

Although the students did not draw arrows showing the relationships amongst hexagons of distinct hives, it was possible to observe the elicitation of such relations during the oral presentation of the conceptual models.

7. 2. Modelling with VISQ

Figure 05, shows the group's VISQ model which corresponds to the conceptual model presented in figure 04.
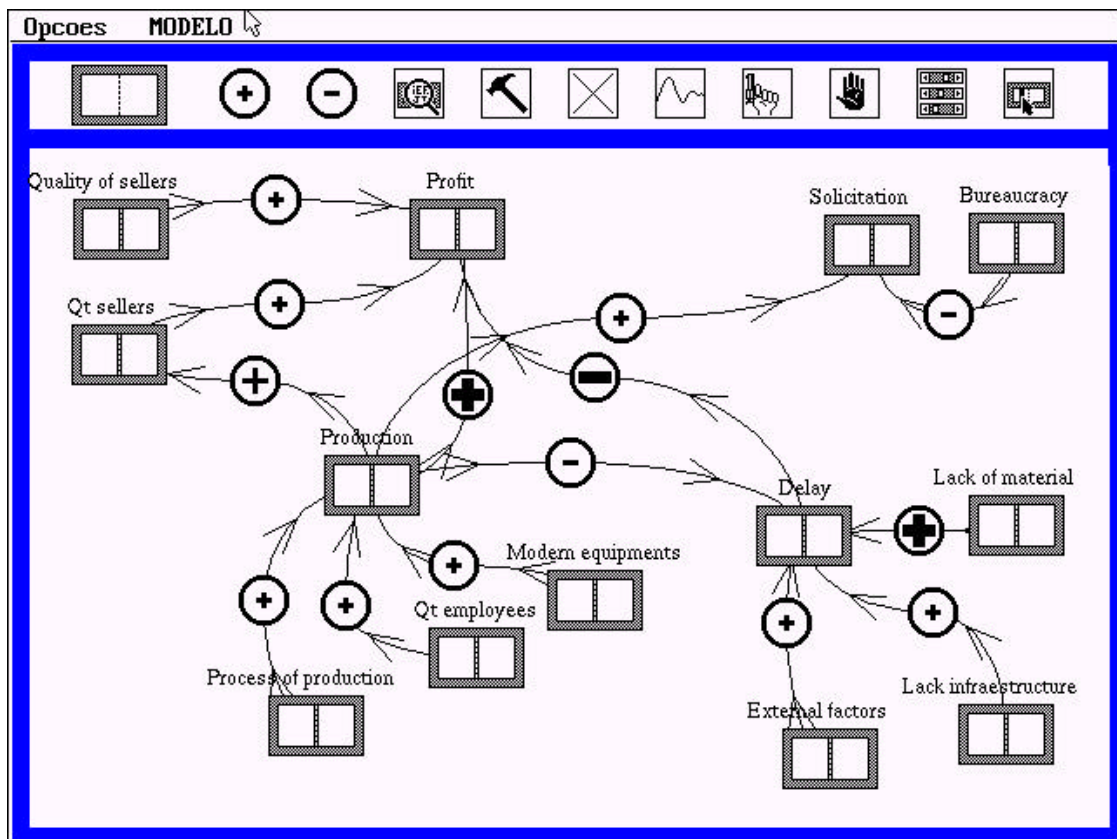

Figure 05 – VISQ model which corresponds to the conceptual model developed by the studied group.

A detailed study of the intuitive conceptual models and VISQ semiquantitative models

shows that, apart from the hive composed by the hexagons <kind of service>, <clients need> and <economic conjuncture>, interpreted as related to links with the external world, there is a topological preservation of the conceptual models with hexagons and of VISQ semiquantitative model. This result seems to reveal that the conceptual model guided the development of VISQ semiquantitative model in some way.

For better understanding of VISQ model structure presented in figure 05, the spacial correspondence between this model and the conceptual one with hexagons presented in figure 04 was broken and the VISQ semiquantitative model was rearranged as presented in figure 06.
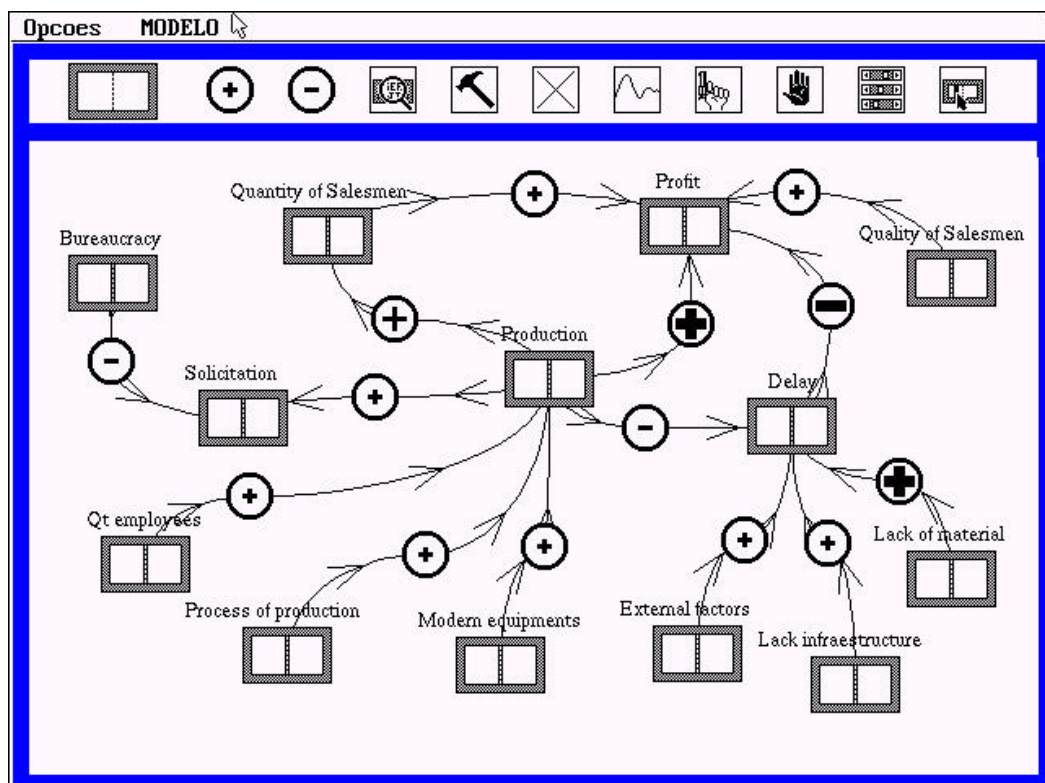

Figure 06 - Rearranged VISQ model to better understanding its structure.

This new arrangement makes it possible to observe that the model does not contain any feedback loop: it is basically composed of *chains*, e. g. |modern equipments| → |production| → |quantity of Salesmen| → |profit|, and the *pairs*, e. g. |lack of material| → |delay|. Another observation is that there are 08 (eight) independent variables which are not affected by others: |quality of Salesmen|, |lack of material|, |lack of infrastructure|, |external

factors|, |modern equipments|, |process of production|, |quantity of employees|, |bureaucracy|. We can say that the model in general was rich in variables but poor in structure, due to the absence of feedback.

In figure 04 conceptual model, besides the concept <Salesmen> qualities such as <intellect>, <friendly>, <patience>, <persuasion> and <education> were also considered. These five hexagons were considered in VISQ as a single variable: |quality of Salesmen|.

The hexagons <quality of employee>, <process of selection> and <project of qualification> appeared in VISQ as a single variable |quantity of employees| . The justification for that would be that the employees are hired through a process of selection and have their qualification guided by the company's project.

The hexagons <raw material>, <quality of product> and <process of production> were grouped in a single variable in VISQ: |process of production|. The kind of raw material used is related to the quality of the product and everything is part of the production process.

The remaining hexagons correspond exactly to the final variables in VISQ.

While running the model of figure 05 aiming at distincting initial semiquantitative values of independent variables (vertical levels of boxes), students verified that it showed *coherence* in terms of dynamic behaviour of the main variables. For example, when a company was considered efficient the delay dropped, resulting in a higher production rate in more profit. We can say that the obtained semiquantitative behaviour was partly in accordance with the more sofisticated behaviour in STELLA, which can be considered a way of validating the work done by the students.

7. 3. Modelling with STELLA

See in figure 07 the model developed by the studied group for the situation in figure 05.
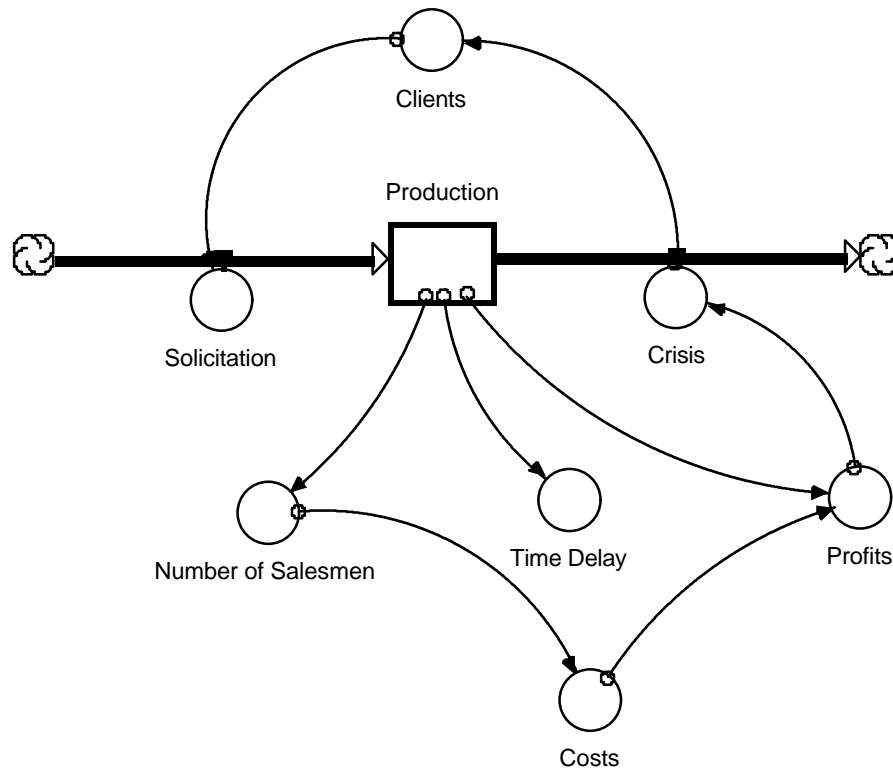
Figure 07 – STELLA model developed by the studied group.

Comparing the model in figure 03 to the ones in figures 04 and 06 we verify a similarity between them. Comparing to figure 07 we see that the topology was partly destroyed. The topology was preserved in only three links ('production' → 'number of Salesmen', 'production' → 'delay' and 'production' → 'profit'). There are three new variables which do not appear in VISQ model ('clients', 'crises' and 'costs'). There are four new links that do not exist in VISQ model, embodying those variables. A positive aspect was the inversion in the direction of causality in STELLA, from 'solicitation' to 'production' and not from 'production' to 'solicitation', inappropriately represented in VISQ model, what makes evident a refinement of the students' reasoning motivated probably by STELLA methaphor.

In modelling with STELLA students took the VISQ model in figure 05 based on the idons in figure 04 as working basis. In figure 07 STELLA model the conversors 'number of salesmen', 'profit' and 'delay' correspond exactly to the hexagons in figure 04 and the variables in figure 05. The conversor 'costs' refers to the process of production and does not appear explicitly in any hexagon. The rate 'solicitation' and the level 'production' correspond to hexagons of distinct groups in figure 04 and to variables in figure 05. The conversor 'clients' does not appear either in figure 04 nor in figure 05 and was used in figure 07 as a determinant factor of 'solicitations' and as affected by 'crisis'. There is a coherence in STELLA diagram in terms of the models with idons and in VISQ taking into account that the 'clients' lead to 'solicitations' (input rate) that will increase the 'production' (which is a level). 'Production' decreases due to 'crisis' (output rate). 'Crisis' affects the 'clients' and the 'production' changes the 'number of salesmen' and 'profit'.

It seems that the process of moving from modelling in VISQ to modelling in STELLA cannot be taken for granted and probably demands complementary activities to be given to the students. Once the intuitive conceptual model already has the groups of concepts necessary for a future quantitative modelling with STELLA, the passage from VISQ to STELLA presupposes a careful reduction of variables and the placing of the remaining ones inside STELLA metaphor. This appears to be the main factor responsible for the insipid character of the developed model (in figure 07) and the consequent destruction of the intuitive original topology.
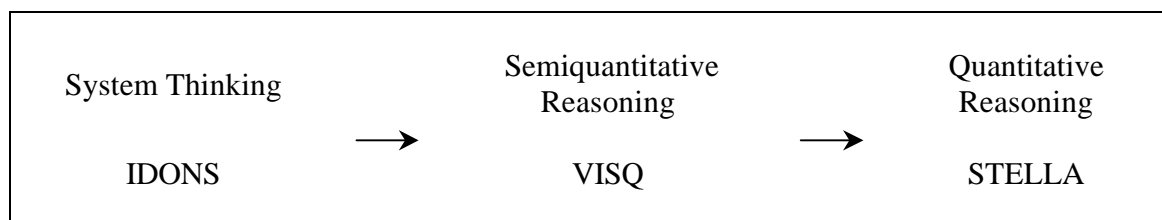
8. Conclusion

Taking into account that this activity was exploratory and introductory, with a small number of students, the results shall not be generalised, and only point to some tendencies that need to be further explored in future research.

We can say that, in the present study, the conceptual modelling with idons helped the students to define a specific topology to the model that would be constructed in VISQ. The model with idons allowed students to work intuitively with conceptual before they could be considered variables. In working with VISQ some hexagons were carefully reduced and groups of hexagons were added in a single variable. Results suggest that it seems recommendable to take students through a phase of developing a conceptual model with idons, before working with the computer (VISQ).

Forrester's work was used as a parameter to define an activity and as a criterion for model validation. Given the sophistication of such model, we were not expecting students to be able of developing a similar model with STELLA. We understand that the attempt of modelling in STELLA, having VISQ model as a basis, even only as a mapping of rates and levels, was worth it. The model or map developed in STELLA by the studied group was of a very insipid character compared to the model in figure 03, but had some relation with the model with idons in figure 04 and with VISQ model in figure 05. The too demanding STELLA metaphor may have destroyed the intuitive original topology, but there was still a correspondence between hexagons and STELLA variables.

Thus, for the sequence presented at the beginning of the article

System Thinking	$\longrightarrow$	Semiquantitative Reasoning	$\longrightarrow$	Quantitative Reasoning
IDONS		VISQ		STELLA

We can say that there is enough evidence to say that the thinking through idons is an interesting tool to be used before VISQ.
Nevertheless, more research is needed to determine in which way the development of semiquantitative models in VISQ can help the development of quantitative models in STELLA. There is an indication that maybe it is possible to develop a flux diagram in STELLA having a VISQ model as basis, but the question of STELLA model quantification could not be developed in such study.

Readers interested in STELLA will find more information about it, as well as a demo version of STELLA Research 6.0 in http://www.hps-inc.com/new/version6.htm .

9. Acknowledgements

10. Bibliography

Forrester, J. W. (1990) *Principles of Systems*, Productivity Press, Portland, Oregon.

Hodgson, A.M. (1994) Hexagons for Systems Thinking. In MORECROFT J. D. W. & STERMAN, J. D. (eds) *Modelling for Learning Organizations*, Productivity Press, Portland, Oregon.

Kurtz dos Santos, A. C. (1992) Computational Modellign in Science Education: A Study of Students' Ability to Manage some Different Approaches to Modelling, Unpublished PhD Thesis, Institute of Education, University of London.

Kurtz dos Santos, A. C. (1995) *Introdução à Modelagem Computacional na Educação*. Editora da FURG, Rio Grande.

Kurtz dos Santos, A. C., Thielo, M. R. & Kleer, A. A. (1997) Students modelling environmental issues. *Journal of Computer Assisted Learning*, Vol. 13, Nº 1, March.

Mandinach, E. B. & Cline, H. F. (1994) *Classroom Dynamics - Implementing a Technology-Based Learning Environment. Lawrence.* Erlbaum Associates, Publishers, Hillsdale, New Jersey.

Novack, J. D. & Gowin, D. B. (1983) Learning How to Learn. Cambridge: Cambridge University Press.

Richmond, B. et al. (1987) *An Academic User's Guide to STELLA*. High Performance System, Inc. Lyme.

Roberts, N. et al. (1983) *Introduction to Computer Simulation - a System Dynamics Modelling Approach.* Addison Wesley, New York.

Sherwood, B. A. & Sherwood, J. N. (1989) *cT Version 2. 0.* Falcon Software Inc. Wentworth, N. H.

Appendix: STELLA model equations

BACKLOG_BL(t) = BACKLOG_BL(t - dt) + (ORDERS_ENTERED_OE - ORDERS_COMPLETED_OC) * dt
INIT BACKLOG_BL = 8000
INFLOWS:
ORDERS_ENTERED_OE = ORDERS_BOOKED_OB
OUTFLOWS:
ORDERS_COMPLETED_OC = DELIVERY_RATE_DR
DELIVERY_DELAY_RECOGNIZED_DDR(t) =
DELIVERY_DELAY_RECOGNIZED_DDR(t - dt) +
(CHANGE_IN_DELIVERY_DELAY_RECOGNIZED_CDDR) * dt
INIT DELIVERY_DELAY_RECOGNIZED_DDR = 2
INFLOWS:
CHANGE_IN_DELIVERY_DELAY_RECOGNIZED_CDDR =
(1/TIME_FOR_DELIVERY_DELAY_RECOGNITION_TDDR)*(DELIVERY_DELAY_
IMPENDING_DDI-DELIVERY_DELAY_RECOGNIZED_DDR)
SALESMEN_S(t) = SALESMEN_S(t - dt) + (SALESMEN_HIRED_SH) * dt
INIT SALESMEN_S = 10

INFLOWS:

SALESMEN_HIRED_SH =
(1/SALESMEN_ADJUST_TIME_SAT)*(INDICATED_SALESMEN_IS-SALESMEN_S)
BUDGET_B = ORDERS_BOOKED_OB*REVENUE_TO_SALES_RS
DELIVERY_DELAY_IMPENDING_DDI = BACKLOG_BL/DELIVERY_RATE_DR
INDICATED_SALESMEN_IS = BUDGET_B/SALESMAN_SALARY_SS
ORDERS_BOOKED_OB = SALESMEN_S*SALES_EFFECTIVENESS_SE
REVENUE_TO_SALES_RS = 10
SALESMAN_SALARY_SS = 2000
SALESMEN_ADJUST_TIME_SAT = 20
TIME_FOR_DELIVERY_DELAY_RECOGNITION_TDDR = 6
DELIVERY_RATE_DR = GRAPH(BACKLOG_BL)
(0.00, 0.00), (10000, 5000), (20000, 10000), (30000, 13500), (40000, 16000), (50000, 17500), (60000, 18500), (70000, 19000), (80000, 19500), (90000, 19575), (100000, 20000)
SALES_EFFECTIVENESS_SE = GRAPH(DELIVERY_DELAY_RECOGNIZED_DDR)
(0.00, 400), (0.5, 400), (1.00, 385), (1.50, 370), (2.00, 350), (2.50, 320), (3.00, 289), (3.50, 250), (4.00, 209), (4.50, 178), (5.00, 150), (5.50, 120), (6.00, 100)