Using Simulations of NetLogo as a Tool for Introducing Greek High-School Students to Eco-Systemic Thinking

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Abstract

In this paper, the effectiveness of the NetLogo programming environment is investigated, as regards assisting students (of various levels of achievement) of the Greek Higher Secondary Education, to understand how some simple ecosystems are structured and to model the systemic behaviour of such ecosystems by conceptualising their Complexity features. This paper is part of a wider research on teaching Ecosystem Complexity to high-school students, with the use of Information and Communication Technologies (ICT's). Specific models from the NetLogo Models' Library were used and students of the 2nd class of the Greek Lyceum (aged between 16 and 17) participated in the investigation. Apart from oral instruction, the students were asked to run the NetLogo simulations and do specific things with the models, answering simultaneously questions on worksheets provided to them. The studying and the evaluation of the worksheets by the researchers, as well as the post- instructional evaluation of the students, both oral (by means of cassettes) and written, through the use of an evaluation sheet, gave research findings that proved to be encouraging in that: a) students developed a greater understanding of the complex/systemic behaviour of ecosystems and b) they were capable, to a certain extent, of analyzing the systemic relations within simple ecosystems and built analogous relations in other, also simple, ecosystems.

Keywords Eco-Systemic Thinking, Education, NetLogo, Classroom, Complexity.

1 Introduction

The aim of the current research was to investigate whether high-school students' ability to achieve systemic thinking, and in particular eco-systemic thinking, could be slightly enforced and enhanced with the use of a specific software. Systems-thinking is defined in many ways, and one way of defining it, is as: "the ability to understand and interpret Complex Systems" [1]. Ecosystems are considered Complex systems with respect to **three essential properties** of them [2]: (i) sustained diversity and individuality of components, (ii) localized interactions among these components and (iii) an autonomous process that selects from these components - based on the results of local interactions - a subset for replication or enhancement. Taking these properties into consideration, it becomes apparent that eco-systems' thinking is a perfectly valid expression of systemic thinking. Many attempts, on the other hand, have been made so far in the literature to define what "modeling" of systems - and especially of Complex systems [4]. Even in the case that the famous alternative definition of the (so called) Complex **"Adaptive"** Systems (CAS's) (i.e. complex systems that "learn" as time evolves and modify their comportment) given by Holland (1995)[5] is used, attributing to such systems four basic properties: aggregation, non- linearity, diversity and flows, it becomes again obvious that ecosystems are indeed complex (adaptive) systems, which "learn" as time evolves, and thus, eco-systemic thinking is a form of systemic thinking and eco-systemic modeling an aspect of systems' modeling. Ecosystems are also, in a variety of other aspects "complex systems" [6] and can, therefore, be treated through their complexity characteristics, which also reveal systemic behavior, since the dynamics within complex systems have all the characteristics of system dynamics [7].

In this respect, the current research examines whether students, of Greek Upper Secondary Education, can understand the systemic features of a simple model-ecosystem, consisting of **only one prey and one predator**. The definition of what "learning about the systemic nature of ecosystems" actually means, is given as: "The main goal of having students learn about systems is not to have them talk about systems in abstract terms, but to enhance their ability (and inclination) to attend to various aspects of particular systems, in attempting to understand or deal with the whole" [8], and is employed in this research.

In his classic paper comparing the way of thinking of "novices" and an "experts" in Complex Systems, Jacobson provides a Table, namely Table 1 in which he juxtaposes the mental models and beliefs of Complex Systems experts and novices [3]. Some of these mental models and beliefs are directly pertinent to system-thinking. These mental models and beliefs, taken from Table 1 of Jacobson, are presented in the table below, together with the system-thinking ability that was treated as related to each one: (see Tab.1)

The current research emphasizes on the fourth column of the above Table and attributes a score for each one of the system-thinking abilities achieved by the students, as it progresses. This is a measure of the students' improvement in systems' thinking as will be shown in the "results" section of the paper.

A separate model of treating knowledge and learning in Complex Systems, very popular in the field of Science Education, is the Model of "SBF - Structure, Behavior and Function", developed mainly by Cindy Hmelo-Silver and her associates [9-11]. In the SBF treatment and evaluation of knowledge about Complex Systems, the learning subject is considered to have adequate knowledge about a (usually complex) system if he/she can describe in exact terms the system's:

Table 1 Juxtaposition of the complex systems novices' and experts' mental models and beliefs, those related to systems' thinking, as taken by Jacobson [3]

Category of Component Belief	Component Beliefs Associated with Clockwork Mental Model	Component Beliefs Associated with Complex Systems Mental Model	Associated System-Thinking Ability
1. Understanding phenomena	Reductive (e.g., step-wise sequences, isolated parts)	Nonreductive: whole-is-greater-than-the-parts	Seeing **only** the stocks vs. Seeing all the stocks **and** the flows **and** the arrows **and** the faucet controls
4. Action effects	Small actions → small effects	Small action → big effect	Seeing a **proportional** increase/decrease in the stock and the flow vs. Seeing a **non-proportional** increase/decrease in the stock and the flow
6. Complex actions	From complex rules	From simple rules	Seeing a stock as affecting **only very close** stocks by the neighbouring flows **vs.** Seeing a stock as affecting **even very distant** stocks by arrays of flows
7. Final causes or purposefulness of natural phenomena	Teleological	Nonteleological or stochastic	**Not observing** the arrows, i.e. the "closed" feedback loops, seeing only "open" procedures **vs. Observing** the arrows, i.e. the "closed" feedback loops, AND NOT seeing only "open" procedures
8. Ontology	Static structures Events	Equilibration processes	Seeing the stocks as reaching a **final, constant size** and the flows as stopping vs. Seeing the stocks as reaching a **final constant size but** the flows as **never** stopping

Table 2 The S-F elements of the modeled Wolves-Sheep-Grass ecosystem and their respective system dynamics' depictions

Properties and Aspects of the modeled ecosystem as system, related to the SBF Conceptual Model.	**Elements of this Property and Aspect**	**System Dynamics Expression of this Element**
Structure	S1) The Wolves S2) The Sheep S3) The Grass	S1) A box ("stock") called "wolves" or "wolves' population" or equivalent S2) A box ("stock") called "sheep" or "sheep's population" or equivalent S3) A box ("stock") called "grass" or "amount of grass" or equivalent
Function	F1) Wolves eat sheep F2) Sheep eat or do not eat grass F3) Wolves die if they do not find something to eat for some time F4) Sheep die if they do not find something to eat for some time (in the case: "grass plays a role") F5) Sheep die due to predation by wolves F6) Grass is reduced when eaten by sheep (in the case: "grass plays a role") F7) New wolves are added due to wolves' births F8) New sheep are added, due to sheep's births F9) Grass is replaced with a certain rate (in the case: "grass plays a role")	F1) An arrow showing the predation or something equivalent F2) An arrow showing the eating of grass (loss of grass) or something equivalent F3) Something depicting the deaths of wolves F4) Something depicting the deaths of sheep F5) Something depicting the deaths of sheep due to predation F6) An arrow depicting the loss of grass F7) Something depicting the addition of wolves F8) Something depicting the addition of sheep F9) Something describing the replacement of grass

(i) Structure (i.e. the parts that constitute the system), (ii) Behavior (i.e. the algorithms that underlie the system and make it perform the way it performs and (iii) Function (i.e. what actions the system really carries out, in the observable level). For the scope and the needs of the current research, the aspect of "Behavior" of the system and the relative characteristics of Systems dynamics were considered highly difficult to achieve for high-school students, so emphasis was given only to the aspects of "Structure" ("S") and "Function" ("F"), as well as their corresponding system dynamics' expressions. In the Table 2 [9], the S and F characteristics of the modeled simple ecosystem of Wolf predating Sheep (and, optionally, Sheep eating Grass) are presented, together with the corresponding system dynamic representation(s) for each characteristic, that the student is expected to find and express.

Table 2 will also be used in the analysis of the results section of the research.

2 Method

2.1 The Objectives

A number of methods and tools have been developed, in order to reveal students' and teachers' conceptions of simple dynamic systems and ecosystems [12]. A variety among these methods of revealing and improving the understanding of "systems", have used agent-based systems and especially NetLogo as a tool [13-16], and furthermore, some of them used the Environment of NetLogo to see how a student changes from "expert" to "novice" in Complex Systems [10, 17]. There is clear evidence that even laypeople that have completed Secondary education cannot easily define the structure or understand even the simplest simulations of ecosystem dynamics [18]. On the other hand, NetLogo educational researchers have demonstrated that this modeling environment helps students, to a certain extent, to create mathematical models of a system, in the form of equations, or create dynamical/graphical models of a system [19-21].

Therefore, the strategy of the current research, which makes it slightly different than all the aforementioned researches, focused on **six** didactical objectives, which stem mainly from **authentic system-thinking abilities related to finding relations in the system and representing it**, whereas the other researches seek for learners' mental models regarding the systems' nature or the learners abilities to model the system. In this context with the help of the teaching sequence carried out in this research, there are - as already said - six objectives. These objectives are that the students should:

- Understand, through computer simulation, the meaning of the entities of a modeled ecosystem. For example: a "stock" (a box) called "wolves" corresponds to the wolves' population, and a "faucet control" corresponds to "wolves' birth rate".

• Be able to conceptualise the effects that parameter changes on the GUI (Graphical User Interface) of NetLogo have on the modeled system.

• Be in a position to **reproduce, on paper, a similar model** of an ecosystem, using the same set of symbols as the ones they were faced with, originally. The only things altered are **the names** of the constituents of the model.

• Develop the ability of constructing a similar ecosystem dynamics' model, given only the parts of it.

• In their oral and graphical description of the dynamics of the system, be a little more closer on the side of the "expert", compared to the one of the "novice", after interacting with the NetLogo models, than before interacting with them. The comparison between "expert" and "novice" descriptions, refers to Table 1 of Jacobson and especially its last column on the right ("associated system thinking abilities") [3].

• In their oral and graphical description of the dynamics of the system they should get a higher score (as explained in the results) regarding the SBF description of the system [9-10], after the interaction with the NetLogo models.

A secondary objective, apart from these six, was to be able to realise that while intervening on an (eco)system, the parts of it that are affected are much more than the ones that one initially sees, a skill that relates even to their active citizenship virtues.

2.2 The Instrument

As a working environment for teaching students, the programming language/environment NetLogo was used (Version 4.0.4). NetLogo is a programming tool suitable for simulating [22], studying and understanding of Complex Systems. It is a modern variation of the Logo programming language, simulating the function of Multi-Agent- Based systems. Many researchers so far have used NetLogo in educating people about understanding the nature of Complex Systems [23-25]. Also specific use of this programming and modeling environment has been done to enhance students modeling abilities and skills, in domains such as graphical modeling or mathematical modeling [18, 20]. Each agent of NetLogo (typically called a "turtle") follows a simple set of rules, defined by the writer of the code. This set of rules "guide" the agent in its motion among certain pixels of the screen, named now "patches". The code additionally defines the action which the turtle should perform on the patch when it meets it, such as changing its colour.

The agents act, to a certain extent, independently from each other and yet the "turtle's" choice of which "patch" to move to and what task to perform on it, is also determined by the "status" of the patch it arrives at - the degree of influence being usually determined by the programmer.

NetLogo provides an extensive "Models' Library", for various complex systems. The two simulations used for our teaching sequence come directly from this

Models Library and are: the Wolf Sheep Predation Model and the "Wolf Sheep Predation (docked)" Model [26-27], which is a variation of the first, concerning more the dynamics and the differential equations (mathematics) of the system. Both models describe a simple predator (wolf) and prey (sheep) ecosystem, the first of the two giving also the option of adding a third population to the system (the grass). In both these simulations, there are two kinds of agents: the "wolves" and the "sheep". [The "grass", which can be also optionally activated, only in the first of the two models, as mentioned above, is not an agent. It is a NetLogo "patch" (pixel) property]. The agents are interconnected by relationships of a simple prey-and-predator nature. Both kinds of agent follow also a rate of reproduction, controlled by the user of the simulation, and they also die when they run out of energy, apart for the sheep deaths due to predation. The first model, "Wolf Sheep Predation" is used mainly to familiarize the student with the multi-agent simulation, in the sense that the students interact with it, change its parameters and see the results both on the simulation screen but also on the graph screen which, in turn, depicts the time-evolution of the populations. The focus of interest for the teaching sequence is the second simulation, called the "Wolf Sheep Predation (docked)" [27]. When opening the corresponding file, the student is faced with two screens. The one is the typical NetLogo console, depicted in Fig.1.

In the left part of this screen the typical agent-model (simulation) of NetLogo for one-prey and one-predator simulation exists. It is called "Agent Model" and the students may interact with it, as in the previous model, to visualise the time-evolution of the populations when altering parameters of the system. The right part of the screen is called the Aggregate Model and its evolution is only graphically depicted. This part of the screen describes the evolution of the two populations, based strictly on the mathematical treatment, and provided, in turn, by a form of the famous set of the two Lotka-Volterra equations [28-29].

Epistemologically and didactically, the difference between the two parts of the screen is that on the left part (the simulation/agent screen) **randomness** plays an important role ("sheep die when and if they encounter wolves") where as on the right part of the screen (the aggregate model screen) randomness and stochastic behaviour play **no role**, since the rate of dying of both populations are strictly determined by "rates" (i.e. differential equations, mathematics).

Apart from this - two-sided - screen, another, very important for this research, part of the second simulation is the screen called "System Dynamics Modeler", created in a Java environment, which is shown in Fig.2.

This screen is exactly the one that focus is given on, being directly related to the "Aggregate Model". ***It represents the dynamic system-model of the simple prey-predator system, depicting additionally its interrelations,***

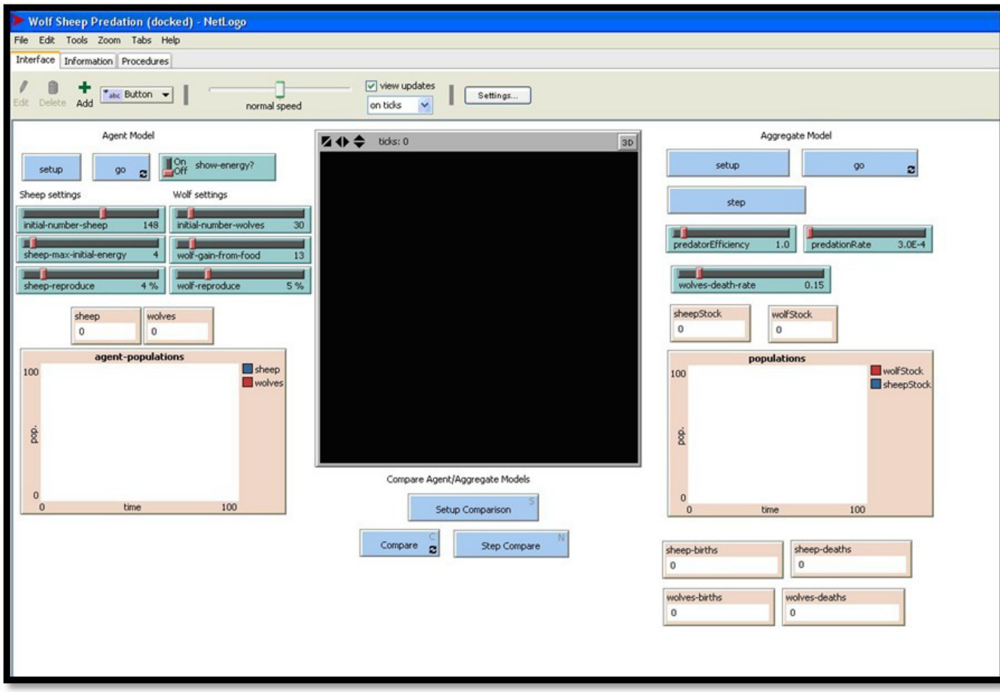

Fig.1 A screenshot of the NetLogo model: “Wolf Sheep Predation (docked)”

feedback loops and flows/stocks.

2.3 The Sample and the Settings

This teaching sequence was part of a wider research, concerning the teaching and learning of Ecosystem Complexity at the Upper-Secondary-Education student level, with the use of computers. For this research, a sample of 10 voluntarily participating students was used. The students belonged to two different senior secondary schools, and were at the 2nd class of the Greek Lyceum (ages between 16 and 17). Their orientation was either the Technical or Science Education, therefore guaranteeing a satisfactory background in Mathematics, Physics and Biology. The two schools were of neighbouring areas of Athens, Greece, and the two groups had similar socioeconomic status, gender mix and school-grade achievement. The students were grouped according to their school achievement in the previous year of the high-school to three categories:

–Low Achievement students (LA). Their overall grade of graduation from the first class of the Senior High school was **less than 14** (in the Greek scale of 0 to 20, where 20 is the best possible grade).

–Medium Achievement students (MA). Their overall grade of graduation from the first class of the Senior High school was **between 14 and 18.5**. (From 18.5

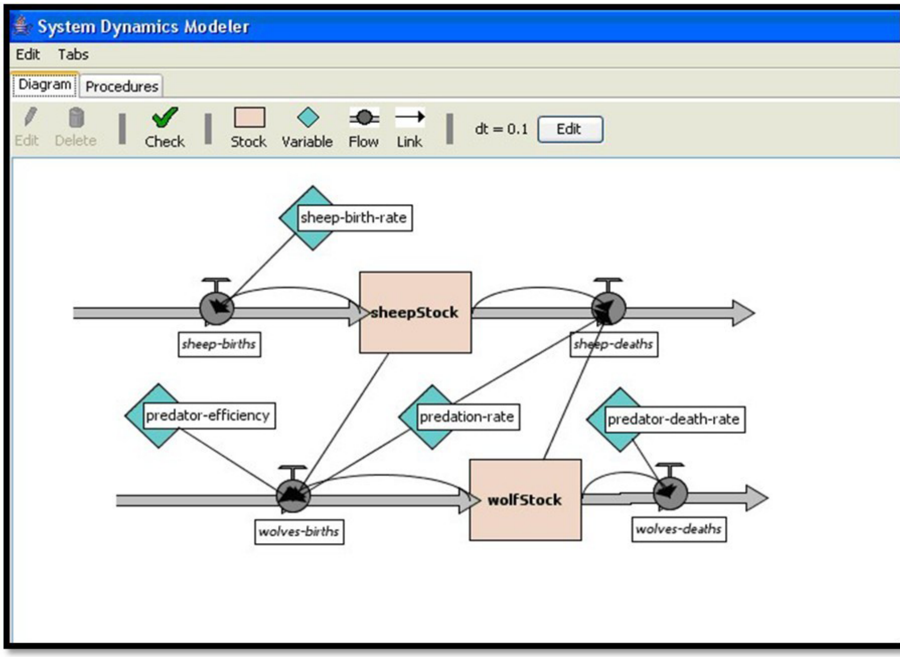

Fig.2 A screenshot of the NetLogo system dynamics modeler of the model: "Wolf Sheep Predation (docked)".

up to 20, the grades characterization is "excellent" in Greece).

–High Achievement students (HA). Their overall grade of graduation from the first class of the Senior High school exceeded **18.5**.

There are two things to notice:

a. The choice of the grade score of 14 as a limit is not arbitrary. In the Greek high school system very few students fall below 10 in the scale of 0 to 20 and also if one gets a grade of 14, he/she is considered as adequately having followed the class in the respective year of studies, even if he has lost a severe amount of teaching hours.

b. In this particular research the parameterisation with respect to the school achievement (LA, MA and HA) was not taken into consideration in detail, but only as an indicative index. In further researches of this research group, samples of students are examined with respect to their systemic thinking and systemic modeling abilities and in these researches, the school achievement plays an important role as a parameter.

Each one of the two groups of the ten students, was taught separately by the first of the authors, for **sixteen teaching hours**, and he provided each student with 4 worksheets - **one for each quartet of teaching hours** - which they completed during the process of the instruction. The students worked with computers, in groups of two or three, depending on computer availability. There was **never a** student sitting alone in a computer screen. In addition to the printed worksheets, students answers and the classroom discussion were tape-recorded.

3 The Instruction Process and the Delivered Material

First teaching session (4 didactic hours)

The first two teaching hours (of the first quartet of hours) were dedicated in familiarizing students with the NetLogo environment, particularly with prey-and-predator simulations. For this purpose, the "Wolf Sheep Predation" Model was used.

Within this part of the first teaching session (the 2 teaching hours), the students were asked to handle each button and "slider" in the NetLogo console - making trials with it and watching the model evolving on the screen with time - and try to learn the button's or slider's function. After each question on the worksheet, there followed a class discussion, mediated by the instructor. The following are characteristic questions from the first-2-hour worksheet:

• Question Number 3: Run the simulation at a low speed ("lower") and try to find out what the sliders "initial-number-sheep", "initial-number-wolves", "wolf gain from food", "sheep-reproduce" and "wolf-reproduce" actually do. Write y-our answers down.

• Question Number 4: 'Now let us discuss and reach a common conclusion about the role of each of the sliders'.

In the rest of the first teaching session (two more teaching hours), through some other questions, the students are introduced visually and verbally to the concept of "(eco)system instability", since some population may occasionally become extinct.

Second teaching session (4 didactic hours)

During the second teaching session, the simulation "Wolf Sheep Predation (docked)" was introduced. The participants were asked first to investigate the "Agent Model" section of the NetLogo screen, which resembles the previous simulation. They interacted with this section, choosing various values and combinations of values for the sliders, and noticing the model's evolution with time, as well as its final outcome, both in the simulation area and on the graph. Their attention was then driven to the right part of the screen, the "Aggregate Model", being now asked to find the meaning and the role of the sliders, noticing that the outcome of the user's interaction with the system is shown only graphically. Simultaneously, the students were given - on their computers' screens - a typed presentation about the Lotka-Volterra equations. The students were then encouraged to discuss their findings about the sliders' role with the class. Next, the students were prompted, by the worksheet, to write down or discuss verbally the relation and differences between the Agent and the Aggregate Model, observing the effects live, by pushing the "Compare" and "Step Compare" buttons.

Third teaching session (4 didactic hours)

In the third teaching session (4-hour), the class was introduced to the **System Dynamics Modeler**. The aim was to conceptualize the direct connection of this model with the Aggregate Models' parameters and the way in which this relation is established. The students were asked what the flows, stocks, arrows and faucet controls actually mean in the Modeler, and how they can interfere with them (through the mouse of their PC). Towards the end of the worksheet, a first - low-level - direct objective was achieved, to see what the hypothetical effect would be on the System Dynamics Modeler, when they altered the position of a slider in the Aggregate Model Worksheet.

Question Number 6: Fill in the gaps below and create similar sentences: "When I increase ...... in the simulation, in essence I make the box (stock) ...... in size". "When I reduce ...... in the simulation, in essence I make the arrow ...... in width.", or "let less flow pass through the faucet control ......". We also asked for verbal answers, which we tape-recorded.

Later in the same session, the students were given the opportunity to think and reconsider Question 6. The issue is whether only one thing would be affected in the Modeler if one changed something in the NetLogo Screen, or more things would be affected. Afterwards, the notion of "systemic thinking" and especially "ecosystemic thinking" was introduced, and its importance to the conservation of the Earth, as a whole. At the end of this third 4-hour session, a paper was given to the students, reading:

"We see the parts of an ecosystem as interrelated and not as separate entities (this is called "reductionist thinking"). It is easy to see that human interference constitutes one of these parts and can affect many more parts than those that we initially estimated!!"

Fourth teaching session (4 didactic hours)

In the last session, further skills of systemic thinking and modeling were developed, through the System Dynamics Modeler. Mainly, it consisted of two stages: At the first stage, students were given a piece of paper other than the worksheet, which was identical to the model depicted in the Modeler, but the terms - the words - had been removed (refer to Fig.3).

Here the students were asked to fill in the following words or phrases: Water deposits in an area / average rainfall rate in the area / birth rate in the area / water returning to the sea, to the lakes or to the under-surface horizon / consumption of water in cubic meters per person / population increase in the area / water increase in the area / peoples' deaths in the area / population of the area

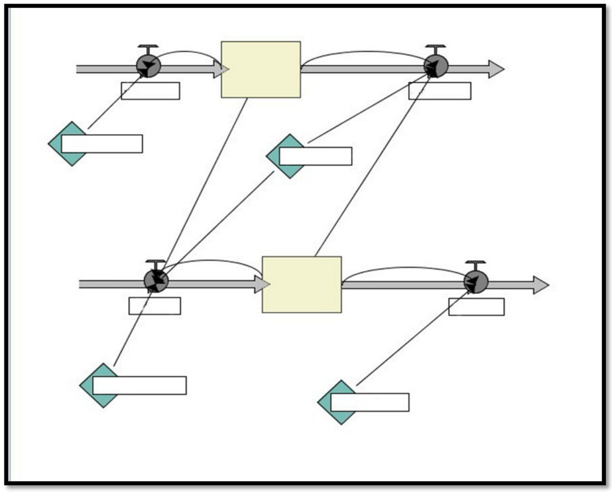

Fig.3 The system dynamics modeler of the NetLogo model: "Wolf Sheep Predation (docked)", without the terms in it..

/ rate of deaths in the area. They did this filling of gaps in the way they think proper.

At the second stage of this fourth session, students were given the elements of the System Dynamics Modeler, as shown at Fig.4.

They were allowed to use each part/element of the figure freely, in order to

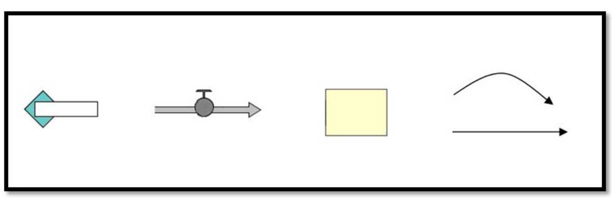

Fig.4 The elements (stocks, flows etc) of the dynamic model of the system.

create a description of the following (eco)-system:

"*The amount of solar energy entering the Baikal lake in Russia, in relation to the seaweeds growing and dying in this lake, and the photosynthesis they perform, engaging this energy.*"

A crucial question was posed to the students after the second and before the third teaching session. It was related to the skills of "novice's" vs. "expert's" description of the system as given by Jacobson [3], as well as to the SBF understanding of the system as given by Hmelo-Silver et. al. [9-10]). The question was this:

Overall Question: "You are asked now to write an essay (around one page or one page and a half) about what you do see in that system of the populations. Describe, among other things, what this ecosystem consists of, what each part of the ecosystem does, and what the ecosystem does as a whole. When is a population extinct? When is it endangered? When does a population fall and when does it augment tremendously? What parameters affect each population and how does a population affects (or is affected by) another or others? You are also encouraged a lot to make drawings about the relations of the populations, using "boxes", various kinds of "arrows", "faucets". Write things or comments, or titles (legends) on or in every part of your figure that you thing it is appropriate to write. Write and draw a lot!"

The same question was also handled to the students after the completion of the fourth - and final - teaching session of the whole sequence, and the results were compared.

4 Results and Discussion

Despite the limitation of the small size of the sample, which does not allow to draw general conclusions, and makes this more of a case study, this research depicted that the use of the NetLogo as a teaching environment, together with the System Dynamics Modeler, could potentially help High-school students in understanding simple (eco)system structures, and to acquire or slightly improve their skills on representing and even building models. Triangulating the results with the ones of using other modeling tools than the System Dynamics Modeler of NetLogo, such as the Stagecast Creator (SC) [30], used for Primary School students, the oral answers of the students were used in the present survey as an encouraging feedback with respect to the use of the software as a means of understanding the model.

At first the results of this research are presented in an indicative form.

The answer of a girl, Christine, of low school achievement, is quoted, to the tape-recorded discussion, following the aforementioned Question Number 6, in the third teaching session: 'Yes, by varying the sliders positions in the Aggregate Model, I can better see what every shape in the System Dynamics Modeler means.'

In Question Number 7, of the same worksheet, where they were asked to reconsider their answer in Number 6, they are prompted to see the wider interconnectedness of the factors in this simple prey-and-predator population system. This is not at all easy for high-school students, as was shown in the research of Barman, Griffiths and Okebukola, recorded as "misconception no. 2"[31]. There, students were found rather to believe that the change in one population affects only its closest pray and itself. In the answer to Question 7, a student, John, is quoted, who is of a medium school achievement:

'It seems that one motion of the slider can change the whole system. So if we touch the "predator-efficiency", we increase the number of births of wolves, thus we increase predation-rate of them which, in turn, increases the number of dying sheep. As a result, the number of wolves is increased in one hand, but the amount of sheep (food) is decreased, so the wolves will have problems. Many such changes are done.'

The concept investigated and aimed at improving here is a concept of what White calls "naive ecology"[32]. The relations in this simple prey-and-predator system are strictly causal ('the wolf eats the sheep thus sheep die', or 'the wolves have no sheep to eat, thus they gradually become extinct') and the learners are asked to follow such causal relations, as far as they can, relatively to the initial point of focus, which could be everything (e.g. 'wolves die'). White's research also depicted that the persons cannot follow such a causal string of facts in ecology too far from the point of origin.

The students' answers are also close enough to the eco-systemic, holistic conclusion, before this was finally distributed to them, written on paper, therefore their stands and attitudes seem to have been adequately investigated and, possibly, changed. Katherine, a student with school achievement belonging to the lower part of the sample, wrote:

'This indicates that whatever we touch in an ecosystem, this also affects the other factors too, and, therefore, we must never change something that needs not be touched, because this would affect many more factors than the ones we initially estimated!'

The one of the two higher system-thinking objectives, which is to represent a very similar system but with differently named parts or terms, was satisfactorily achieved, as is represented by the Fig.5 given by Denis, who belonged to the medium area of the sample as regards school grades achievement.

This skill here refers mainly to the Systems-Based Inquiry (S-BI) protocol used by Sweeney and Sterman, in ecosystems, and especially its first two parts:

Part I: Systemic scenarios: Participants consider system dynamics in [six] simple scenarios. These scenarios emphasize feedback dynamics.

Part II: Homology challenges: Participants imagine [six] related but different systemic scenarios. This requires participants to use homological reasoning.' [12].

Homological reasoning, as well as analogical system-thinking, both in their very simple expressions, was cultivated, to a certain extend, to all of the students, as Denis's drawing (who reflects an average of the sample) reveals. Passing to an ecological phenomenon other than "predation", which is "water consumption", the students appear to be 100% correct in adopting the terminology and conceptualising the analogies.

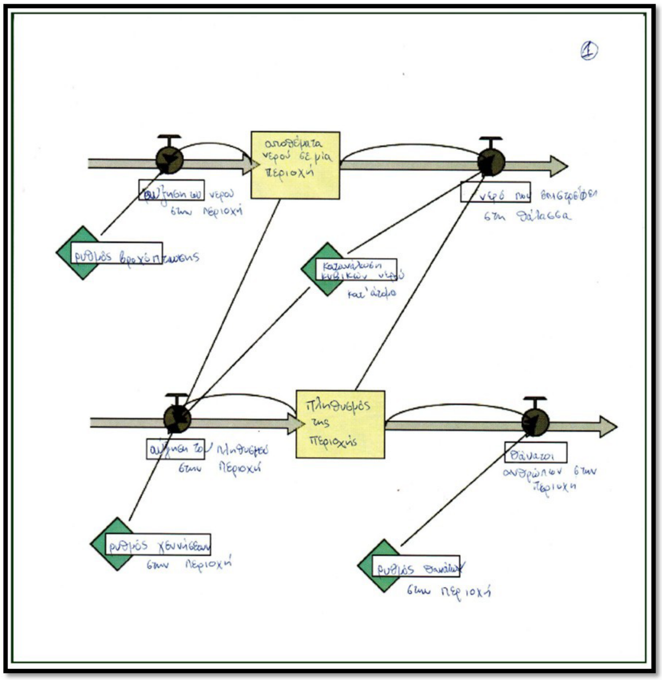

Fig.5 The Denis' first sheet.

Finally the other, even higher, system-thinking and system-constructing objective, aimed at, was to construct a model - again similar to the initial - having only the elements of it. Such modeling tasks are not easy, as researchers have shown [17, 33]. Hogan used only textbook-based teaching and asked the learners to construct simple food webs, in the sense of only putting the arrows in them ('who eats what'), giving the reasoning for their choices. The results were poor. Jensen and Brehmen asked a sample of post-secondary-education individuals to study a predator-and-prey model very close to the one we chose. It is depicted in Fig.6.

The task here was to establish population equilibrium in this system. The learners tried this on the computer (changing a numeric parameter, i.e. the "foxes") and what they relied on, was either mathematical approach or negative feedback-loops. The results were again poor (less than 50% did it) and as one of the main reasons for this low performance, the authors give:

'One possible reason why the rabbit-fox problem is difficult may be that it is not easily decomposed into subsystems or homomorphs. Since they are so closely intertwined, it is not feasible to split the system into a rabbit system and a fox system. Therefore it is not possible to simplify it. This may contribute to the difficulties in forming a clear-cut model of the system.' [18].

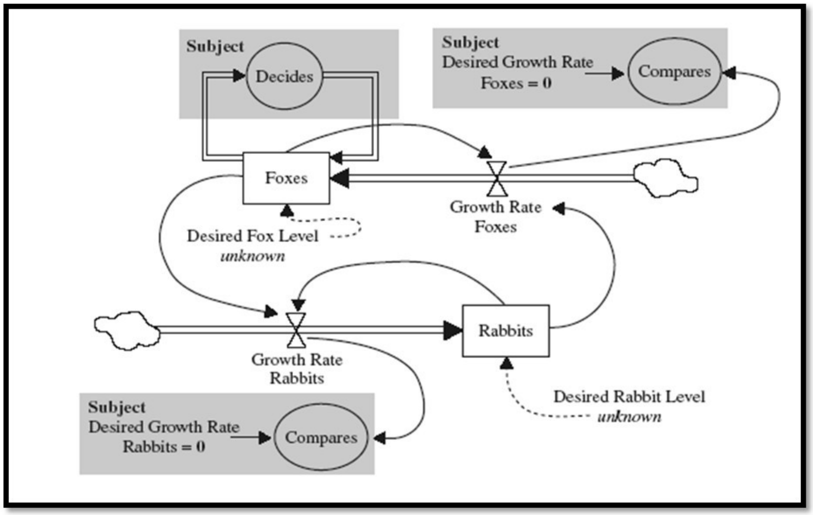

Fig.6 The figure of Jensen and Brehmer

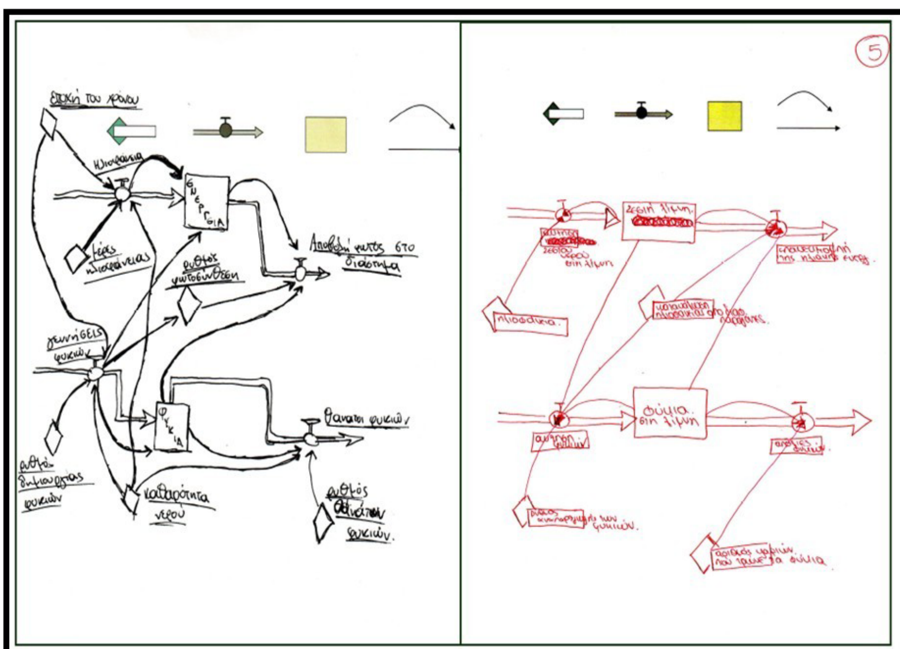

Fig.7 The sheet as completed by George (at left) and Christine (at right).

Therefore, one important competency in understanding an (eco)system, is decomposing it to its parts, which is what the half of our last activity is about. The other half of the activity is attempting, with these same parts, to build a similar ecosystem.

As a measure of the results of this last activity on the sample, we present two drawings: Figure 7 depicts the model made by the highest-school-achievement student of the whole sample (George), as well as the one made by the lowest-school-achievement student of the whole sample (Christine).

It can be noticed that, even though the "better student" has made a more flexible shape, and he adds even subtle-unneeded details, whereas the "weaker student" sticks more to the original and omits certain terms, the basic representation of this alternative ecosystem ("Lake Baikal and the seaweeds") is essentially achieved in both drawings.

As regards the "numerical" representations of the results, each one concerning the six didactic objectives mentioned in Section 2.1 of the current paper, the results were:

First Objective.

The 7 out of the 10 students corresponded totally correctly the elements of the system dynamics model with the entities it describes. It seems to have been an easy task, especially with the aid of the NetLogo model.

Second Objective.

8 out of 10 students gave all the correct answers when writing what is affected in the modeled system by each slider's and each button's variation. Again the proportion of successful completion of the task is high, combined with the use of the NetLogo Models.

Third Objective.

Once again 7 out of the 10 learners constructed on paper a quite similar model of an ecosystem, with only the names of the terms altered. High performance also appeared here, with the help of the NetLogo screen.

Fourth Objective.

Here - as was expected - there was relative failure. Only 3 out of 10 students succeeded in building correctly on paper, the dynamics' model of a system "from the scratch", given only the elements of it. It is a high systemic-thinking ability and, even with NetLogo, it cannot be easily enhanced.

Fifth Objective.

As regards the Table 1 of the classic paper of Jacobson a score was attributed to each of the 10 students, as regards their performance of **the last right column of Table 1**. The Question of reference is of course the "Overall Question", mentioned before in the paper, in which the students' answers are scrutinized with respect to their content. Each time a student acts as a "novice" on the modeled (complex) ecosystem, in his/her writings, descriptions or in his/her shapes of the system's dynamics he/she gets **a "0"**, for the corresponding aspect mentioned in the last column on the right of Table 1. On the contrary, each time the student acts as an "expert" on the modeled ecosystem he/she gets an 1 for this aspect. Since there are five aspects of systemic thinking, it is obvious that the maximum score each student could take is "5" and the minimum score is "0". For the whole sample of 10 students the respective maximum score is "50" and the minimum score is "0". The results and the scores of this attributing system are shown in Table 3, both before and after the study of the NetLogo's System Dynamics' Modeler (the "Overall Question" was delivered to them twice). Interpreting the

Table 3 The (pre- and post-interaction with the model) scores achieved by the 10 students, as regards the Jacobson [3] model of mental modes, component beliefs and the associated with them system-thinking abilities.

Category of Component Belief and Associated System-thinking Ability	**Overall Score achieved by the 10 students BEFORE interacting with the two NetLogo Models**	**Overall Score achieved by the 10 students AFTER interacting with the two NetLogo Models**
1. Understanding phenomena	42	44
4. Action effects	14	17
6. Complex actions	20	39
7. Final causes or purposefulness of natural phenomena	19	38
8. Ontology	12	15

findings of Table 3, one can see that:

– The study of the System Dynamic Modeler of NetLogo and the interaction with NetLogo model "Wolf Sheep Predation (docked)" was very helpful for the students , as regards "Complex Actions" and "Final Causes or Purposefulness" of systems, which in systemic terms means it helped them to "see very distant interactions within elements of the system" and to "see closed loops within the system and not only open processes". Especially the first of these two aspects, is in close proximity, with what Sharona T. Levy and Uri Wilensky define as a "mid-level" which means that the students understand better a system if they can describe it by means of the actions of a group of neighbouring and interacting parts [34], not by the actions of one single part alone and not by the action of all the parts as a whole.

– In the domain of "Understanding phenomena", which in systemic terms means: "seeing most the compartments and the flows in the system", the students performance was significantly good from the beginning, and the interaction with the System Dynamic Modeler of NetLogo and the model itself, failed to improve it significantly.

– In the domains of "Action Effects", and "Ontology" which in systemic terms mean respectively: "seeing beyond proportionality between stocks' size and flows' rates in the system", and "seeing the size of stocks as dynamic, even when it looks constant", the students performance was poor in the beginning, and the interaction with the System Dynamic Modeler of NetLogo and the model itself, seems to have failed also to make it better.

Sixth Objective.

Once more, the question that was scrutinized is the "Overall Question" and the drawings or the writings of students in it, about the system, both before and after their study of the System Dynamics Modeler and the "Wolf-Sheep Predation (docked)" Model of NetLogo. Analyzing again the **content** of the writings and the drawings of the students in this question, a scoring system was established:

– for each one of the three "Structure" elements of the system that the student managed to find, he got a score "1". Consequently the score for each student would range from "0" to "3", and the score for the whole sample of 10 students would range from "0" to "30".

– for each one of the nine "function" elements of the system that the student managed to find, he got a score "1". Consequently the score for each student would range from "0" to "9", and the score for the whole sample of 10 students would range from "0" to "90".

– Additionally, it was decided that for each "faucet control" or "rate" that the student would describe, for the corresponding "Function" element, he would get "0.5" point more, since this reveals a slightly deeper understanding of the relative "Function" aspect of the system. Thus, the score for each student here would range from "0" to "4.5", and the score for the whole sample of 10 students would range from "0" to "45".

The cumulative results for SBF treatment of system dynamics are shown in Table 4.

The results show that the interaction with the System Dynamics' Modeler of

Table 4 The (pre- and post-interaction with the model) scores achieved by the 10 students, as regards the SBF Model [9] of knowledge of , learning about and description of the system and the associated with them system dynamics' expressions ("Behavior" is excluded).

Aspect of the Systems description according to the SBF Model of Knowledge and Learning ("Behavior" is Excluded, as said) "Structure"	**Overall Score achieved by the 10 students BEFORE interacting with the two NetLogo Models**	**Overall Score achieved by the 10 students AFTER interacting with the two NetLogo Models**
"Structure"	21	28
"Function"	33	68
"Function" with "Faucet Controls"	10	41

NetLogo, as well as with the Model "Wolf-Sheep Predation (docked)":

– helped the students conceptualise better - to a certain extent - the elements that constitute the system (the "structure") . It should be stressed here that the element mostly missed before interaction was "grass", which is an expected result.

– helped the students much more to conceptualise the "functional" aspects of the system, which are mainly: (i) the "flows" (inflows, outflows) and (ii) the "interaction arrows" between system elements. This is a gain for system dynamics' knowledge and students' systemic thinking.

– proved extremely helpful in making students conceptualise and describe the "faucet controls" which are actually the "rates", within the system. This is an aspect of the system description and understanding of its "Function", that was very poor before the interaction with the NetLogo models and the Dynamics' Modeler, and improved significantly afterwards.

5 Conclusions

Taking into consideration the restrictions of the current research (small sample size, absence of pre-test and post-test evaluations) and the imposed settings on the teaching sequence (few hours of teaching, students working out of their classroom schedule) , it is, nevertheless, argued, that there are significant conclusions from the research.

At first, it is concluded that the combined use of a NetLogo Model and the System Dynamics Modeler associated with it can make students improve their understanding and their system-analysing abilities of a simple modeled ecosystem.

Secondly, it is concluded that upon interaction with NetLogo models and System Dynamics' Modeler, a student who is a "novice" in conceiving and describing systems and relations within systems, can slightly move towards the direction of being an "expert" on it, or at least on some of the system's aspects.

A third conclusion is that low-level system thinking abilities exist at large even before working with NetLogo model, and remain there after interacting with it. The same is valid, on the opposite view, for high-level thinking abilities. They are mostly absent and remain absent after the interaction with the NetLogo models and the System Dynamics Modeler. The abilities that are mostly enhanced by NetLogo, are the **medium-level** system-thinking, system-analysing and system-representing abilities.

Finally, a core concept of this research and a conclusion of it, is that a learner who is weak in: (i) seeing detailed structures in a system, (ii) seeing loops, (iii) predicting time-evolutions in it, (iv) observing large-reaching interactions among the elements of the system and (v) making generalizations about the system behavior will definitely benefit somehow, if he/she is taught about the system, not only with the graphic representation of the system dynamics but also with the study of (and interaction with) an agent-based simulation (such as a NetLogo model) of the system. Questions regarding the time-evolution of the system, questions regarding extreme events ("What if a stock becomes too large or too small"? "What if a stock vanishes"? "What if a flow diminishes in thickness"?) and questions regarding random events ("stochasticity") ("what if wolves find no sheep to eat"?) may not be easily answered for the novice, by the graphic or mathematical representation of the system dynamics, but are clarified by the NetLogo simulations.

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