



A Constructionist Method for Teaching Teachers about Basic Properties of Complex Systems, using a NetLogo Model.

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Abstract

*The current research report discusses a Constructionist approach used to teach prospective Greek Primary School Teachers, about five certain properties of Complex Systems (CS's), by the use of the programming and modeling environment of NetLogo, and especially by the use of a NetLogo Model called "Ants". The research presented here was part of a broader research project, which had as **central research question**: if and to what extent the NetLogo models can help future educators conceptualize specific properties of Complex Systems in Nature. Students underwent approximately one-hour-lasting interviews, by the first of the authors, which were fully recorded. The whole interview was taking place in front of a computer, which had the NetLogo Model "Ants" activated, as well as some variations of it, created by the researchers. The students interacted with the model all of the time, in a constructionist manner of learning and discussing, and in an inquiry-based-learning strategy, so as to complete the interview.*

After the thorough examination of the results obtained by the interviews, it becomes evident that: the use of the NetLogo Model helps undergraduate Primary School Teachers conceptualize five basic properties of the Complex (Adaptive) Systems, and to build a representation of the compoment of these systems on their own.

Keywords

NetLogo, undergraduate teachers, teaching, complex systems.

Introduction.

The core idea behind constructionist teaching, which is learning-by-making (Papert and Harel, 1991, Papert, 1980), as well as working with the learner with a not-so-much predetermined plan, but changing the teaching methodology according to the feedback that the teacher receives in



each step of the teaching sequence, is optimally applied by the use of computers. (Kafai & Resnick, 1996). The use of the Logo-like environments is appropriate for involving the learner in activities which would lead him, with the instructor only as a mediator, to the cognitive results aimed at, as much of the literature proves (Healy & Hoyles, 2001; Laborde et al., 2006). An environment used extensively in the recent years for teaching learners of various ages about basic concepts of Mathematics and Science, is NetLogo (Wilensky, 1999). NetLogo is a Multi-Agent-Based Modeling and Programming environment, based on the Logo language as invented by Seymour Papert, and on the StarLogo Microworlds as invented by Mitchel Resnick. The use of many “turtles” (agents), the number of which is determined by the user, as well as the user-friendly interface makes NetLogo an ideal tool for instruction, especially for the conceptualization of complex systems (Tisue & Wilensky, 2004). A lot of research has been carried out on what exactly “conceptualization of complex systems means” (Jacobson, 2001) and more specifically on what shift in the person’s way of thinking this requires, and on to what aspects of the system’s conceptualization it refers, such as the Structure, Behavior and Function (SBF) (Hmelo-Silver & Pfeffer, 2004). Especially researchers like Sharona Levy have extensively used the programming environment of NetLogo in large empirical researches to see how it affects the learners’ understanding of Nature (Levy & Wilensky, 2008; Levy & Wilensky, 2011). In this research, the model “Ants” from the NetLogo Models’ Library was chosen, since it addresses a natural-like system that is both **complex** and **adaptive**, like many other natural systems (Levin, 1998). In addition to this, the Model “Ants” – which also exists in StarLogo (Resnick, 1997) – helps the learning subject to develop certain mental qualities. Such qualities are: (i) decentralized thinking (Resnick, 1996; 1998), which means understanding that a system may work without a central control or leader and (ii) thinking in levels (Wilensky & Resnick, 1999), which means realizing that local interactions among members of a system may lead to a totally different and unexpected overall behavior.

The research presented here was part of a broader research project, which had as its **central research question**: “if and to what extend the NetLogo models can help future educators to conceptualize specific properties of Complex Systems in Nature”. These properties included **the ones discussed in this paper**, which are: (i) self-organization, (ii) lack of central control or leadership, (iii) emergence of an overall (human-intelligence-like) behavior through local exchange of a simple set of information, (iv) non-repeatability, even with identical initial conditions (stochastic properties) and (v) existence of critical values for certain parameters.

The Sample and the Research Procedure.

The research was addressed to undergraduate students of the Department of Primary Education, University of Athens Greece, who had chosen to be taught the optional course: “Environmental Science and Education: The Laboratory Approach”. The Constructionist context of introducing students to Complex Systems (and mainly ecosystems as Complex Systems), consisted in having them in pairs in front of Computers in which the NetLogo Models were installed, and having them trying to find out what the model (here “Ants”) does and how they can interact with it. The answers were written on worksheets. This constructionist introduction to the NetLogo Model is explained in the APPENDIX .

After the familiarization with the NetLogo environment and with this specific model, the interview with each pair of students followed.

Each interview, during the research process, was aimed at referring to one couple (n=2) of undergraduate students (when it could not be achieved, instead of two, one was interviewed). It



lasted one hour to one hour and a half.

The couple's interview started by being acquainted with the NetLogo Model, the specific one being "Ants", by playing with the buttons and the sliders and by watching the screen. Simple initial questions accompanied this procedure such as: "what do you think this button/slider does?" or "what is this that you watch in the screen?" or "what do you notice?" The main questions of the interview had always three phases: (a). Answer before you try it in the model (prediction), (b). Answer after you try the model many times and – if you like – change the parameters (testing) and (c). Compare (a) and (b) and reach a final answer. Also give your explanation why your answer is valid.

Each one of the two students in the couple (when in couples) could discuss with the other in stages (b) and (c).

The specific sample which participated in the interviews were N=15 undergraduate students of the Department of Primary Education of the University of Athens. This sample was part of a larger research sample, consisting of 85 students, who participated in the overall research. All of these 15 students were attributed with specific values for four different parameters, i.e.:

- **Year of Study.** The parameter takes the values: **A**, **B**, **C** and **D** (no students of the Department of later years participated).
- **Orientation during the Third (final) Class of High-School.** The parameter takes three values: **Sc** (Science) – did not exist in this specific sample – **Theor** (Theoretical, Classical Studies) and **Tech** (Technological).
- **Whether or not they had chosen Biology as an exam topic for the entry exams to the University.** The parameter takes two values: **Biol-YES (Y)** and **Biol-NO (N)**.
- **Whether or not they had chosen Informatics among the optional topics either in the years of the high-school or in the University.** This parameter takes two values: **Info-YES (Y)** and **info-NO (N)**.

In the Table 1, which follows, the values of the parameters for each member of the sample that was interviewed are provided.

Student's Number	Year of studies	Orientation	Biology	Informatics
1	3	Tech	N	Y
2	3	Theor	N.A.S ¹	N.A.S
3	4	Tech	N.A.S.	N.A.S
4	3	Theor	N	Y
5	3	Theor	N.A.S	N.A.S
6	3	Theor	Y	N
7	3	Theor	Y	Y
8	3	Tech	Y	Y
9	3	Theor	N.A.S	N.A.S

¹ Never At School. This means that some students had **never** the chance to choose this topic, for example students having taken University entrance exams with another system, or students coming from Cyprus.



Theory, Practice and Impact

10	2	Theor	Y	Y
11	2	Theor	N.A.S.	Y
12	2	Tech	N	Y
13	2	Theor	N	Y
14	3	Theor	Y	Y
15	3	Theor	Y	Y

Table 1. The sample interviewed, with respect to the values of the parameters.

Each pair of students were initially interviewed with respect to the initial “Ants” Model of NetLogo (Wilensky, 1997), with the slight difference that the sliders, the buttons and the rest of the NetLogo interface screen was translated in Greek. This Model is shown in Figure 1, below.

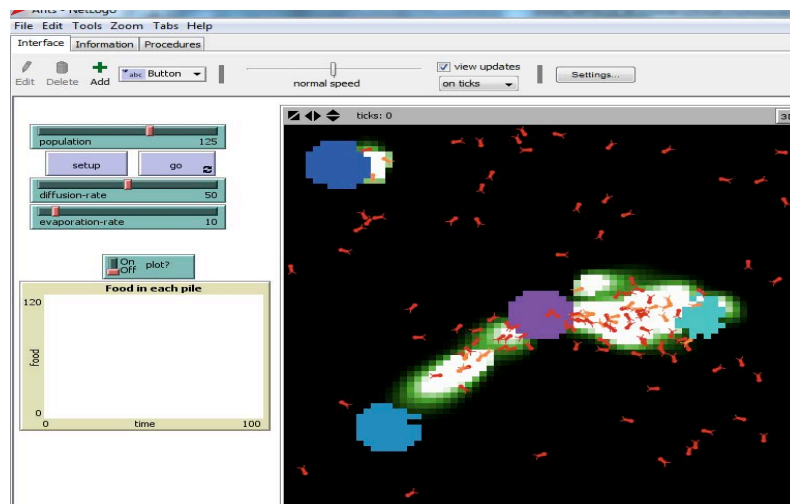


Figure 1. A screenshot of the NetLogo Model “Ants”

At a later stage of the interview, the undergraduate students were asked questions about a variation of the Model “Ants”, in which there are *only two* food-sources, identical and *equidistant* from the ants’ nest. In Figure 2 below, a screenshot of this Model is given.

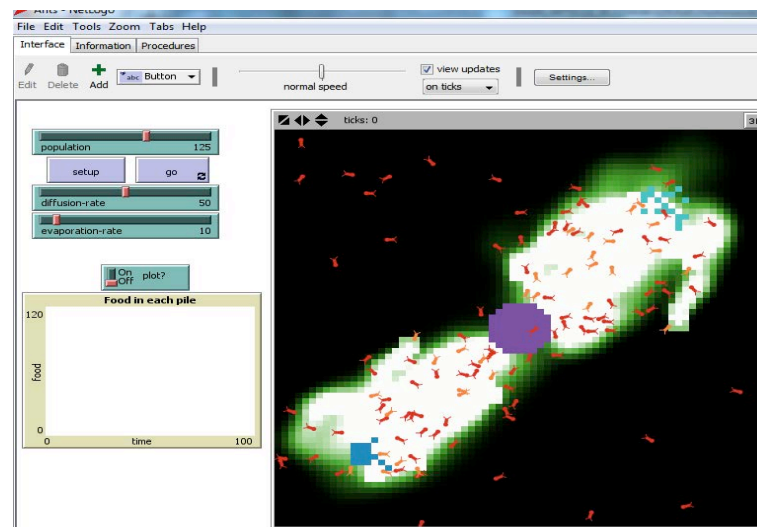


Figure 2. A screenshot of the NetLogo Model “Ants” with ONLY TWO food piles, in EQUAL DISTANCES from the nest.

Finally in the interview, a variation of the Model “Ants” is used, in which there is *only one* food-source, but with *an obstacle* between the ants’ nest and the food source. In Figure 3 below, a screenshot of this Model is given.

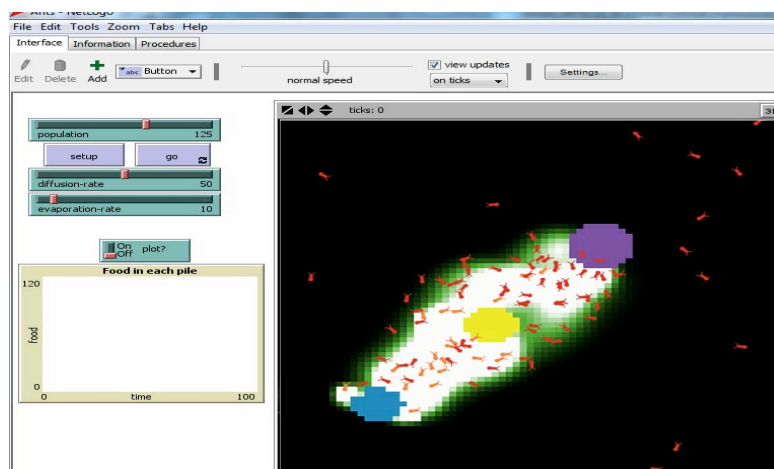


Figure 3. A screenshot of the NetLogo Model “Ants” with ONLY ONE food pile, and AN OBSTACLE between the ants’ nest and the pile.

The interviews with the students were conducted in front of a PC screen, with the NetLogo models installed on it, by the first of the authors, and were built within a constructionist framework, combined with inquiry-based-learning techniques.

Simultaneously to this sample, a **control group** was formed with $N_{CONTR} = 8$ undergraduate students. They were also divided in four pairs, they had a similar distribution of parameters with the one given in Table 1, and they gave identical interviews with the initial sample, with one major difference: they *did not have* a computer and did not interact with the NetLogo Model at all. Instead, the model “Ants” was described and taught to them on whiteboard, step-by-step, by the first of the authors.



Results and Discussion

A. Initial “Ants” Model of NetLogo.

As becomes apparent from the interviews, the students (Question 2, “Which is the inherent logic of the accumulation of food within the population of the ants?”) tend to see a centralized control for the ants’ troop, as they initially become acquainted with the model. Out of the $N = 15$ students,

- the $N_1 = 0$, before their further involvement with the model, tend to believe that the first ant that reaches the food-pile, is some kind of leader for the others.
- the $N_2 = 14$ give scientifically “wrong” answers about the role that the pheromone plays (the “white” substance).
- the $N_3 = 5$ have not a clear image of the role that the *number*, (the “population”) of the ants plays in the time-evolution of the model.
- the $N_4 = 5$ are not able to determine what is the effect of the value of the sliders: “diffusion-rate” and “evaporation-rate” to the consumption of the food piles.
- the $N_5 = 2$ seem to believe that the order by which the food piles are consumed will always be the same, no matter how many times the model’s run is repeated.
- the $N_6 = 14$ argue (in various ways) that the fact that the first food pile eaten is the closest to the nest, is statistically explained, i.e. more ants “hit” it, due to proximity.

In the control group, the corresponding numbers were:

$$\begin{array}{l}
 N_{\text{CONTR},1} = 6, \quad N_{\text{CONTR},2} = 6, \quad N_{\text{CONTR},3} = 6 \\
 N_{\text{CONTR},4} = 8, \quad N_{\text{CONTR},5} = 6, \quad N_{\text{CONTR},6} = 8
 \end{array}$$

But as the constructionist interview proceeded, and they played several times with the model, the numbers clearly improved:

- N_1 remained $N_1' = 0$
- N_2 was reduced to $N_2' = 2$
- N_3 was reduced to $N_3' = 0$
- N_4 was reduced to $N_4' = 0$
- N_5 was reduced to $N_5' = 1$
- N_6 was reduced to $N_6' = 1$.

The results are graphically shown below (fig.4):

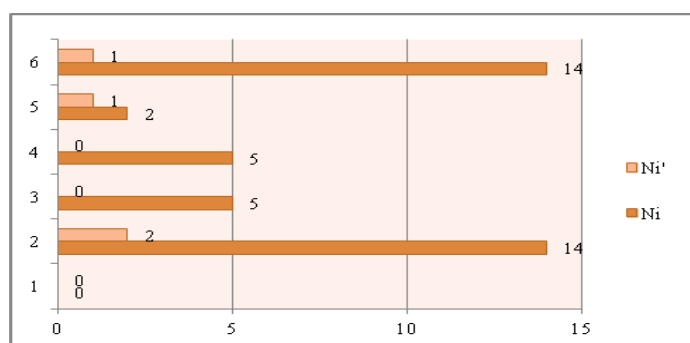


Figure 4. The “answers” before (N_x) and after (N'_x) the interview (Model “Ants”)



The corresponding results in the control group were :

$$\begin{aligned} N'_{CONTR,1} &= 5, & N'_{CONTR,2} &= 5, & N'_{CONTR,3} &= 6 \\ N'_{CONTR,4} &= 6, & N'_{CONTR,5} &= 6, & N'_{CONTR,6} &= 8 \end{aligned}$$

Other results stemming from this initial application of the Model “Ants” in the interviews, were:

- The $N_5=2$ students belonged to the same group, when the research was carried out in the overall sample.
- The members of the sample who had taken Biology as an optional topic ($N_{BIOL} = 6$ in total) for the University Entrance exams, gave more well-documented and combinational answers, as regards the parameters of the pheromone (diffusion rate and evaporation rate).
- The persons that had entered University in another way (those taking older forms of entrance exams, those moving to the Education Department after completing studies in another Department or people from Cyprus) gave very simplified answers.

B. Variation of the “Ants” Model, with two equidistant food-piles.

In the beginning, out of the $N = 15$ undergraduate students, only $N_7 = 2$ realized that one of the two food piles will clearly be consumed first. The others thought that they are consumed practically simultaneously, with a slight advance of one of the two. Also, $N_8 = 5$ believed that the pile consumed first is always the same one, or at least in most cases.

In the control group, the corresponding numbers were:

$$N_{CONTR,7} = 4, \quad N_{CONTR,8} = 6.$$

Later, after extensive trials of the model, the numbers improved.

- N_7 increases to $N_7' = 6$
- N_8 falls dramatically to $N_8' = 0$

The results are graphically shown below (fig.5):

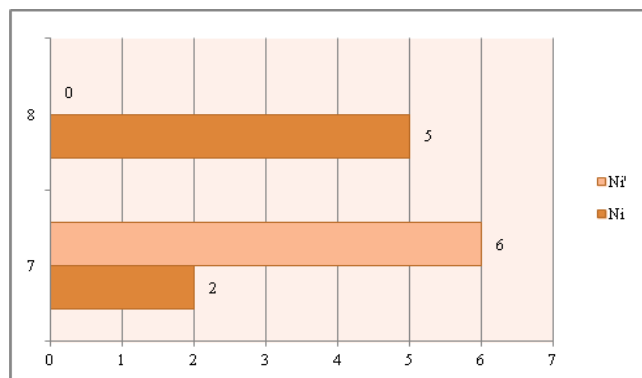


Figure 5. The “answers” before (N_x) and after (N'_x) the interview (Model “Ants, variation with two food-piles”)

The corresponding results in the control group were:

$$N'_{CONTR,7} = 5, \quad N'_{CONTR,8} = 6.$$

Further analyzing the interviews’ results, it could be seen that:



- The $N_7 = 2$ considered both food piles as equally capable of being consumed first, still only one of them, they said, will precede.
- As is obvious both from numbers N_7 and N_7' , the prevailing view were always that the two equidistant food-piles would be consumed practically simultaneously.
- Once more, the members of the sample who had taken Biology as an optional topic ($N_{BIOL} = 6$ in total) for the University Entrance exams, gave more alternatives in their answers.

C. Variation of the “Ants” Model, with one food-pile and an obstacle.

In the beginning, $N_9 = 3$ argued that the ants will bypass the obstacle in random ways.

Also $N_{10} = 1$ argued that they will create a curved trajectory in the one side of the obstacle.

Only $N_{11} = 2$ could see that this curve will be the tangent to the obstacle.

And only $N_{12} = 4$ were able to see that there will be TWO such identical trajectories one adjoined the obstacle.

In the control group, the corresponding numbers were:

$$\begin{aligned} N_{CONTR,9} &= 5, & N_{CONTR,10} &= 2, & N_{CONTR,11} &= 4, \\ N_{CONTR,12} &= 2 \end{aligned}$$

Afterwards, the Numbers get much better.

- N_9 reduces to $N_9' = 0$
- N_{10} reduces to $N_{10}' = 0$
- N_{11} increases to $N_{11}' = 12$
- N_{12} increases to $N_{12}' = 8$

The results are graphically shown below (fig.6):

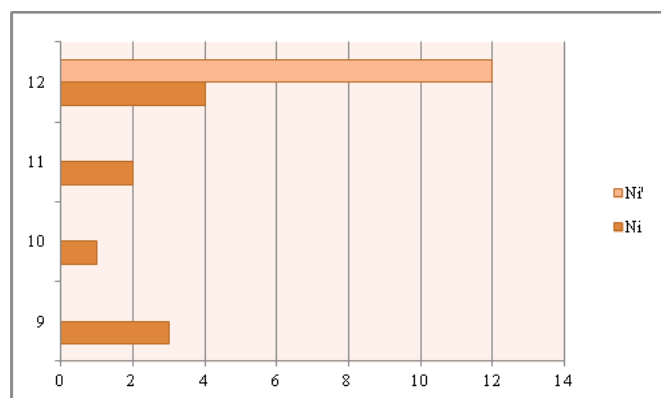


Figure 6. The “answers” before (N_x) and after (N'_x) the interview (Model “Ants, variation with one food-pile and an obstacle”)

The corresponding results in the control group were :

$$\begin{aligned} N'_{CONTR,9} &= 2, & N'_{CONTR,10} &= 2, & N'_{CONTR,11} &= 6, \\ N'_{CONTR,12} &= 4. \end{aligned}$$



- In this latter form of the “Ants” Model, used in the interview process, the students answered mainly based on their experience with NetLogo and on the things they saw with the Models, regardless of their pre-existing knowledge.
- In this part, a great variety of answers were given, combining arguments in many ways.
- Again in this part, the persons that had entered University in another way (those taking older forms of entrance exams, those moving to the Education Department after completing studies in another Department or people from Cyprus), found it difficult to answer in many cases.
- The vast majority of the students coming from a theoretical orientation in high-school (9 out of $N_{\text{THEOR}} = 11$), needed a lot of guidance to formulate an answer.

Conclusions

Initially there are some “case-affected” or technical conclusions from this research: At first, the students coming from a technological orientation in high-school ($N_{\text{TECH}} = 4$), did not encounter any special problem in handling the NetLogo interface, as regards its usage and the understanding of its functions. Secondly, all of the students of the sample (15 out of 15) altered their answers after testing the Models many times, emphasizing on the usefulness of the method. Thirdly, most of the “inadequate” answers came from the undergraduate students that had entered University with another system of entrance exams, than the one mainly valid in Greece nowadays.

But stress should definitely be given to the more general conclusions, referring to the usefulness and the effectiveness of NetLogo, and this specific model, in the conceptualization of Complex Systems on behalf of future educators.

First of all the 11 out of the 15 students – a percentage of around 73% – towards the end of the interviews had switched to an almost common form of terminology, the one appropriate for Complex Systems and for NetLogo, and they ended up giving well-documented answers.

It should be stressed also that when the undergraduate students were in couples, the answers tended to be much more alike, since the discussion among them affected their views. So we have a definite *peer-effect* very common in constructionist methods working in pairs. The same is valid for the four groups of the control group.

As can be seen from the relatively poor performance of the control group, related to the basic sample, NetLogo seems to be a great instruction tool for getting the learning subjects acquainted with the properties of Complex Systems, compared to classical, oral instruction. Complex systems are much better realized when seeing them evolving in time on a screen, and when interacting with their properties, than when being simply taught about them in a series of lectures.

Constructionist approaches and teaching through NetLogo seems to be giving the learners, a better feeling about understanding the subject of Complex Systems, compared to oral instruction. One of the very last questions on the worksheet was: “Was it helpful, in understanding?” and 11 out of the 15 students of the main sample answered positively, as shown in the figure 7, whereas only 2 out of the 8 persons in the control group gave affirmative answer to this.

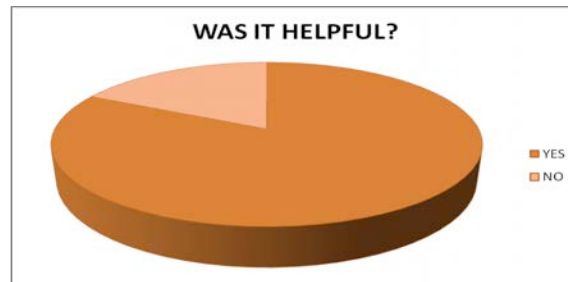


Figure 7. Answers in question: “Was it helpful, in understanding?”

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APPENDIX

The Constructionist set of Questions on the Worksheet, to introduce students to NetLogo Model Ants.

1. What are the buttons that you see on this screen? What do you thing each one is doing?
(*Always write your answers, after discussing within the pair*).
2. Try to press button named “SetUp” once. What is this that you see in front of you?
3. Press “Go”. Can you find out what this troop of ants does? Describe in your own words.
4. What is this white substance doing? Try to give a description, after trying the situation many times (always restart by pressing SetUp and then Go)
5. Do you see any resemblance with real ants? Give a description, after trying the model as many times as you like, altering the parameters.
6. What is shown on the plot, when you have it “on”?
7. What is the overall logic, or strategy, in the ants motion? Can you see it?
8. What do you thing of the buttons “diffusion-rate” and “evaporation-rate”? Try them with many different values to see if you can find out what they are doing.
9. If you work with one ant, and then with very few ants, do you notice any differences? Which ones.
10. In general, do you see if the population of ants plays a role in the situation? If yes, how you would describe it?