Ecosystem Food-webs as Dynamic Systems: Educating Undergraduate Teachers in Conceptualizing Aspects of Food-webs' Systemic Nature and Comportment

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Abstract

The current research aimed at attempting to familiarize Greek prospective Primary School teachers with notions of the dynamic systems nature of ecosystem food-webs and evaluate the results. The sample consisted of 85 undergraduate students of the Faculty of Primary Education, of the University of Athens, Greece, who had chosen the optional topic of the autumn semester: "Environmental Science: The Laboratory Approach".

Students were initially given specifically designed pre-test worksheets, to find out their initial knowledge and pre-instructional ideas about the structure and the properties of food-webs as systems. Following this, instructional-teaching took place in four stages.

In the first stage of the instruction process, students received real data concerning pellets of barn owls (tyto alba) gathered from two areas of the United States, and were asked to complete given worksheets. At this stage, students' discussions were recorded, hence trying to extract answers to issues such as: the food-webs' ability to reflect biodiversity; their mental representation of a food-web as a system; and what would happen should a "node" of the food-web-network disappear.

The second stage involved students interacting with computer software in two phases. In the first, students were asked to reconstruct, on a computer screen, the barn owl food-web, given the arrows and the food-web elements. In the second stage, students used the System Dynamics Modeler of the NetLogo (version 4.0.4) simulation environment, as an interactive tool for learning.

In the third stage, after familiarizing themselves with the Modeler, using the simple predator-prey ecosystem "Wolf Sheep Predation (docked)" model, students interacted with a variation of the Modeler, created in order to learn things about the stability and instability of food-webs as systems and, as a result, of ecosystems.

In the fourth-final-stage, following the instruction, post-test worksheets were handed out to students and stratified samples of them were interviewed on further ideas, predictions and possible extensions of their knowledge.

The results gathered helped to reach encouraging conclusions related to the fact that students seemed to have conceptualized food-webs as dynamic systems.
Keywords food-webs, dynamical systems, stability, teaching, NetLogo

1 Introduction

In the recent scientific literature, the study of ecological food-webs is important in understanding the systemic behavior of ecosystem populations, in revealing aspects of their comportment as complex systems, as well as in making predictions about their future states. Typical questions in this latter field of research are: whether an ecological system will become more stable or unstable in the case that one population becomes extinct, or whether the interconnectedness in the food-web is increased or decreased. Other problems concerning the systemic nature of food-webs are: (i) the degree of relation - if any - between the biodiversity and the connectivity in a food-web, (ii) the relative importance of the abundance of a population in the food-web as compared to its biomass content.

The relationship between the systemic structure of food-webs and the properties of ecological systems as "complex systems" has been thoroughly researched. It is stated, for instance, that when a hypothetical food-web is formed by adding edges at random to a set of N "nodes", a connectivity avalanche occurs when the number of edges is approximately N/2, which means that critical phenomena arise[1]. The critical phenomena have the form of a phase-change, where a connected sub-web is clearly formed, and the food-web looks more "connected".

Such relations between the systemic structure, food-web behavior and the complexity of ecological systems, are the basis of this research. The broader research project, carried out in the Faculty of Primary Education of the University of Athens, Greece, aimed at familiarizing prospective primary school teachers with the concepts of Complex Systems, specifically ecological systems. Similar researches have been carried out in many European and North American educational systems[2], due to its outmost importance in developing complexity-thinking abilities in future educators, especially with respect to non-deterministic thinking, holistic attitudes, absence of pre-existing ideas about a central-control in all ecological phenomena and non mechanistic, non-clockwise treatment of all procedures in nature[3-4].

The inherent relation between systemic-thinking and "complexity-thinking" is among the core ideas in this research[5-6]. A person who has developed the ability to conceive a system as whole and is additionally able to conceptualize the relations between these parts, is also capable of understanding complex system properties such as emergence and feedback loops[6]. The well known property of complex systems - "the whole is greater than the sum of the parts" - is implicit in the systemic treatment of natural entities.

Food-webs are a clear case of the direct relation between aspects of ecological complexity and the systemic nature of ecosystems. In a wide known definition given by Asher[7]: "...'complexity' is the multiplicity of interconnected relationships and levels." The existence of this property of multiplicity in ecological food-webs, when systemically treated, is obvious. Asher declares that all the characteristics so often attributed to complex systems (and, therefore, complex ecological systems), such as emergence and non-linearity, are consequences of the fundamental properties identified in his definition[8]. Another famous statement about complexity is that: "...Complex interactions result from multiple pathways linking organisms with abiotic resources"[9]. Once more these pathways become revealed in detail, within the ontological, systemic representations of food-webs in various ecosystems.

A broader link between ecological complexity and the systemic nature of food-webs is the notion of "connectivity", i.e. the number, form, complicatedness and scale of connections between organisms (but also between abiotic components) in an ecosystem[8]. The greater and broader the connectivity of a food-web, the more properties of complex systems is found in it. In Fig.1, connectivity is depicted as one of the aspects of ecological complexity[8].

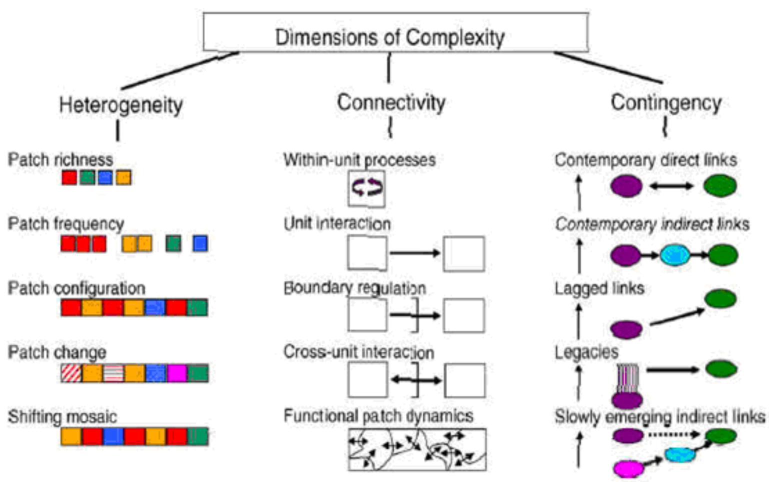


Fig.1 Connectivity as one of the aspects of ecological complexity. Connectivity and complexity increases from top to bottom.

Lastly, there is the concept of 'stability'. The majority of ecologists believe that as food-web complexity increases, the stability of the ecosystem as a whole increases[10-12], in the sense that no populations or species tend to become extinct or to have an unrestrained increase.

2 Method

2.1 The Objectives

The main scopes of the current research were:

(i) To test and improve the ability of prospective Primary School teachers (undergraduate students of the Faculty of Primary Education) to create representations and then construct (on paper and on screen) relatively simple food-webs, given the species that participate in these webs.

(ii) To help students conceptualize the main properties of food-webs as systems. For example, the property that not all populations have the same importance in the food-web, or that biodiversity and multiplicity of food-webs depend on geographic latitude (they increase as one moves from the polar to the equatorial zone).

(iii) To increase students' abstractive and comparative thinking, by providing them with a scientific/theoretical food-web, and then asking them to construct one similar to it based on the data of food-web-findings from certain areas.

(iv) Enticing students to examine the relationship between food-web interconnectedness and ecosystem stability.

Lateral objectives of this research were also to: help students understand and derive information from systemic diagrams; depict graphical representations of physical concepts, such as stability and instability, and to verbally express opinions about systemic properties of ecological systems.

2.2 Research Instruments

In addition to pre-test and post-test worksheets, with each one lasting one and a half teaching hour[1], undergraduate students were given data in form of Tables, Diagrams of food-webs, and Worksheets.

During each of the four teaching sessions (each lasting two hours) students had to complete a worksheet containing both open and closed questions. Recorded classroom discussions were instigated so as to reach unanimous conclusions.

Computer interaction was a composite part of each teaching session. Specifically:

(i) "Microsoft Word", with regards to its "Drawing" tools, and

(ii) "NetLogo version 4.0.4."[13] as well as the System Dynamics' Modeler, built-in in NetLogo.

2.3 Sample and the Settings

The sample consisted of 85 undergraduate students (66 women and 19 men) from the Faculty of Primary Education of the University of Athens, Greece, who

[1]Pre-test and post-test sheets, as well as the teaching sequences worksheets, are available, upon request of the reviewers.

had chosen the optional subject "Science and Environment: The Laboratory Approach".

Students were grouped with respect to the following parameters:

A. Year of studies (A1- freshmen to A4- senior)

B. Selected Biology as an exam subject for their University entry National Exams (B1 implies 'yes' and B2 implies 'no').

C. Students' orientation in the final year of high-school, namely: (i) Science, (ii) Humanities and Law and (iii) Technology, Economics and Informatics (Denoted as: C1, C2 and C3, respectively).

D. At high-school or university, did the student select optional topics relevant to computers? - This parameter implies a pre-existing familiarity with computers (D1 implies 'yes' and D2 implies 'no').

The sample of 85 students was divided into five groups; four of 18 students and one of 13 students. The first author of the paper met up with each group once a week, and the students worked either alone (e.g. when completing worksheets) or in groups of two or three, when working on a computer.

In the interviewing phase, each student underwent a recorded interview, lasting about an hour.

3 The Instruction Process and the Delivered Material

The overall teaching sequence started with a very short interview with each one of the 85 undergraduate students, in an effort to group them according to the parameter values mentioned above. Their basic knowledge of ecosystems and food-webs, if any, were also questioned.

Each group of students was then asked to complete a pre-test worksheet[2], with questions, tasks, and interactions with the computer.

Each group received four weekly teaching sessions (I to IV), each lasting two teaching hours (two 50 minute-sessions).

Teaching session I:

Students are given real data from a table[14], depicting findings regarding the pellets of the barn owl (tyto alba) from two different regions of the United States of America: Northwestern and Southwestern.

The table with the pellet findings is given in Fig.2.

The Barn owl (tyto alba) is a very important bird species for the study of food-webs and biodiversity, as it is a "high-level" predator and it has the property of emitting 'pellets', where the spinal cord of its preys remains intact. Therefore, by studying the pellets of the barn owl, one can more or less study the biodiversity and the abundance of the species living in a given area.

[2]Both the pre-test and the post-test sheets, as well as the teaching sequences worksheets, are available, upon request of the reviewers.

	Northwest United States				Southwest United States			
Prey: Groups and Genera	No. per 50 pellets[1]	Prey Weight[2], grams	Total genera biomass, grams	Total group biomass, grams	No. per 50 pellets[1]	Prey Weight[2], grams	Total genera biomass, grams	Total group biomass
Pocket Gopher Thomomys	7	150	1,050	1,050	**		0	0
Rat				450				1,890
Sigmodon	**				11	100	1,100	
Oryzomys	**				8	80	640	
Rattus	3	150	450		1	150	150	
Vole Microtus	12	40	480	480	8	40	320	320
Mice				386				402
Peromyscus	4	22	88		6	22	132	
Mus	7	18	126		11	18	198	
Reithrodontomys	6	12	72		6	12	72	
Perognathus	4	25	100		**			
Mole				110				165
Scapanus	2	55	110		**			
Scalopus	**				3	55	165	
Shrew				24				192
Blarina	**				7	20	140	
Cryptotis	**				11	4	44	
Sorex	6	4	24		2	4	8	
Other Prey				162				148
Bats	4	7	28		2	7	14	
Birds	6	15	90		4	15	60	
Insects	4	1	4		4	1	4	
Crayfish	4	5	20		2	5	10	
Small Reptiles	1	20	20		3	20	60	
Total Habitat Biomass / 50 pellets / region					2,662			3,117

Notes:

1. Assume each owl expels two pellets per day. Assume there is one owl per sample area. Data represents 25 feeding days.
2. Prey weight is the average for each species.

** Does not occur

Fig.2 The pellet findings for tyto alba in Northwest and Southwest U.S.A.[14]

Given the above table, students were asked to answer certain questions (more details follow in the results section).

Teaching session II:

In the second teaching session, which took place one week later, students were given a worksheet with an actual representation of the food-web of the barn owl (Fig.3), as derived from scientific literature[15].

The worksheet contained questions asking to correlate the theoretical food-web of the barn owl with the actual two food-webs that stem from the table in Fig.2.

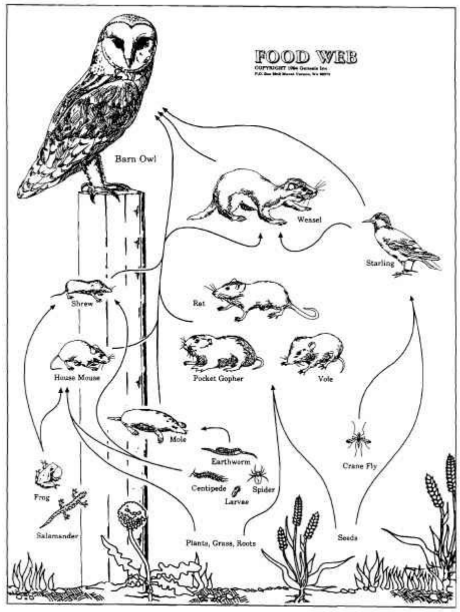


Fig.3 The Food-web of the barn owl, as given in the scientific literature[15].

Students attempt to represent, on paper, two food-webs (one for each region), where the names of prey and predators must correspond to the given pellet-findings table. This involved having to exclude or add species to Fig.3.

Following this, students answered questions regarding the complexity of the food-web as a system, in relation to geographical latitude, the relative importance of species and their biomasses in the food-web system.

Teaching session III:

In the third teaching session, students were given a simpler table of the barn-owl-pellet findings, containing only those species which have a significant change in their abundance between the Northwestern and the Southwestern States.

Students were asked to work in groups of two or three and to open an existing Word (*.doc) file named “Exercise in the Food-web of the Barn Owl.” A screenshot of this word file is depicted in Fig.4.

Students were asked to cooperate in moving the pre-existing arrows of the Word File and the pre-existing shapes, to form, on the screen, a simplified food-web of the owl, once for Northwest and once for Southwest. Each of the two files was uniquely named. They were then asked to answer a series of questions on the worksheet, the most significant being:

‘Question Number 9.

a) Which one of the two food-webs that you have represented on screen is more

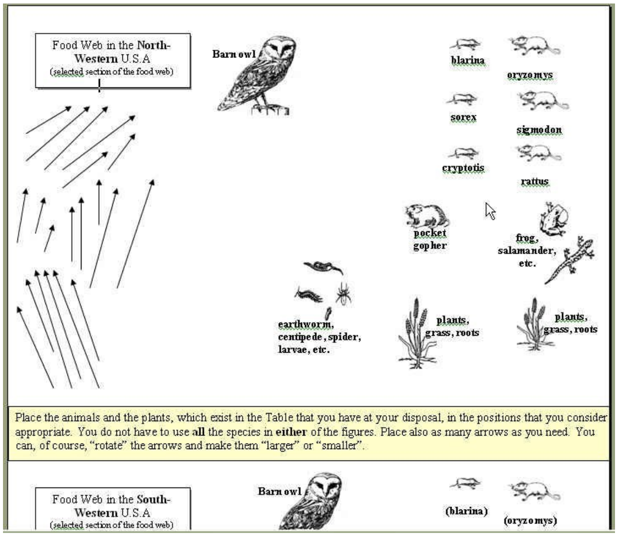


Fig.4 A screenshot of the Microsoft Word File Exercise in the Food-web of the Barn Owl. The objects (animals, plants and arrows) are movable.

complex? The one for the Northern or the one for the Southern United States? Justify our answer.

b) In which of the two food-webs does the species of the barn owl (tyto alba) have more possibilities of becoming extinct? Why?'

Teaching session IV

In the final teaching session, the students were asked once again to work in groups. This time, they interacted with the NetLogo version 4.0.4 programming and the simulation environment[13]. Specifically, they worked with the "Wolf Sheep Predation (docked)" Model[16]. This Model is accompanied with a "System Dynamics Modeler" file, created in Java platform[16]. Both these files in the Model are depicted in Fig.5 and 6 respectively.

Students, after trying to interpret the terms in the "System Dynamics Modeler" screen, focused on interacting with the sliders in the "Aggregate Model" section (right part of the interface screen) of the "Wolf Sheep Predation (docked)" Model. This section is nothing more than the graphical representation of a simple one-predator-and-one-prey population system, obeying to two simple Lotka-Volterra equations. Students were guided by questions in their worksheet, to try and "destabilize" this system, by finding certain positions of the three sliders ('predatorEfficiency', 'predationRate' and 'wolves-death-rate') where the wolves or the sheep become extinct, and hence, the other population becomes extinct too or deviates exponentially. The effort was to guide them to the conclusion that this is relatively easy, when there is such a simple food chain.

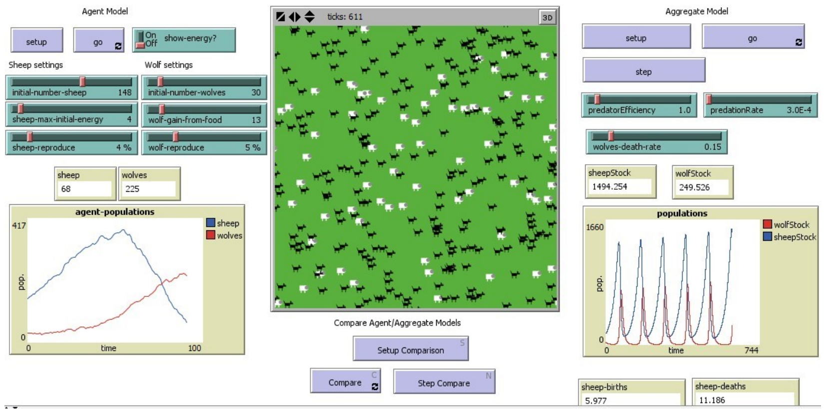


Fig.5 A screenshot of the NetLogo "Wolf Sheep Predation (docked)" Model[16], with both sections of the interface screen (the "Agent Model" and the "Aggregate Model") activated.

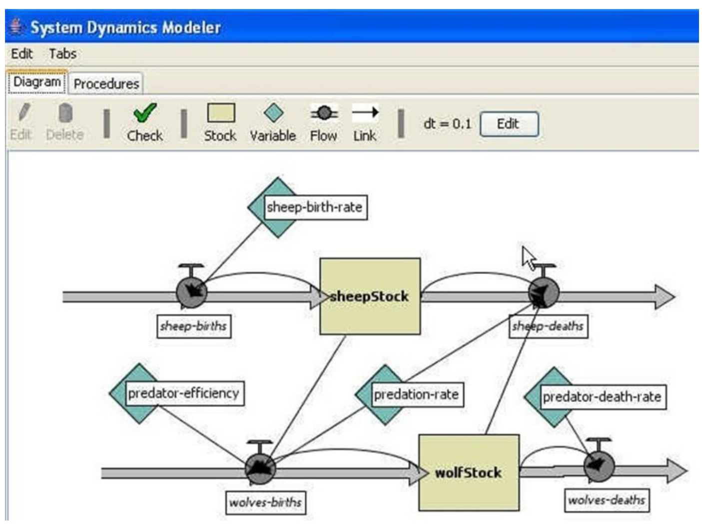


Fig.6 A screenshot of the System Dynamics Modeler screen, belonging to the NetLogo Wolf Sheep Predation (docked) Model[16]

In the next step of this session, students were confronted by a variation of this simple prey-and-predator system, where, instead of one there are two species of prey. The idea behind this concept is depicted in Fig.7 and in Fig.8. In Fig.7, the simple food chain of the initial "Wolf Sheep Predation (docked)" Model, is explained. In Fig.8, the new simple food-web is shown. This food-web was constructed, by creating a very simple variation of the "System Dynamics Modeler" that was named: “System Modeler Food-web without grass”.

In Fig.9, below the new “System Modeler Food-web without grass” screen,

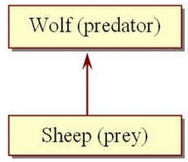


Fig.7 The food chain corresponding to the initial Wolf Sheep Predation (docked) model, in the Aggregate Model part.

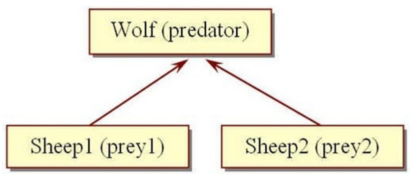


Fig.8 The simple food-web corresponding to the new “System Modeler Food-web without grass” Model.

which the students had in front of them in the computers, is depicted.

And in Fig.10, the interaction / interface screen of the same Model (“Sys-

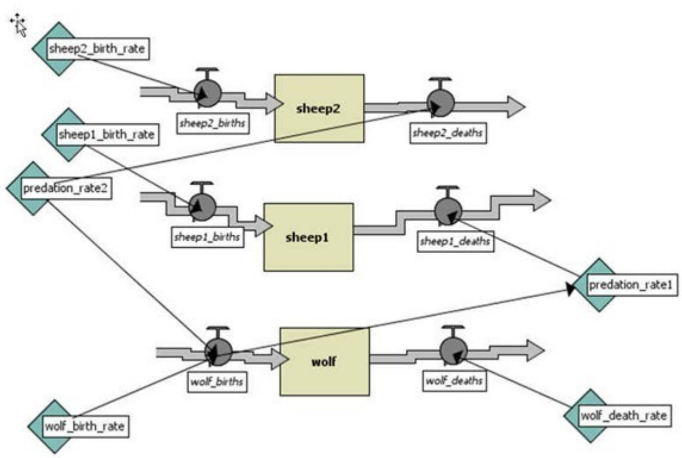


Fig.9 A screenshot of the “System Modeler Food-web without grass” Model (“Diagram” window from “System Dynamics Modeler”)

tem Modeler Food-web without grass”) is shown, where the students were again asked to "destabilize" the system, by making one or two of the three populations extinct, with the use of the sliders.

The concept behind this variation is that, in this case, it was more difficult

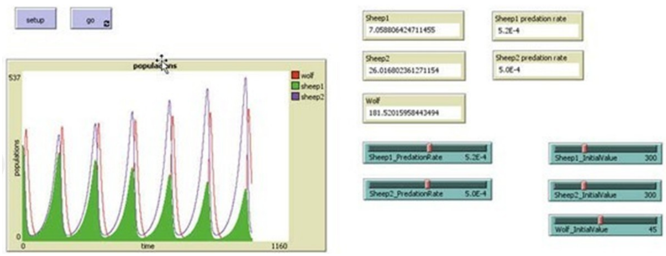


Fig.10 A screenshot of the interface of the "System Modeler Food-web without grass".

to "destabilize" the eco-system.

Twenty days following the final teaching session, a post-test was delivered to all groups of students[3], containing identical questions to the initial pre-test worksheet.

Following the teaching session, a phase of one-hour interviews with a "stratified" sample of 17 students, begun.

4 Results and Discussion

Initially, students were handed a diagram, similar to Fig.3, containing only the names and the images of the species involved in the barn owl food-web, without the predation connections between them. They were then asked to hand-draw the food-web, as they thought it should be and provide an explanation behind their food-web diagram.

a. 72 out of the 85 students (percentage 84.7% of the sample) drew the web with arrows pointing, as they should, from the prey to the predator.

b. 57 out of the 85 (percentage 67.1%) used in their argumentation on why they drew lines like that, the rationale "who is eaten by whom", instead of "who eats who".Both these findings imply that the students have conceptualized a "bottom to top" perspective of ecosystems as systems, instead of the "top to bottom" perspective, the former being considered as the appropriate systemic treatment[17].

At a later stage, the students were asked to create on paper, a barn-owl-food-web for the Northern and Sothern states of America. Here, the systemic-thinking

[3]Both the pre-test and the post-test sheets, as well as the teaching sequences worksheets, are available, upon request of the reviewers.

skill examined was to correlate the theoretically existing elements ("stocks") and relations ("flows") in a system, with the actual ones, even if the latter have sometimes different names.

The drawing of a student, Alex, for the Northern and for the Southern United States, are depicted below, in Fig.11.

The drawings of Alex show good correlation between given data and theory,

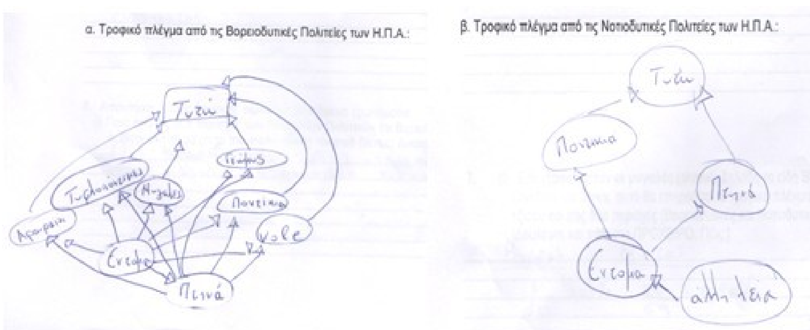


Fig.11 The food-web of the barn owl, as drawn by a student, Alex. Northwest U.S.A. (left) and Southwest U.S.A. (right)

even though this specific student reveals a "misconception", by creating a more complex food-web in the North instead of in the South.

Due to the discrepancies between the theoretical food-web and actual barn-owl-pellet table data, with regards to the type of species present, a "scoring system" was established for the drawings in the worksheets:

Whenever the student includes one of the eight species in his drawing, one (1) point is given. Whenever the student misses one species, or includes a wrong one, zero (0) points are given.

The actual scores and the corresponding numbers of students, are depicted in Table 1 below.

By calculating the average and the standard deviation of the scores of the students, we find:

$$\text{Mean value} = 4.36$$
$$\text{SD} = 1.85$$

The resulting mean value and standard deviation for the sample reveal a satisfactory ability to correlate to systems, achieved by the teaching sequence, which is an encouraging outcome.

Table 1 The scores of the n=85 students, in correlating the parts ("stocks") of the theoretical and of the actual (real-data) barn-owl-food-web.

Number of students	Score
4	0
3	1
5	2
12	3
21	4
13	5
19	6
6	7
2	8

In concluding the results concerning objective (i), some statistical analysis was performed. Frank Draper [18], based on earlier work of Barry Richmond[19] proposes seven skills of systems thinking of students and the associated levels of activity[18]. Each skill has also levels of acquainting it within it. For the current work, only the following skills and the specific sub-levels were considered relevant, ordered in increasing achievement difficulty:

Table 2 Some of the proposed skills of systems' thinking of students and the associated levels of activity[18] as they were selected for the current work.

Skill 1 (structural thinking), Level II	Identifying stocks and flows in phenomena
Skill 3 (generic thinking), Level II	tabincellcRecognizing and using stock-and-flow generic structures
Skill 4 (operational thinking), Level II	Building paper-and-pencil stock-and-flow diagrams
Skill 5 (scientific thinking), Level I	Manipulating and modifying pre-constructed computer models
Skill 6 (closed-loop thinking), Level I	Identifying simple internal causal relations

In the pre-test and post-test work sheets, with questions and interactions with the computer, there was effort to measure all these skills, based on a marine food-web, as retrieved by[20].

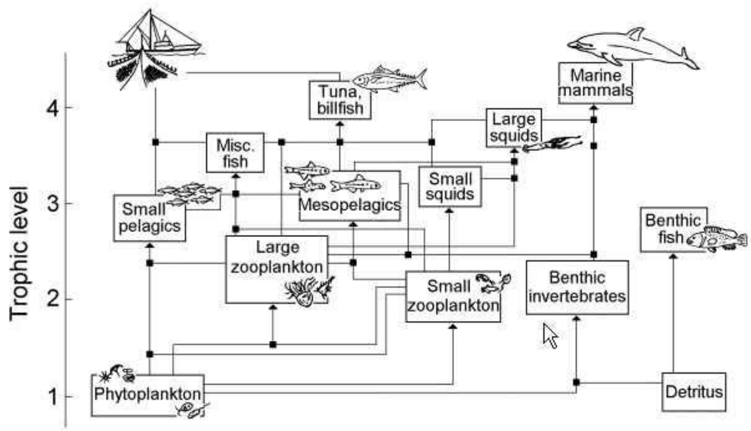


Fig.12 The marine food-web delivered to the students in the pre-test and post-test worksheets[20].

By semantically-analyzing and content-analyzing students' answers in both pre and post test, each was graded from 0 to 5 according to the skills demonstrated by their answers. Following this, the non-parametric Wilcoxon signed-rank test was carried out. There were statistically significant shifts of systemic-thinking skills in all levels of the scale 0-5. The results are briefly depicted in Table 3 below.

Table 3 Results of the non-parametric Wilcoxon signed-rank test for the sample of n=85 students.

grade	significance level
0	p= .018 (¡0.05)
1	p= .014 (¡0.05)
2	p= .021 (¡0.05)
3	p= .023 (¡0.05)
4	p= .019 (¡0.05)
5	p= .011 (¡0.05)

The findings are again considered encouraging, for the impact of the chosen teaching method.

Objective (ii)

Referring to the "relative importance" of each population ("stock") in the food-web- as-a-system, the students had to use the Table of food-web-pellets, together with simple calculators, to answer specific questions :

Q1: Which species of prey contributes more to the barn owl's food in each area of U.S.A. (Northern and Southern)?

Q2: Is this the same species for both areas?

Q3: If all the species of shrew (blarina, cryptotis and sorex) become extinct, which one of the two areas' food-webs will be affected more? Or will they be equally affected? Justify your answer.

Q4: If the only species of vole (microtus) becomes extinct, which one of the two areas' food-webs will be affected more? Or will they be equally affected? Justify your answer.

We briefly present the "correct" answers to Q1-Q4 and the corresponding ratio of students that found them:

Q1: the mice. (Correct answers: 76 out of 85. Percentage 89.4%)

Q2: yes, it was the same. (Correct answers: 71 out of 85. Percentage 83.5%)

Q3: the South will be affected much more. (Correct answers: 40 out of 85.Percentage 47.1%)

Q4: the two areas will be almost equally affected. (Correct answers: 32 out of 85.Percentage 37.6%)

In the following Fig.13, the percentages of correct answers, with respect to each question, are presented as a bar chart.

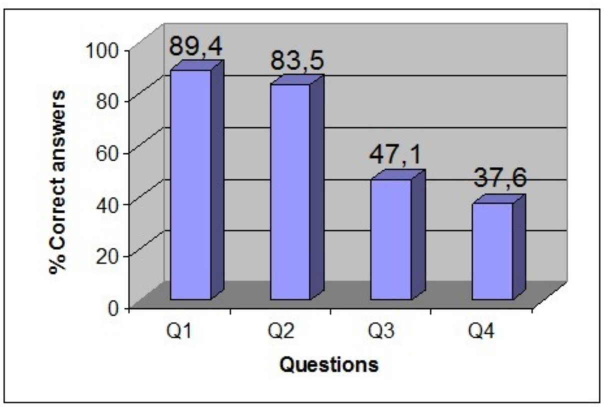


Fig.13 The percentages of students' correct answers, with respect to each question.

What can be observed is that within the same food-web as a system, the students are adequately capable of finding the prevailing "stock" (population), but this capability is reduced, when having to think comparatively between two food-webs/ systems. This has also been noticed by other researchers[21].

The answers obtained, regarding the question outlined below are shown in Table 4.

'The diversity of species and the complexity of the food-webs increases, de-

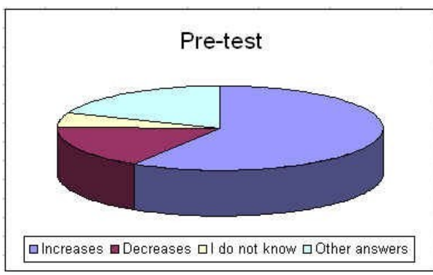
creases or does something else, as one moves from the poles to the Equator? Explain your answer.'
From the n=85 undergraduate students, the results were:

Table 4 Results of the non-parametric Wilcoxon signed-rank test for the sample of n=85 students.

	"Increases"	"Decreases"	"Do not know/ I cannot answer"	Other answers
Pre-test	50	14	5	16
Post-test	73	6	r.2	4

In Fig.14, the findings of Table 4 are expressed in the form of pie charts.

It is easily concluded, that following the teaching sequence, students seem to have conceptualized that as the geographical latitude decreases in absolute values, the diversity and the connectedness of food-webs as systems increases.



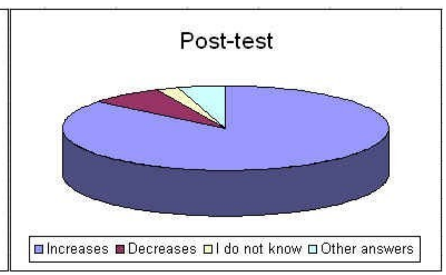


Fig.14 Comparative pie-charts, depicting the relative (%) answers of the students to the question referring to biodiversity and the geographical latitude, in the pre- and post-test.

Objective (iv).

After interacting with the Word file "Exercise in the food-web of the barn owl" (Fig.4), students were confronted with two questions in their worksheets:

Q1: Which one of the food-webs is more complex? The one of the North or the one of the South? Justify your answers.

Q2: In which one of the two webs, the barn owl faces greater dangers of becoming extinct?

It was considered as encouraging that in both questions the students selected the correct statement, which means:

In Q1 : 63 of the 85 students (74.11%) answered "the food-web of the South".

In Q1 : 55 of the 85 students (64.71%) answered "in the food-web of the North".

Table 5 The answers of the students referring to stability as related to food-web complexity.

	"I agree"	"I disagree"	"Do not know/ I cannot answer"	Other answers
Pre-test	46	21	11	7
Post-test	68	11	5	1

Furthermore, both in the pre-test and the post-test, there was the question:'Do you agree or disagree with the following statement: "The more complex the food-web is in an ecosystem, within an area, the more stable the ecosystem is, i.e. the more difficult it is for species populations to become extinct." Justify your selection.'

From the n=85 undergraduate students, the results were:

It is apparent that the opinion of students, after interacting with the software and with the barn-owl-pellet data, lies closer to that which prevails in science nowadays. Additionally, students' ability to correlate food-web interconnectedness with ecological stability improved through their interaction with the "Aggregate Model" of the NetLogo "Wolf Sheep Predation (docked)" Model. Following attempts to 'destabilize' the system by moving the sliders in Fig.5, students were asked to fill-in the cloze question in the worksheet:

The system becomes unstable, i.e. one population is extinct, in N1 =...cases or in N1=...combinations of the three slider values [here we expect the same integer number]. These values are ....

The same was repeated for the System Modeler Food-web without grass (Fig.10)

This new system becomes unstable, i.e. one population is extinct, in N2 =...cases or in N2=.... combinations of the two slider values [here we expect the same integer number]. These values are.......

In the first case N1 varied from 1 to 6, and in the second case N2 varied from 0 to 2. The exact results are depicted in Table 6.

Table 6 The findings for the n=85 students, as regards the (integer) number of cases they succeeded in destabilizing the system of populations.

Integer Number	Mean Value	Standard Deviation
N1	3,418	1,082
N2	0,760	0,112

The drawn here is that the more "complex" the food-web the more difficult it is to "bring it to instability".

5 Conclusions

The overall teaching sequence used, including drawing of shapes, interaction with simple computer software, oral instruction, as well as discussion and personal interviews with the undergraduate students, seemed to have had adequate results in their conceptualizing the systemic properties and comportment of food-webs.

The students within the evaluation phase in each worksheet, as well as during the post-test stage, gave answers and descriptions regarding: food-web structure, relation of food-web complexity with ecosystem stability and the dynamic system properties of the food-web, which were close enough to the scientifically accepted ones.The research is still continuing with interviews and new samples of students are being used for instruction.

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