ENHANCING FIFTH GRADERS UNDERSTANDING OF COMPLEX ECOSYSTEMS THROUGH A MODEL-BASED APPROACH UTILIZING STAGECAST CREATOR™

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ABSTRACT
We report a study in which we designed and implemented a curriculum within the context of ecosystems aimed at fostering scientific modelling skills and enhancing conceptual understanding among fifth graders through the use of Stagecast Creator™. We describe how activities supported students to improve and expand their models by adding new information collected from observations and personal knowledge about real-life ecosystems. Paper-and-pencil tests were used both before and after the study to evaluate students' modelling skills and understanding of concepts related to ecosystems. The data analysis followed both qualitative and quantitative methods. The results indicated the importance of the synergy of the study's goals: to learn about marine ecosystems and develop modelling skills. We found significant differences between students' pre- and post-test scores, suggesting that our approach facilitated the development of both modelling skills and enhanced conceptual understanding of marine ecosystems of fifth graders.

KEYWORDS
Modelling skills, ecosystems conceptual understanding, computer-based tools

INTRODUCTION

A number of researchers underline the necessity of integrating technological tools in science teaching and learning (Barab, Kenneth, Barnett and Keating, 2000; Hogan and Thomas, 2001). The research outlined in this paper has been triggered from these calls for reforming the science curriculum. Specifically, we report on a study in which we designed and implemented a curriculum within the context of ecosystems aimed at fostering scientific modelling skills and enhancing conceptual understanding among fifth graders through the use of SC. In addition, we discuss how the SC contributed towards the enhancement of conceptual understanding and modelling skills.

THEORETICAL BACKGROUND

A plethora of units in science curriculum involve the study of dynamic systems, e.g. biotopes in ecology, barometric phenomena in climatology, circulatory system in anthropology, etc. The complexity of the structure of these systems, as well as the simultaneous multivariate processes being executed within them impede learners' understanding of concepts and relationships related to the system. Therefore, the acquired knowledge is isolated, fragmented and inert. Many researchers (Stratford, Krajcik and Soloway, 1998; Wilensky and Resnick, 1999; Louca, Druin, Hammer and Dreher, 2003) have argued that systems' exploration and understanding would be facilitated, if students are given the opportunity to explore these systems through creating dynamic computational models. Through the creation of dynamic models students are engaged in a process of combining isolated knowledge about poorly-understood concepts and relationships into larger, more clearly-understood constructs in a way that allows them to represent, reconstruct and explore that knowledge within a computational model (Stratford, Krajcik and Soloway, 1998).

Consequently, meaningful learning in science can be thought of as a dynamic process of building, organizing and elaborating knowledge of the natural world. According to Constantinou (1999), physical science can be characterized as a complex network of models interrelated by a system of theoretical principles. Models are units of structured knowledge used to represent observable patterns in physical phenomena. Accordingly, physical understanding can be perceived as a complex network of modelling skills, that is, cognitive skills for making and using models (Booch, Rumbaugh and Jacobson, 1999; Stern, 2000). The development of modelling skills provides the opportunity for students to make sense of their own physical experiences and to evaluate information reported by others.

The modelling approach can potentially provide a backbone structure for constructing meaning in physical science. In this approach, students are guided to develop a set of generic modelling skills in one domain and to transfer those same skills in other domains, further elaborating and developing them with experience and practice. The modelling approach to learning is iterative in that it involves continuous comparison of the model with the reference physical system with the express purpose of gaining feedback for improving the model so that it accurately represents as many aspects of the system as possible. It is also cyclical in that it involves the generation of models of various forms until one can be found that successfully emulates the observable behaviour of the system (Papadouris and Constantinou, 2001).

The study of ecosystems can be used as a multidisciplinary platform for the development of modelling skills, because ecosystems are physical entities consisting of organised units of biotic and abiotic elements, as well as relationships and interactions among its consisting units. The constituent components of an ecosystem determine, control and modify ecosystem's operations. Each part affects the behaviour of the whole, depending on part's interaction with other parts of the ecosystem. Understanding and reasoning effectively about ecosystems involves understanding a number of different types of causal patterns. Particulary, while tracing food effects perturbations, one might apply two kinds of causality patterns: simple linear causality or domino like and interactive causality (Bell-Basca et al., 2000). Linear causality refers to a causal pattern where an initial cause triggers a chain of consecutive effects, and every new effect becomes a new cause (e.g., the disappearance of the primary consumers within an ecosystem may result in the disappearance of secondary consumers and in turn to the disappearance of tertiary consumers and so on). Interactive causality refers to the case where a change in a species population can be a cause and effect at the same time. For example, an increase to the population of primary consumers within a food web could be the cause of a decrease in the population of the producers and the effect of the increase in the population of secondary consumers.

A number of researchers that aimed at exploring students' conceptual understanding of various concepts related to ecosystems came to a congruity that students hold numerous of misconceptions about ecosystems and the nature of interrelatedness of the components of ecosystems (Adeniyi, 1985; Barman, Griffiths and Okebukola, 1995; Hogan, 2000; Bell-Basca et al., 2000). For example, Strommen (1995), while examining first graders' conceptions of a forest habitat, found that students' ideas consisted of mostly concrete facts that missed the broader conceptual relationships among the rest of the organisms of the ecosystem. This weakness was associated with students' deficiency of systemic thinking. Additionally, Barman, Griffiths and Okebukola (1995) noticed that students believed that a change in one population will not be passed along several different pathways of a food web and that a change in one population will only affect another population, if the two are related in a predator-prey relationship. Similarly, the results of Hogan's (2000) study point to limitations in awareness of patterns of systems interactions as constraining students' systems reasoning in ecology.

The advent of age-appropriate computer-based modelling tools (e.g. Stagecast Creator, Model-It, Logo) enabled new ways of overcoming some of the conceptual and reasoning difficulties associated with the representation and interpretation of complex systems. An important aspect of computational modelling is that it allows students to visualize abstract concepts (Barab, Kenneth, Barnett and Keating, 2000), complex relationships (Singer, Krajcik and Marx, 2000) and multiple processes by creating structures through which they can explore and experiment. Although computational tools seem to be promising in facilitating individual's learning, a few studies have focused on student's development of modelling skills (Talsma, 2000; Carney, 2002). Van Driel and Verloop (2002) stated that 'not much is known about the variety of teaching activities concerning models and modelling that are actually applied by science teachers…' (p. 1258). Our study is focusing on this exact issue. More specifically, our study aims at answering the following questions:

- Is it feasible to foster conceptual understanding in the domain of ecosystems among eleven year olds through a modelling-based approach?
- Can a computer based environment be used to support, in an efficient way, students' development of modelling skills and conceptual understanding in the context of ecosystems?

METHODS

Participants and setting

The sample was comprised of 16 fifth graders (8 boys and 8 girls) who were studying in a mid-sized suburban school in Cyprus. Participants were randomly assigned in groups of four and were asked to work for the purposes of the study in the school's computer lab. Each group had access to a computer. Despite the fact that all participants were computer literate, special attention was given to orienting students to the use of Stagecast Creator (SC). The intervention lasted about two months.

Experimental design

The research was carried out in two stages (see figure 1).

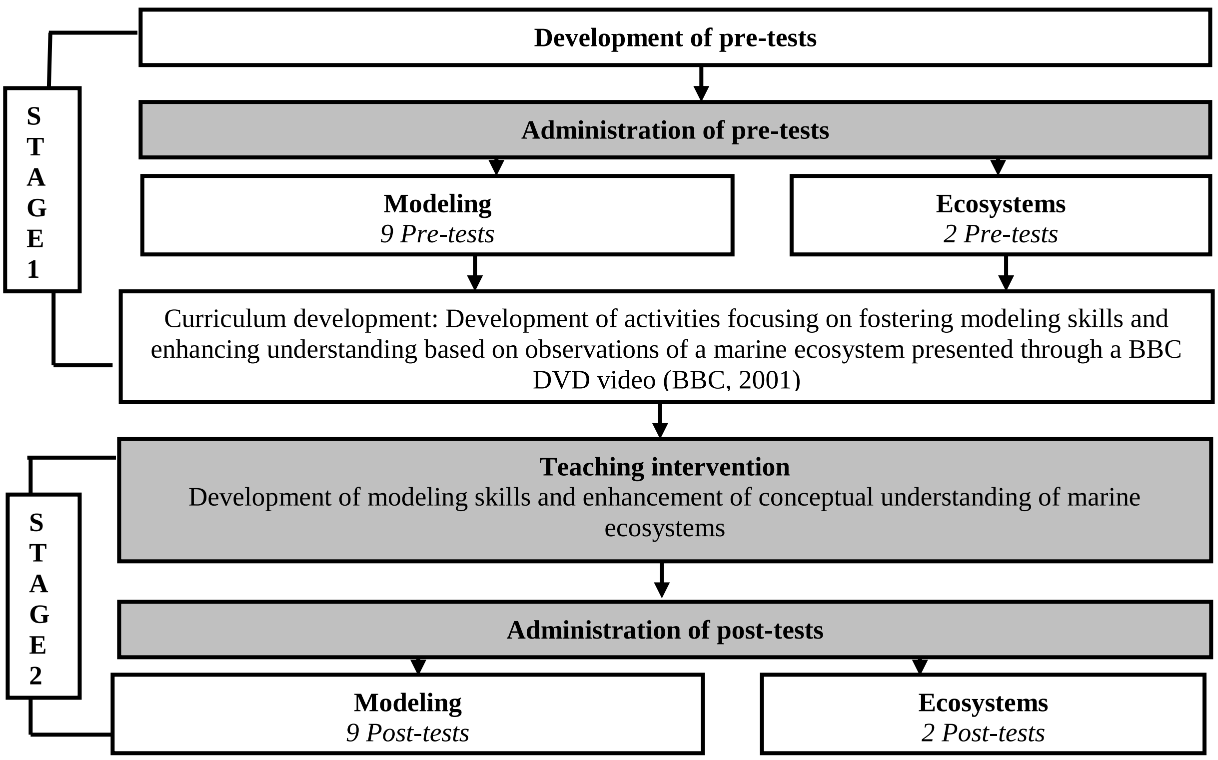

Figure 1. Experimental design

Stage 1

Stage 1 involved the development of the curriculum materials that were implemented during the intervention. Hence, we undertook epistemological analysis of both modelling skills and the concepts related to ecosystems in order to identify prerequisite concepts and skills for the development of curriculum focusing on the enhancement of modelling skills and conceptual understanding

Based on the epistemological analysis of each of our objectives, we developed a series of pre-tests to evaluate students modelling skills and conceptual understanding related to ecosystems prior to the intervention. Descriptions of each of the pre-tests are provided in Table 1.

Table 1. Descriptions of Pre-tests that Evaluate Modelling Skills and Conceptual Understanding of the aspects of the Concept of Ecosystem

Skill / Conceptual understanding	Pre-test	Context	Aspects
Modelling	*Pre-test 1*	Traffic system	Model formulation
	Pre-test 2	Traffic system	Extraction of information from a given model
	Pre-test 3 & Pre-test 4	Bicycle	Comparing models and real phenomena
	Pre-test 5 & Pre-test 6	Elbow	Comparing one model to another
	Pre-test 7 & Pre-test 8	Respiratory system	Appreciation of a model as a representation of a physical phenomenon
	Pre-test 9	Ant colony	Consistency of a model with all relevant phenomena and ideas for improvement
Ecology	*Pre-test 1*	Forest ecosystem	▪ Understanding of the basic needs of living organisms ▪ Formulation of food chains ▪ Populations relationships ▪ Ecological balance
	Pre-test 2	Forest ecosystem	▪ Understanding and formulation of food chains ▪ Food relationships ▪ Population concept ▪ Reproduction rate ▪ Species interactions ▪ Understanding and formulation of food pyramids ▪ Ecological balance

Data collected through the various pre-tests were analysed using phenomenography (Marton & Booth, 1997). Both the types of responses and the difficulties (e.g. conceptual, reasoning, epistemological) that emerged from the analysis guided our effort to design a structured intervention to help participants overcome specific difficulties and gain conceptual understanding concerning concepts related to ecosystems.

The development of modelling skills begins by observing a physical phenomenon, whose complex procedures and operations between its features make it difficult for individuals to gain a clear understanding of how this phenomenon is executed in real life. In our case, the complex phenomenon that students were expected to model was a marine ecosystem. Students were given a DVD titled "The Blue Planet" (BBC, 2001) and had the opportunity to access and study it in several stages of the intervention. The idea was to allow students to make observations of the physical phenomenon, collect information that was needed for their model, make comparisons between the physical phenomenon and their model, etc.

The next decision we had to consider concerned the modelling medium which students had to use to build their models. We decided to utilize SC in our study as it has been used effectively for the development of modelling skills among middle-school students (Constantinou, 1999; Louca & Constantinou, in press). SC is a programming environment that enables the design of microworlds (Smith and Cypher, 1999), and hence the building of models, although it has not been designed to be used as a modelling tool. Programming in SC is done by demonstration (the user can create a script which is monitored and modelled by the program, and this script can be performed by the program when the criteria of its original design are met), without writing a code or syntax as is needed in traditional programming languages, and hence it becomes accessible for use with younger children.

The development of the curriculum was based on the philosophy and principles of the "*Physics by Inquiry*" pedagogy (McDermott 1996). This teaching approach rests on the premise that students are more likely to learn physics when they are engaged in both hands-on and minds-on activities. Students always work in groups of three or four and interact with materials in order to gain experiences and develop practical and scientific skills, as well as the ability to process and manipulate multiple representations. Throughout the instruction, students are expected to perform observations, formulate hypotheses, construct operational definitions for the concepts they are inventing, develop interpretative models accounting for their observations and evaluate them on the basis of specific epistemological criteria.

Overview of activity sequence

In the first activity, students observed a marine ecosystem as presented in the DVD (BBC, 2001) and at the end they answered specific questions (e.g. "*What is going to happen if the phytoplankton vanishes in the sea?*", "*Which of the following organisms (shark, phytoplankton, herring) has the largest population in the sea?*", etc) based on what they already knew about marine ecosystems and what they observed through watching the DVD. They discussed their answers in their groups and no answer was given to the students by the instructor until the end of the intervention. Right after, they were prompted to make a drawing of the observed phenomenon, compare it to their peers' drawings, and discuss about similarities and differences between their drawings. Through the curriculum, students were informed that the drawing they sketched to represent the observed physical phenomenon was called a *model*, and that individuals often construct models to improve their understanding of a physical phenomenon.

Afterwards, students watched preselected segments of the DVD and they were asked to identify the three basic needs (nutrition, reproduction, shelter) of the organisms that lived in a marine ecosystem. The next step of the activity sequence was related to model improvement; students had to go back to their initial paper-and-pencil model and add further information to represent the three previously identified needs of the marine organisms. After completing this task, a classroom discussion was organized by the instructor to summarize the steps that were followed for model improvement [(i) compare the model to the physical phenomenon, (ii) identify new features from the physical phenomenon that have not been included in the model, (iii) represent the new identified features to the model, (iv) the new product is the improved model of the physical phenomenon].

By the end of this discussion, students were challenged to state whether the drawing was the most appropriate tool to formulate a "good" model for the observed phenomenon, and hence they identified possible disadvantages of the paper-and-pencil models (e.g. they are static representations, they do not inform us what is happening as time passes, etc). After identifying the weakness of formulating paper-and-pencil models, students were encouraged to suggest other tools that would enable them to develop dynamic models to represent in a better way the physical phenomenon. Students recalled their previous experience[1] with SC that enabled them to build better models, as it allows to make the characters of the model move around in the screen. Therefore, they improved the paper-and-pencil model by building a dynamic model of the observed marine ecosystem in SC. At this stage we did not expect that students would build a complete model of the physical phenomenon by programming all characters to perform

[1] The study reported in this paper is part of an extended study that aimed to develop programming skills and modeling skills to fifth graders through the use of SC in the context of marine ecosystems. Prior to the reported study, the same participants have been working with SC for two months period and they were guided through a specially developed curriculum to develop several aspects of the programming skill.

all the observed behaviors, but what was anticipated was to include some of the organisms and setting, through programming, some of their behaviors (e.g. movement) to their models.

In order to reduce the complexity of the ecosystem due to the multiplicity of its inhabitants, we decided to isolate nine organisms of the marine ecosystem (phytoplankton, kelp, herring, crab, mussel, urchin, sea otter, sea-gull, shark) to help students focus on organisms' behavior and interactions within the ecosystem. Students collected relevant information about their nutrition habits for each of these organisms from particular segments of the DVD, as well as from additional informative leaflets specially designed for the purpose of this activity. As soon as students organized the collected data in a two column table referring to "*Who eats who*" and "*Who is eaten by whom*", they were introduced to new concepts related to the previous activity. The new concepts were *nutrition, producers, consumers, food relationships, predator and prey*, and *energy*, and they were prompted to apply the new concepts to the case of the organisms being studied (e.g., name the producers/consumers, write sentences to show which organism is the predator for whom, etc). This activity served as a prerequisite to the formulation of food chains; students were called to represent a food relationship between two organisms of the marine ecosystem in a diagram by linking the corresponding organisms with an arrow according to their food relationship. At the end of this task, they got informed that this was called a "food chain" and they were encouraged to discuss why the term "food chain" was appropriate for this type of diagram. What we aimed through this activity was to guide students to identify the food chain as a *food relationship model* and, also, to appreciate the importance of the food chain model as a means to represent a relationship between two organisms in a minimal manner. An extended activity came next, challenging students to produce a diagram in which every single food chain was linked to another through energy transfer arrows, based on common food relationships among the organisms, and therefore the concept of a food web was introduced as an extended version of the food relationship model.

Based on what they had learned so far, students were encouraged to go back to their original SC model and make improvements in such a way that their refined model included the nine organisms being studied, and also, their food behavior for each of them. In order to build the food behavior for a character, students were expected to use the concept of energy for this character. Then, they created a rule so that a character's level of energy was associated to its eating habits and movement rules (e.g. the character would gain some amount of energy when eating a particular prey and loose an amount of energy as it moved in the sea). Finally, they created a rule for removing a character from the screen (it represents its death), when its energy level dropped below a specified number. During this activity, students could access the real marine ecosystem through the DVD, make comparisons between their evolving model to the physical phenomenon, and improve their model so that it represents more aspects of the corresponding phenomenon. At the end of this activity, students were introduced to the concept of *ecosystem*, and discussed issues regarding its components and the processes that occured within it.

The next activity aimed at introducing two new concepts; *population* and *reproduction*. The new concepts were discussed with reference to the concept of energy, and right after students were prompted to compare their SC model to the physical phenomenon by focusing on the population and reproduction issues. Finding out that their model did not represent the process of reproduction, and that the population size for each of the species had been verified in a random manner, students went through a new model revision phase in order to enrich their model. What we expected students to do at this stage was to create rules for reproduction, decide the energy level of the parents that would be able to mate and specify the energy level of the offspring.

At this stage, the instructor organized a classroom discussion on whether the food web model that had been developed in the previous sessions enabled students to collect information of the population size of each of the marine organisms. After identifying the weakness of this particular model concerning the representation of the population size, students were told to make a drawing (a new model) to represent the relative size of the population of the nine organisms. Through guiding instructions and prompts, students worked collaboratively to draw a food pyramid, and hence the curriculum introduced the concept of *food pyramid*, as well as relevant concepts such as *producers, 1st class consumers, 2nd class* *consumers*, etc. As soon as students got familiar with these concepts, the instructor organized a classroom discussion through which students identified the pyramid as a model to represent population and food relationships.

At this point, students would have already formulated three different models based on their understanding of how the marine ecosystem being studied operates; these are the *SC model*, the *food web model*, and the *food pyramid model*. In order to differentiate the three models based on their role and their scope, students made comparisons among these models and specified the different kinds of information one could collect through studying each one of the models. We considered this activity as fundamental to the development of modeling skills, because it set the boundaries to the development of epistemological awareness concerning models and modeling in science. In other words, we expected that students after the study would be able to reason why it was important to build models of a physical phenomenon.

In order to complete the development of the concept of the ecosystem, students were introduced to the concept of *ecological balance* through studying two food pyramids, one being at the state on ecological balance and the other at the state on ecological imbalance. Students were prompted to predict what was going to happen over time to the ecosystem that each pyramid represented, and in order to test their prediction, they were asked to decide which of the previously models they developed would help them in this way. Hence, they tested their prediction using the SC model (the population size of the each of the species was reduced or increased according to the food pyramid), and observed what happened as time passed. Based on this activity, students were expected to name the SC model as the “ecological balance model”, and investigated different scenarios related to the ecological balance of the ecosystem (e.g. what was going to happen if the phytoplankton vanished? etc).

As a final activity, the instructor organized a classroom discussion where students were guided to summarize the various steps that should be followed when modeling a physical phenomenon and discussed the features that should be included in a model: (*objects*, *variables*, *interactions*, *procedures*). Students were encouraged to identify and applied each of these features to the ecological balance model.

Stage 2

Stage 2 involved the implementation of the study’s curriculum. The curriculum included checkpoints at specific stages where students were asked to discuss their findings and reasoning with the instructor. The role of the instructor is to help students articulate their thoughts, identify inconsistencies regarding their models and also negotiate epistemological, conceptual, practical or any other difficulties they might encountered.

After the completion of the intervention, the same pre-tests that were administered at the beginning of Stage 1 were administered again to the participants to obtain comparable pre-test and post-test results concerning students’ mastery and transfer of modelling skills and conceptual understanding in previously unfamiliar domain. The context of each of the pre- and post-test differed to the context of the curriculum that was implemented during the intervention in order to ensure students’ ability of transferring skills and concepts in new contexts.

RESULTS

The data obtained through the various tests were analysed in two ways. First, open-ended questions were analyzed using phenomenography (Marton & Booth, 1997), and responses subsequently coded and transformed for analysis by MANOVA, Repeated Measures, to test whether there were any significant differences in the responses prior to and after instruction.

The results that produced from the statistical analysis and refer to the comparison of students’ conceptual understanding of various aspects related to ecosystems in the pre- and post-tests, are shown in Table 2.

Table 2. Summary of Quantitative Results Obtained Through the Pre- and Post-tests Concerning the Development of Conceptual Understanding in the Context of Ecosystems

Aspects of the concept of ecosystem*	**Wilks' λ**	**F**	**Hypothesis df/error df**	**Sig.**	**Partial η^2**
Understanding of the basic needs of living organisms	.11	125.69	1/15	.0001	.89
Organizing a set of given species on a food pyramid	.44	19.129	1/15	.001	.56
Understanding of population relationships among given species	.11	120.65	1/15	.0001	.89
Prediction of the consequences within an ecosystem due to a dramatic change in the population of a species	.076	183.54	1/15	.0001	.92
Evaluating the change within an ecosystem with the most serious consequences	.12	140.55	1/15	.0001	.88
Identifying a food pyramid that is at the state on ecological balance	.50	15.00	1/15	.002	.50
Drawing the progress of two food pyramids, one that is at the state on ecological balance and one that is at the state on ecological imbalance, over time	.17	73.54	1/15	.0001	.83

* *For each aspect, students were required to explain the reasoning behind their answer.*

As is shown in Table 2, the results indicate significant differences between students' scores in pre- and post-test scores for all aspects of the concept of ecosystem. The multivariate η^2 based on Wilks' λ for all aspects of the ecosystem was quite strong (ranging between .5 and .92), indicating that a great percentage of multivariate variance of the dependent variable (conceptual understanding performance) of the MANOVA model is associated with the group factor (intervention).

In order to highlight the contribution of SC to the development of modelling skills and conceptual understanding in the context of ecosystems, we provide the qualitative results of two questions related to students' ability to predict the consequences to an ecosystem, when a particular change in the population of one species occurs. Those results are shown in Table 3.

Table 3. Types of Responses, Quotes and Frequencies of Students' Performance in Two Items of Pre-Post-test 1 Prior To and After Instruction

Item	**Type of response**	**Quote**	**Frequency (n)** Prior to Instruction	After
Item 4.1 (pre-test 1)	Correct response with correct reasoning	*Yes, it will change. The crows will be on the verge of extinction and probably the insects will be increased and eat more plants, so the plants will be reduced and the monkeys will probably reduced. The crows will be on the verge of extinction, because they will not be able to find food, e.g. frogs. The insects might increase, because their predators –the frogs – will vanish and the monkeys might also disappear, because they feed on plants and the insects will eat more plants now. To be more confident with my response, I would like to have a model of ecological balance in SC to observe what is going to happen when this change occurs.*	0	15
	Partial response answer with correct reasoning	*The crows will disappear, because they will not have any food to feed in.*	12	1
	Wrong response or irrelevant response or failure to respond	*It will change, because if the frogs that are green, then there will be only soil on the ground.*	4	-
Item 4.2 (pre-test 1)	Correct response with correct reasoning	*The plants will decrease and since the plants are on the basis of the pyramid, every other organism will decrease. When the plants decrease, the insects will not be able to find food and they will decrease. Hence the frogs won't find food and they will decrease, the crows will decrease, because they feed on frogs. But in order to be surer of what is going to happen, I need a model in SC to run and see if my answer is correct.*	0	13
	Partial response answer with correct reasoning	*The plants will decrease, because they will be consumed by the monkeys.*	9	3
	Wrong response or irrelevant response or failure to respond	*It won't change anything, the monkeys feed on birds, if they left (the monkeys), it would be better.*	7	-

The results provided in Table 3 indicate that, after instruction, participants were able to provide correct predictions regarding the consequences to the population of each species after the occurrence of a particular change. Based on the quotes of the correct responses with correct reasoning, it is evident that students appreciate SC contribution as a modeling tool (e.g. "*I would like to have a model of ecological balance in SC*"), as well as a conceptual tool (e.g. "*I need a model in SC to run and see if my answer is correct*") to guide their learning in the context of ecosystems. Their responses also emphasize the development of epistemological awareness towards models and the modeling process; this is inferred when students end their response by highlighting the importance of hypothesis or prediction testing through the use of a SC model.

DISCUSSION

The study reported in this paper was intended to answer two research questions. According to the first question, which refers to whether it is feasible to enhance students' conceptual understanding in the domain of ecosystems through a modelling-based approach, the results indicate that students' conceptual understanding concerning marine ecosystems was improved. This finding is aligned to the notion of Halloun and Hestenes (1987) that modelling, as an instructional approach, may serve as a medium for the development of conceptual understanding in the domain of ecosystems and that it enables students to transform their preconceptions to scientific ideas, as well as to overcome any conceptual, reasoning, and epistemological difficulties that hinder their learning.

Moreover, the results concerning students' appreciation of SC as both a modelling and conceptual medium, that enables prediction making and hypothesis testing, indicate that SC has been substantiated as an effective tool to scaffold students' development of modelling skills and conceptual understanding in the context of ecosystems. The impact of SC to students' learning has also been evident through the implementation of the activity sequence that was described in a previous section of the paper. Particularly, students used SC to create dynamic models of the observed marine ecosystem, they applied new concepts to their models through building and debugging rules to set a required behaviour to a character, and validated their model by repeatedly contrasting it to the physical phenomenon and adding missing information.

A potential factor that accounts for the effectiveness of the present study is associated with the activity sequence that was specially designed for the purpose of our research. It is important to state that, from our perspective, curriculum design is an essential empirical process that integrates research and development. Effective curriculum development emerges through a rigorous methodological approach that integrates the results of research in the curriculum design process. In the instance of integrating computer-based tools to instruction, there is an emerging need to supplement these tools with appropriately designed, carefully structured and properly validated curriculum material (Louca and Constantinou, in press).

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