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## Abstract

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This deliverable reports about the results of the first phase of evaluation activities of DynaLearn by Tel Aviv University (TAU). The evaluation activities were designed with the aim to address the evaluation questions posed in the DOW, in correspondence with the functionalities and features afforded by the modelling environment in this first phase. We report about three evaluation activities: Two with Undergraduate students at Tel Aviv University, and one with Junior-High School students attending a summer course in Marine Biology. Results are discussed for each activity, and summarized into main themes including conclusions for further work in the general discussion chapter.

## Internal review

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# 1. Introduction

This deliverable reports about the results of the first phase of evaluation activities of DynaLearn by Tel Aviv University (TAU). The evaluation activities were designed with the aim to address the evaluation questions posed in the DOW, in correspondence with the functionalities and features afforded by the modelling environment in this first phase. The main questions were operationalized and decomposed into specific questions and integrated in an evaluation framework guiding the development of the activities, methods, procedures and instruments.

In the following section the framework will be briefly described, as well as an overview of the current phase evaluation activities. Report on the activities is presented in chapter 2, 3 and 4 of this report, and a summary discussion of the results of this phase in chapter 6.

## 1.1. DynaLearn pedagogical and technological components

The DynaLearn project's main goal, as stated in the Description of Work (DOW) is "*to develop an interactive learning environment that allows learners to construct their conceptual system knowledge, either individually or in a collaborative setting*". The learning environment under development integrates three well established, but as yet independent, technologies to create an individualised and engaging cognitive tool for acquiring conceptual knowledge in environmental science. The software integrates a diagrammatic approach to constructing qualitative conceptual models, ontology mapping and semantic technology to ground model building terms and compare models, and virtual character technology to provide individualised feedback and enhance motivation of learners.

Underlying the integration of DynaLearn into teaching is the perception of learning as a complex process amalgamating several approaches: constructivism, social-constructivism, and constructionism (Kafai & Resnick, 1996; Papert, 1991; Vygotsky, 1978); a situated perspective (Collins, Brown, & Newman, 1989); and a learner-control perspective (Merril, 1994). As a whole, we rely on the robust body of theoretical and practical knowledge that locates the learners (individuals and groups) as active partners at the centre of the learning process, in the dual role of main engine and main beneficiary of this process. As a constructivist environment, DynaLearn represents a highly rich learning playground for the construction and exploration of complex systems.

The DynaLearn approach and paradigm are grounded in the "Learning-by-Modelling" (LbM) pedagogical approach. In this approach, students are involved in interpreting, manipulating and constructing models of systems, fostering both conceptual understanding (of subject-related content knowledge) and the gradual development of robust scientific reasoning skills.

Scientists and researchers in many disciplines frequently rely on modelling and model-based reasoning to formalise abstract ideas, to simplify and clarify complex phenomena, to predict trends, and to explain mechanisms and processes (Bar Yam, 1997). In recent years, increasing effort has been oriented towards the development of pedagogical tools and approaches for supporting model-based reasoning at all levels of schooling in the science education community.

Integrating all above components, namely, the different technologies embedded in the learning environment and the target pedagogical and learning objectives with DynaLearn, we defined the framework for the design of the evaluation activities.

## 1.2. Evaluation framework

The evaluation framework is built as the inquiry space for the formulation of the evaluation questions and the design of the evaluation activities aiming to answer to these questions. Our main goal for the evaluation is:

**To assess the contribution of learning by qualitative modelling with DynaLearn on students' understanding of ecological systems.**

In specific terms, we aim to assess the effect of Dynalearn's key features and the process of modelling on students':

- Conceptual understanding (CU) - *their learning of content knowledge related to the behaviour of complex ecosystems.*
- Scientific reasoning, Qualitative reasoning, and System Thinking (SQS) - *their acquisition of scientific reasoning skills and ability to cope with complexity, through QR approach and language.*
- Motivation and attitudes (M/A) - *towards learning science and learning by modelling.*

The above, as function of learning whit an environment encompassing:

- Conceptual Modelling (CM) - in terms of DynaLearn's specific modelling language, modelling process and 6 modelling levels. - the Learning Spaces.
- Conversational agents (VC) - as these act in various functions and roles while interacting with the learner.
- Semantic Technologies (ST) - individualization of learning via DynaLearn tools for ontology mapping, diagnostic procedures, and the semantic repository.

The evaluation inquiry space is thus depicted in Figure 1.1. In the Figure also indicated as shaded cells the issues covered in our first phase evaluation activities. Most questions and data collected relate to the effect of conceptual modelling with DynaLearn on students conceptual understanding, acquisition and application of scientific skills and system thinking, and on motivational aspects (Questions of types 1a, 1b and 1c). In the last stage of this evaluation phase, with the availability of features related to DynaLearn's semantic technologies, we also conducted initial activities about their effect on learning (Questions of types 3a and 3b).

	1 CM	2 VC	3 ST
a CU	Most covered		Initial activities
b SQS	Most covered		Initial activities
c M/A	Most covered		
			Initial activities

Most covered  
 Initial activities

**Figure 1.1:** evaluation inquiry space

In the DOW the overall set of questions to be addressed is presented, formulated in general terms (Pp. 20-21). These questions, and the cells in the inquiry space into which they are inscribed, are:

1. Does the diagrammatic approach (as organised in the DynaLearn setting) actually allow learners to address more complex problems? **[1a, 1b]**
2. Does the meta-vocabulary from which a conceptual interpretation is built, provide learners a domain independent analytic instrument that enables them to construct more fine grained and thorough analyses of how systems work? **[3a, 3b]**
3. Do the embodied conversational agents establish the 'involvement momentum' required for learners to actually benefit from the added value provided by the software for handling conceptual knowledge? Which agents work best? And why or why not? **[2a, 2b, 2c]**
4. Do the instruments to individualise learning (ontology mapping, diagnostic procedures, and semantic repository) adequately steer learners in acquiring the target subject matter? **[3a]**
5. Does the personal autonomy cause learners to be more motivated? **[general - L]**
6. Do learners actually learn better when using the full set of DynaLearn results? **[general - L]**
7. And are students more motivated to take on science curricula? **[1c, 2c, 3c]**

For questions 5 and 6 relating to the most general issues and aims of the DynaLearn project, the answers will be: (a) gradually constructed upon the cumulative results for the various sub-questions along the project, and (b) addressed in the next phase's evaluation activities when DynaLearn as integrated learning environment will be available.

As mentioned above, the questions in the DOW were operationalized and specific sub-questions were generated for planning and conducting the evaluation activities. For example, dealing with question 1 required to specify the aspects of the diagrammatic approach faced by the students, and the variables by which we assess students' understanding complex phenomena.

The specific evaluation questions, variables and interpretative schemes for the result are detailed for each evaluation activity in the following chapters.

## 2. Evaluation activity No. 1: Undergraduate students LbQM

### 2.1. Introduction

The study was conducted in the context of an undergraduate course in Marine Biology in Tel-Aviv University's Faculty of Life Sciences. Data collection took place during the Fall/Winter academic semester 2009/2010. This study's questions address DOW questions 1 and 7, and partially 5.

The specific evaluation questions addressed in the activity were:

#### **Does students' involvement in Qualitative Modelling (QM) of ecological systems improve:**

- Understanding the complexity of ecological systems?
- Modelling capability and scientific reasoning skills?
- Motivation to learn science by QM?

Additional evaluation objectives for this activity were:

- To provide descriptive information on the integration of QM in regular courses.
- To serve as pilot study for the definition of the evaluation framework and the development of evaluation instruments.

### 2.2. Method

#### 2.2.1. Participants

Participants were 10 undergraduate students in the Marine Biology course, attending the qualitative modelling workshop in addition to the course's regular classes. They chose to participate voluntarily, and were awarded an extra credit for their participation.

#### 2.2.2. Variables

Data were collected for four main variables, in correspondence with the research questions: "Understanding of systems (structure, processes, behaviour)"; "mastery of scientific skills"; "modelling capability"; and "motivation".

For the first three students' concept maps and models were analysed in regards to 13 parameters, as detailed in section 2.3.1 and Table 2.1. Data for "motivation" were collected using the questionnaire presented in section 2.3.2.

#### 2.2.3. Implementation instruments: The modelling workshop

Participants The workshop lasted seven meetings conducted once a week for two hours each time (total 14 hours). The practical modelling work was conducted using Garp3, the qualitative modelling environment upon which DynaLearn was further developed. The modelling tasks were designed as a

progression in correspondence the features characterizing the progression of Learning Spaces in DynaLearn.

In the meetings the students were introduced to: (1) the qualitative modelling approach - its logic and terminology as manifested in the software; (2) the use of concept maps to represent the entities of a given system and types of relationships among them; (3) ways to express quantities in a qualitative model: assign values to entities and processes and define quantity spaces; (4) way to address processes occurring within the system (such as predation or competition) or caused by external agents (such as over-fishing or pollution); (5) ways to determine conditions and look at their consequences in dynamic systems, and (6) ways of tailoring together existing model fragments into more complex representations of marine environment.

Each meeting comprised two parts: an explanation and demonstration part conducted by the lecturer, and a 'hands-on' part where students carried out a model building task along the lines of the one in the demonstration. Each meeting included an exercise mainly aimed to assess students' ability to handle the software and follow the modelling process. This was part of the data collection plan (to be detailed later).

The evaluation task that followed the series of meetings was meant to evaluate students' growing capabilities in modelling. the growth in their conceptual understanding and their ability to follow and actively participate in a scientific investigation related to environmental issues using the software.

This task was based on several recent peer review scientific papers that dealt with topics covered in the theoretical part of the Marine Biology course (three credit points). The papers dealt with issues such as:

- Competition between indigenous and invasive species
- Induced responses in native populations to invasive predators
- Effects of intensive recreational diving on coral reef communities and coral conditions
- Symbiotic relationship between coexisting species in a specific habitat
- Effect of pollution (the antifoulant tributyltin-TBT) on marine gastropods
- Effects of ocean acidification on the development, physiology and behaviour of larval and adult stages of intertidal gastropods.

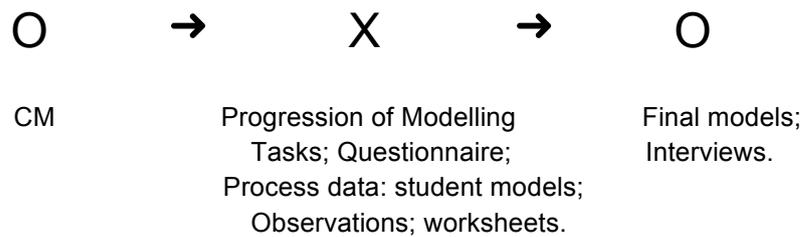
These papers were distributed amongst pairs of students. The students were asked to read the papers, understand the phenomenon described, analyze the components, relationship and process that were described in the paper, represent them in a concept map and gradually build qualitative models that fully represent the dynamics of the relevant ecological system. The modelling process followed several levels of complexity that were elaborated on during the course. In their modelling process students raised questions, hypothesized and predicted how a marine system would behave under specified conditions, and tested these hypotheses through simulation.

#### 2.2.4. Study's design and Data collection instruments

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The evaluation activity followed a "One group Pretest-Posttest" design (Creswell, 2003), as shown in Figure 2.1. In it 'X' represents the exposure to a sequence of modelling tasks and 'O' represents an observation or measurement obtained by different instruments.

The progression of modelling tasks comprised 6 stages, from the initial identification and definition of structural components of the system to building a complete model and running simulations.



**Figure 2.1:** the study's design

The data collection instruments included students' concept maps (CM), a widely used tool for assessing conceptual understanding (Novak & Gowin, 1983; Ruiz-Primo & Shavelson, 1996; Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005). This instrument was applied before students were exposed to the qualitative modelling tasks. The progression in modelling capabilities was assessed through unstructured observation and by the intermediate products in students' modelling tasks. Final model and students' reflection on it served as a post-test measure of both students' understanding and their modelling capability in scientific reasoning.

An attitude questionnaire was administered at the end of the workshop to measure motivational aspects. The questionnaire contained a set of items describing cognitive as well as affective aspects of the modelling activities. Students were asked to respond, on a scale from 1 (not agree) to 7 (mostly agree) to the items. Their responses revealed their perception regarding the contribution of the modelling experience. The questionnaire's components are detailed in the results section.

### 2.2.5. Data analysis

A mixed method approach leaning approach, mainly qualitative in nature, was adopted in this study. Comparing between the initial concept of maps that represented the relevant ecological system studied with the final products of the modeling process, enabled to trace growth in both conceptual understanding of ecological concepts, the ecological complexity underlying the ecosystems, and the acquisition of modeling capabilities and scientific reasoning skills.

This comparison followed several stages. First we determined criteria for the comparisons. The criteria used were:

- Reference to entities and quantitative accuracy (coverage and accuracy)
- Reference to process (coverage and accuracy)
- Reference to interrelationship amongst and between the entities, and processes
- Identifying causal relationships (direct, indirect)
- Expressions of assumptions, hypotheses, questions
- Drawing inferences (accuracy, creativity)

This analysis, written in a narrative, descriptive form was then quantified using cross-case display (Miles & Huberman, 1994, pp. 245-287), and later on was summarized for better description and for generative meaning.

A second qualitative analysis was a content analysis of interviews with three representative pairs of students. The results of these analyses were in the form of 'stories' each describing a different

modeling experience that emerged from these interviews. The stories portray a continuum of coping with the modeling task from only reproducing a model that fits data presented in a scientific paper toward going beyond the information provided in the paper, identifying research questions and generating new knowledge. These stories are presented as three vignettes.

## 2.3. Results

### 2.3.1. Students' evolving understanding of complexity and system concepts

To assess students' understanding we conducted analyses of their concept maps (CM) and explanations at the pre-test stage compared with their models (M) and explanations at the post-test stage. The analyses comprised three phases: Analysis of the CM, M and explanations by several dimensions; coding the data; and generating interpretations.

In Table 2.1 (next page) the initial analysis of the CM and M and the coding of the data is presented. For each student the products were analyzed focusing on the different aspects of the system (e.g., structure, processes, observed behaviour, predicted behaviour). Structural aspects of the representation include the definition of entities (e.g., number, correctness, relevance), their configuration, and the interrelationships among them (e.g., number, types and direction of links). Processes analysed in the representations include causal relationships (e.g., one-to-one, one-to-many, causal chains, causal nets), direct and proportional influences, and feedback-loops. At the behavioural level we analysed the students' interpretations of the system's behaviour, their ability to probe different scenarios, and to hypothesize about alternative behaviours.

The evolving understandings and acquisition of systemic perspective along the learning process is summarized in Table 2.2 (this page). Overall, the ability to represent appropriately structural and behavioral aspects of the system evolved through the modelling sessions. Causal relationships were better identified and integrated in the models, and new knowledge beyond what is already described in the paper was generated.

**Table 2.2:** Overall comparison between CM and M stages

Entities	From detailed but isolated entities representation in the CM to parsimonious and relevant to the system in M
Proper hierarchy	Improved representation towards M
Proper quantities	Ignored in CM and comprehensively and correctly addressed in M
Processes	From detailed but isolated entities representation in the CM to parsimonious and relevant to the system in M
Causal relationships	From simple causal interrelationships in CM to causal differentiation in M
Raising hypotheses	Both in CM and M
Scenarios/hypotheses	Scenarios fit hypotheses and proper interpretations of simulations - only in M
Generating new knowledge	Absent in CM. Generated while working on the models (M)

**Table 2.1:** Comparison of Concept Maps (CM) and end Models (M) by each student

Criteria for assessing CM & M	Students												
	1	2	Model 1-2	3	4	Model 3-4	5	6	Model 5-6	7	Model 7		
1. Entities: no. of, correctness and relevance (CM) (+++; ++; +)	12	5	3	2	2	3	3	4	4	7	5		
Entities: no. of, correctness and relevance (M) (+++; ++; +)	+	++	+++	+	+	+	+	++	+++	+++	+++		
2. Proper hierarchy CM & M (+++; ++; +)	+	++	+++	+	+	+++	+	++	++	+++	+++		
3. Proper quantities (+; -; 0) - representing meaningful values CM	0	0		0	0		+	+		+			
- Producing variation, landmark values M			+			+			+		+		
4. Processes: no. of, correctness and relevance (CM) (+++; ++; +)	16	4		1	1		1	4		5	2		
Processes: no. of, correctness and relevance (M) (+++; ++; +)	+	++	2	+	+	2	+	++	1	+++	++		
5. Number of links CM	30+	30+		10	20		12	12		50			
6. Feedback links CM (+; -; 0)	+	+		0	0		0	0		+			
Feedback links M (+; -; 0)			+			0			0		0		
7. Causal links with directions CM (+; -; 0)	+	+		+	+		+	+		+			
Causal links with I and P M (+; -; 0)			+ pi			+ pi			+ p		+ p		
8. Interpretation CM: $A \rightarrow B$ (+) If $A \rightarrow B$ (++)	++	++		+	+		+	+		+			
Interpretation M: $A \rightarrow B$ (+) If $A \rightarrow B$ (++)			0			++			+		++		
9. Questions raised CM (+; 0)	0	+		0	0		0	0		0			
Questions raised M (+; 0)			+			+			0		+		
10. Hypotheses raised CM (+; 0)	0	+		+	+		+	+		+			
Hypotheses raised CM (+; 0)			+			+			+		+		
11. Scenarios fit hypotheses questions M (+; 0)			+			+			+		+		
12. Proper interpretation of path M (+; 0)			+			+			+		+		
13. Generation of new knowledge M (+; 0)			+			+			0		0		

### 2.3.2. Students' motivation

A set of items reflecting the cognitive as well as effective impacts of modelling ecological systems using the software comprised the context of Likert-type questionnaires, students responses from 1 – 'do not agree' to 7 – 'agree' revealed their perception regarding the contribution of the modelling experience.

**Table 2.3:** Sample items from the motivation questionnaire

Sample items	Average score (SD)
Using the software contributed to the conceptual understanding of the ecosystem Do not agree 1 2 3 4 5 6 7 Agree	3.3 (.5)
Using the software enabled me to better understand the complexity of the ecosystem: Do not agree 1 2 3 4 5 6 7 Agree	3.8 (.5)
Working with the software opened new ways of thinking about an ecosystem I could not have reached without it Do not agree 1 2 3 4 5 6 7 Agree	4.2 (.5)
The software motivated me to try to build models Do not agree 1 2 3 4 5 6 7 Agree	4.5 (.6)
For building an ecological system I will use the software Do not agree 1 2 3 4 5 6 7 Agree	4.8 (.8)
I will recommend my fellow students to participate in the course Do not agree 1 2 3 4 5 6 7 Agree	4.2 (.4)

As shown in Table 2.3, the higher scores are related to the students perception of the software's motivational value for building ecological models (in the course and in the future as well), and to the contribution of the work with the software to their system thinking. At a lesser extent the modelling work was perceived by the students as contributing to their conceptual understanding.

Additional data on students' perception of the contribution of the modelling experience was obtained in the interviews conducted after the completion of the course. A brief summary of the main themes reported by the students is exemplified in the following vignettes.

- **Progressive ability to define the modelling focus:** “at the beginning we included all kinds of components, almost everything... at the end we left only the essential... we went through stages [while modeling] ... first considering the whole system of relationships, all things that might affect the system... then at a given stage we defined what are the essential things we want to focus in: Goby, Shrimps and burrows... at the end we isolated what is at the core of the paper”
- **Goal-oriented trial-and-error:** What to model? first the students tried different configurations looking for desired/known results, did experiments until reaching these results. Once they

have got the expected results they began “trusting” the system and they switched phase, towards formulating hypothesis and predictions with new scenarios.

- **How the ecological system 'really' works:** "the first learning stages emphasize linear relationships, however, the real strength of the tool is in the creation of feedback loops and reciprocal relationships".
- **Aiming to reduction but still fostering meaningfulnes:** "How to simplify reality without losing meaningful properties of the system".
- **Teaching the software how to behave:** "The most important thing is to cause the software to behave the way we think it should ... Why we don't get results the way we expected them to be".
- **Translation among representations:** "I know now how to take a scientific paper and translate it into the software"
- **Learning by doing (the constructivist way):** "Unlike Mathematics or Physics, where students learn by practice exercises, marine biology lessons are mainly based on memorizing material. The modeling course gave “Marine Biology” the 'practice exercise' edge".

### 2.3.3. Focal stories

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The observation and interview materials were summarized in the form of focal stories depicting specific learning processes in the workshop. Three of these stories are briefly presented here.

#### **First Story:**

**"Teaching the software how to predict what is already known and how to predict things not yet known"**

**The paper:** "Diving down the reefs? " (Hasler & Ott, 2008).

The study described in the paper focuses on two major effects of coastal tourism on coral reefs in the Red Sea – coral damage and sedimentation caused by divers. As these reefs are only minimally affected by bleaching and fishing is prohibited, the study focuses exclusively on the effect of diving tourism.

Sites with intensive recreational diving were compared to similar sites with little or no diving activities. The sites were comparable in depth and geomorphologic structure.

Data on coral cover, their conditions as well as data on fish populations – corallivorous and herbivorous and data on the weight of sediment that are laid on the corals as a result of divers' movements were recorded in differing distance from the entrance to the diving site.

The paper describes the study sites, the sampling method used and the type of measures of the fish community and the sedimentation used in the study. The statistical methods used in analyzing the effect of diving on the communities are explained and the results are shown using different types of representations.

The results of the study show a high negative impact of current diving intensities on coral communities and coral condition. Corallivorous and herbivorous fish were apparently not yet affected, but are endangered if coral cover decline continues. The conclusion drawn from this study advocates reducing the number of dives per year, producing ecologically sustainable dive plans for individual

sites, and reinforcing the environmental education of both dive guides and recreational divers. These measures are essential to conserve the ecological and the aesthetic qualities of these dive sites.

### **Students' work on the paper**

The paper was assigned to two graduate students one with a previous degree in computer sciences and the other in law studies.

The initial assignment required the students to read the paper, analyze the ecological system described, identify main entities in the system, and the types of relationship between them. The students were also asked on the basis of this analysis to draw a concept map, generate questions, hypothesize what might occur in the system as a result of changes that might occur in the magnitude of the entities identified.

Two concept maps were drawn individually. They were quite similar in the entities and covering the relationship they touched upon. In both maps divers were considered as external agents effecting the system. One of the maps distinguished between two separate zones in the reef: reef flat and reef slope, while the other was more generic. However, the two maps differed in the narratives that accompanied the drawings. One of the students emphasized more processes that occurred in the system, while the other one emphasized a more causal relationship. There were also other differences. The first student expressed several hypotheses while the second one was more interested in raising questions regarding the impact of diving on the reef and especially in looking for threshold points of the reefs' recovery.

Further assignments were targeted at learning to model the phenomenon described in the paper. These assignments require the students to hypothesize and predict certain behaviours of a system under different conditions, and to test their hypotheses by running scenarios with the use of the software.

The modelling process was bound to the information provided in the paper and to previous knowledge the students had. The modelling efforts were aimed first at replicating the results shown in the paper and at a later stage toward predicting results not yet found, i.e., stepping beyond what the paper presented.

Observing the students throughout the meeting, following their regular exercise, analyzing their products and interviewing them enabled us to detect the learning they went through while advancing in the modelling process. A description of steps in this process are used in detecting the learning process.

### **Second Story:**

#### **Modeling as a Tool for Better Understanding of Ecological Systems**

**The paper:** "Butyltins Concentration Levels and Imposex Occurrence" (Chaivarini et al, 2003)

The study described in this paper traces the effect of marine traffic on concentration of TBT (Butyltins) concentrations in sediment and its further effect on imposex in marine snails. Sediments and snail samples were collected from several sites that are under different levels of ship traffic. Four hundred and sixty-nine specimens of snails were collected. They went through analyses that determined their level of imposex and chemical analysis that determined concentration of TBT in their tissues.

The biological analyses have shown a widespread occurrence of imposex cases. Chemical analyses showed low levels of contamination in sediments, but significant contamination in snails.

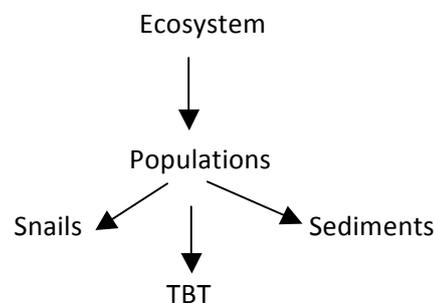
High correlation was found between TBT in snails and induced imposex. There was a lack of correlation between the intensity of marine traffic and both imposex occurrence and TBT concentration

in snail tissues. As very low concentrations of TBT are able to induce high stages of imposex in snails, it seems that the specific snail is too sensitive to be used as a bioindicator of TBT contamination.

### Students' work on the paper

The paper was handed to two students who were asked in an initial stage to read the paper, identify the main entities involved in the ecosystem described, the relationship among them and represent them in a drawn concept map. On the basis of this concept map, to raise questions in regard to the phenomenon described, hypothesize possible scenarios and predict the behavior of the system under certain conditions.

The initial concept maps produced by the two students were rather poor. They detected only part of the relevant entities mentioned in the paper. One of them correctly detected only 3 out of 6 entities, and the other detected 4 out of 6. Further relevant components that play a role in the system, such as processes, agents, were also only partially identified – 1 out of 7 and 4 out of 7 respectively. The concept maps drawn showed the wrong hierarchy, for instance: one concept map regarded snails, TBT compounds and sediments as subentities of population.



Also, wrong measures were attached to the identified entities, for example the entity sediment is measured by the amount of living organisms in the sediment was considered as a measure of the entity sediment.

The hypotheses drawn by one of the students were either incorrect or vague and some touched irrelevant issues dealt with in the paper, for instance: Increase in TBT concentration leads to decrease of organisms in the sediment.

From the writing of the hypotheses, it was evident that the student did not understand the meaning of the imposex phenomenon. They thought of it as a change in gender from female to male and did not relate it to fertility of females.

Once the final models were produced, they showed the meaningful learning that occurred from the initial stage of drawing the concept map until the final models.

They demonstrate better understanding of the paper that was assigned to them, better conceptual understanding of the system, growth in modeling capabilities and growth in their ability to test some hypotheses that appear in the paper via simulation and interpret their results in accordance with information provided in the paper.

### Third Story: Experimenting impossible experiments using DynaLearn

**The paper:** "Association Between Arrow Goby *Clevelandia ios* and the Ghost Shrimp *Calliasassa californiensis* Dana in Natural and Artificial Burrows" (Hoffman, 1982).

*Clevelandia ios* is a small fish that inhabits the burrows of a shrimp. The relationship between the two species was studied in order to determine whether it can be regarded as a case of commensalism,

mutualism or parasitism. Observation was carried out both in the field and in a simulated environment in the laboratory. Results indicated that the fish and the shrimp were found to co-occur in burrows less frequently than they would be expected to be by chance under both field and laboratory conditions. In addition the fish were found to inhabit the shrimps' burrows only during the spring and summer months.

The author of the paper contrasts his findings with those of other studies that dealt with fish and burrowing shrimps and concludes that the shrimp clearly provides a shelter for the fish, however, no data are available on the function of the fish in this relationship.

The fish may be selecting empty burrows or burrows with a small number of shrimps to avoid shrimp agonism. Alternatively, the fish may be chased out of the burrows having high densities of shrimps. The shrimp does not gain any benefit from its association with the fish as it always acts agonistically toward the fish. Therefore this relationship appears to be commensal or even parasitic. Presently no data are available to show any benefit to the shrimp.

### **Students' work on the paper**

The two students that were assigned the paper were asked to read it carefully and analyze the ecosystem it describes. In analyzing the entities of the system both refer only to the two populations – the Arrow Goby (fish) and the Ghost Shrimp, ignoring other details mentioned in the paper, such as the natural habitat and the laboratory habitat. The only process referred to by both students was predation.

The differences between the two students was evident in the concept maps they created. One of them was simple and contained only a few links. It differentiated between two zones in the habitat: the tidal area and the open sea. The shrimp mostly inhabits the tidal area and the goby, the open sea. The relationship between the two species was defined as predation. Two links in the concept map related the quantity (number) of the goby and the quantity (number) of shrimps with a heading that says "increase in the quantity on one species causes the decrease in the quantity of the other".

The concept map of the other student was much more detailed. It contained twenty links. Here, there is also a distinction between the muddy tidal area and the open sea. Birds were added as an entity to the concept map and there is a differentiation between processes occurring during the winter and summer months. Burrows are also treated as entities and are measured by their length.

The interpretation given to the concept maps by the two students were also different. One of them mentions contingency relations. Increase in one entity causes an increase or decrease in another entity. The other student predicts changes due to some possible scenarios: "If birds will be taken out of the system, gobies will prevail during the winter." "If the number of shrimps will increase, less gobies will inhabit the burrows" etc.

The modeling activity resulted in a much better understanding of the paper. Some explanations given by the students demonstrate it:

- "Gobies live in burrows of certain shrimp species. They use it as refuge from predators and desiccation during low tide".
- "Ghost shrimps are burrowers".
- "Prior experiments provide support to view the shrimp – goby symbiosis as a case of mutualism. The shrimp is blind and depends on the goby to guard him. On the other hand the shrimp provides the goby with shelter and food".

The students understood the experiment described in the paper and on the basis of its results raised a question regarding the type of symbiosis between the goby and the shrimp.

The diagram they co-produced using the software to represent the system contained three main entities: Goby, Shrimp and burrows, each accompanied by adequate quantities and properly defined quantity space.

Their modeling process was based on several stated assumptions:

- All scenarios occur during the summer.
- The only entities in the system are the gobies and the shrimp.
- Burrows are dug by the shrimp. Gobies use these burrows.
- Burrows are needed for both the gobies and the shrimps.
- Empty space in the burrows is a limiting factor.

On the basis of these assumptions, the students run several simulations that led them to decide what type of symbiosis exists between the goby and the shrimp. These simulations enabled them to test the effect of changes in the number of shrimps on the number of burrows, and further on the availability of space in the burrows and consequently on the number of gobies.

The hypotheses tested are:

- Increase in the number of shrimps (leads to increase in the number of gobies).
- Decrease in the number of shrimps (leads to increase in the number of gobies).
- Stable number of shrimps (leads to initial decrease, but later on to an increase in the number of gobies).

These hypotheses were verified on the basis of their simulation. Following the simulation the students concluded that:

- As long as there are shrimps – the goby population will increase.
- If the shrimp population will be extinct, the goby population will grow until it reaches stability.

The paper defines the symbiotic relationship between the two species as commensalism, the student came out on the basis of their qualitative modeling effects with another conclusion that the relationship between the goby and the shrimp is that of competition on available space in the burrows.

These conclusions are a further step in generating knowledge beyond that generated by the author of the paper and they are an example of the constructivist type of learning through modeling.

## 2.4. Concluding remarks

In this evaluation activity undergraduate students attended a qualitative modeling workshop complementing the regular Marine Biology course. At the focus of the evaluation activity were questions concerning the contribution of the modelling process to students understanding of ecological systems concepts and complexity, and to their motivation to learn these concepts through modelling activities. In the following we will briefly summarize our observations concerning the study's questions.

### 2.4.1. Contribution of Qualitative Modelling to students' learning

The modelling activity contributed to students' cognitive transition towards a systemic view of the phenomena under study. This perception evolved through active involvement in constructing models

for the phenomena described in scientific papers, and manipulating these representations for observing and predicting system behaviours.

Along the classes based on the completion of modelling tasks, several transitions were observed:

- Structure [from extensive/redundant to parsimonious]
- Processes [from simple linear relationships to differentiated causality and reciprocal relationships, towards understanding of ecological equilibrium]
- Increasing activation of inquiry skills [questioning, hypothesizing, predicting, generating new knowledge]

As well, an analysis of students' performance and explanations from the perspective of high-order or meta-level insights, we observed::

- While modeling, the necessity to define (and reduce) models' ingredients supports the understanding of the constraints/possibilities of modeling vis-à-vis the real phenomena.
- The value of the models, besides their intrinsic value as object for learning, have an added value as paradigmatic examples -- potentially applicable for of inquiry into other complex systems.
- The need to understand "the logics of the software" (DL "language"?), to "trust" its outputs.
- Ways to solve conflicts between expected outcomes (based on scientific definitions) and actual outcomes, or to create situations perceived as "not allowed" by the software
- Using updated scientific papers enabled not only to reproduce and represent information provided, but also to explore other directions of inquiry and create new knowledge. In this sense, the modeling activity using the software fits the constructivist approach toward learning.

#### 2.4.2. Students' attitudes and motivation concerning the Contribution of QM

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Overall the students showed interest and motivation to learn with the software. They perceived the modelling activity as an opportunity "to integrate knowledge we had compartmentalized from different courses in the past" into a systemic representation of the phenomena. Main observations were:

- The main gain perceived was about QM's contribution to system thinking and understanding the complexity of the ecosystem.
- As well, about QM's contribution to motivation for model building as learning experience, also in the future.
- Less strong was the perception of the contribution of the modelling work to the learning of subject topics.

## 3. Evaluation activity No. 2: Junior High students' LbM with DynaLearn

### 3.1. Introduction

During Summer 2010 a course in Marine Biology was conducted with 25 students from "The Young Persons Institute for the Promotion of Creativity and Excellence" at Tel Aviv University. The course lasted 25 teaching sessions during one week, and included a field trip, short lectures, laboratory, and computer work for modelling with DynaLearn. The evaluation questions correspond to DOW questions 1 and 7, and partially 5. The specific questions we focused on were:

#### **Does LbM with DynaLearn contribute to Junior-High School students':**

- Conceptual understanding of a set of key concepts that represent the relevant content-domain (ecological systems)?
- Ability to model a complex system and represent it at different levels of complexity using the qualitative reasoning approach embedded in DynaLearn?
- Gradual acquisition of scientific and reasoning skills due to the modeling activity?
- Capability to apply the knowledge and skills gained for approaching new ecological phenomena?
- Motivation and attitudes toward learning by modeling?

In the following sections the evaluation methods, results and conclusions are presented.

### 3.2. Method

#### 3.2.1. Participants

Participants were 25 Junior High School students (13-14 years old) from schools in the central area of Israel. Participants comprised to two groups: experimental group - 10 students who performed all course's activities including modelling work with DynaLearn, and control group (15 students) who performed all activities except modelling with DynaLearn, which was replaced by a computer-based inquiry task. The course's plan and activities will be described in a later section. All students enrolled voluntarily in the course.

#### 3.2.2. Variables

The variables for which data were collected and analyzed were defined in correspondence with the research questions:

1. knowledge of a set of key ecological concepts.
2. understanding of ecological systems (structure, processes, behaviors).
3. modeling capability.
4. grow of scientific skills.

5. application of knowledge in new contexts.
6. Motivation.

The detailed description of the variables scales and values, and corresponding scoring schemes applied, are presented in the respective items of the results section.

### 3.2.3. Implementation instruments: The course and modelling workshop

The course and modelling activities for the experimental group were integrated in the course's plan shown in Table 3.1 (the evaluation activities will be described in the next section on data collection).

**Table 3.1:** Course and modelling activities plan

Course Structure		
Day	Content / Activities	Evaluation Activities
Day 1	<i>Lecture</i> – Introduction to life on the seashore.	<i>Quiz</i> - Knowledge of main concepts in ecology.
	<i>Field Trip.</i>	
Day 2	<i>Lecture</i> – How animals feed on the seashore  <i>Modelling demonstration</i> - Animals that filter seawater and wave movements (Chthamalus barnacle example). Learning space 2, 3.	Drawing a <i>concept map</i> of the seashore habitat.  <i>Modelling task</i> - on topic: "Attachment to the rock substrata and wave movement" (The Patella limpet example). Learning space 3.
Day 3	<i>Lecture and movies</i> - on predatory relationships in the seashore  <i>Laboratory</i> – getting acquainted with Actinia, a sea anemone and other predator gastropods  <i>Modelling demonstration</i> – Prey/predator relationships, P and I causal relationships. (The Conus snail example). Learning space 4.	<i>Modelling task</i> - on topic: "find a predator-prey interaction on the internet and build a model of it". Learning Space 4
Day 4	<i>Lecture and movies</i> - symbiotic relationships in the sea.  <i>Laboratory</i> - Symbiotic relationship in the coral reef.  <i>Modelling demonstration</i> – The burrowing shrimp and the Gobi fish relationship. Learning space 4.	<i>Modelling task</i> – modelling complex relationships between Patella (limpet), Chthamalus (barnacle) and Pachygrapsus (crab). Learning space 4.
Day 5	<i>Lecture</i> – Human effects on the environment.  Modelling demonstration - over-fishing. Learning Space 4	<i>Modelling task</i> - modelling the case of the invasion of a jellyfish into the Mediterranean Sea. Learning space 4.  Answering <i>challenging questions</i> .
Day 6	Representation and summing up day	<i>Quiz</i> – Knowledge of main concepts. <i>Students presentations and models.</i>

The table presents the sequence of classes in 6 days, for about 4 hours a day. During the course several types of pedagogical activities were implemented: A field trip, short lectures and demonstrations, laboratory work and experiments, modelling demonstrations and hands-on activities with DynaLearn, and presentation of students' work. Each day began with a lecture/lab component, followed by a modelling session. The modelling session comprised a demonstration and an assignment that focused on different features and learning spaces from simple to more complex and comprehensive tasks.

### 3.2.4. Study's design and Data collection instruments

The evaluation activity followed a "Pre- Post- test control group + repeated measures" design (Creswell, 2003). The design and allocation of treatment (X) and observation (O) activities is presented in Table 3.2. "Alternative X" and "Alternative O" indicate the alternative computer-based activity and observations conducted with the control group. For the observation points, "e" and "o" indicate the group - experimental or control (e.g., "O7e" or "O7c"). By the obvious demand of time required for completing the set of modelling activities, the experimental group's course lasted 24 teaching sessions, while the control group's course lasted 15 teaching sessions.

**Table 3.2:** the study's design

Group	Pre-	Trip	CM	LS2	Model + doc.	LS3	Model + doc.	LS4	Model + doc.	Post; CM; Challeng; Mot.
<b>Exp.</b>	O1e	X1	O2e	X2	O3e	X3	O4e	X4	O5e	O6e, O7e, O8e, O9e.
<b>Ctrl.</b>	O1c	X1	Alternative X + Alternative O							O6c, O7c, O8c, O9c.

The evaluation carried out was targeted toward each of the evaluation aims:

- ***Assessing the conceptual understanding of a set of key concepts that represent the relevant content-domain (ecological systems).***

The instrument used for this purpose was a short open **quiz** on the main concepts treated in the course, some of which are dealt with within the scope of the national curriculum as well (see Appendix A).

Time of Assessment: At the beginning of the first day before the opening lecture and at the end of the fifth day (O1e, O1c, O6e, O6c).

- ***Assessing the ability to model a complex ecological system and represent it at different levels of complexity using the qualitative reasoning approach embedded in DynaLearn.***

Data collection was accomplished by using two instruments: Concept Maps and the products of the modelling activity (models and documentation) of the experimental-group.

**Concept Maps** were selected to serve as one of the evaluation tools for measuring students' understanding of ecological systems' behavior. Students from both experimental and control groups were provided with a short explanation of ways to draw a concept map acknowledging entities and relationships (nodes and links). No constraints were placed on the way to structure the map, thus, the maps reflected their conceptual understanding of ecological complexity due to traditional and nontraditional (modeling) modes of instruction.

The maps were drawn by the experimental group twice: at an early stage, right after the introduction to the activity (intervention) and at the end of the activity (intervention). While the first map represented intuitive thinking, the second map reflected the impact of all components of the intervention: the field trip, the modeling sessions, discussions and the interactive scaffolding activities that took place during the intervention.

The control group provided maps only at the end of the activity, thus these maps were regarded as final products that reflected conceptual understanding of ecological complexity due to traditional mode of instruction.

The scoring guides applied for evaluating the concept maps will be detailed in the results section.

The second instrument comprised the **models** created by the students in Learning Spaces 2, 3 and 4, and the written **documentation** of the models provided by the students for each model. The protocol written by the students referred to the questions:

- What is the phenomena/system represented in the model?
- What entities/quantities were defined? Explain.
- What processes were included in the model? Explain.
- What insight was gained in this modelling experience?

Time of Assessment: At the beginning and end of the course, and at the beginning of days 3, 4 and 5 (O2, O3, O4, O5, O7e, O7c).

- ***Assessing the gradual acquisition of scientific and reasoning skills due to the modeling activity.***

The protocols of the modelling tasks and its questions served the purpose of assessing the growth of knowledge and scientific reasoning skills developed during the course (see protocol questions in the results section 3.3.3).

Time of Assessment: At the beginning of days 3, 4 and 5 (O3, O4, O5).

- ***Capability to apply the knowledge and skills gained for approaching new ecological phenomena.***

A set of "challenging questions" was administered at the end of the activity to students in both groups, aiming to trace the application of system thinking in new contexts. The questions required to use the ecological knowledge gained for providing descriptions, explanations, and predictions about a marine ecosystem. The questionnaire and its scoring guide is presented in Table 3.3.

Time of Assessment: At the end of the course (O8e, O8c).

- ***Assessing students' motivation and attitudes toward learning by modeling.***

Students' answers (on a scale ranging from "1- do not agree" to "4 - fully agree") to several statements comprised a questionnaire that revealed their attitude toward modelling using DynaLearn and their preferences of learning by modelling vs. being engaged in other types of activity. The statements are detailed in the results section, in Table 3.11.

Time of Assessment: At the end of the course (O9e, O9c).

**Table 3.3:** Challenging questions

Questions	Scoring Guide	
1. Describe features -morphological or behavioural- of one tidal zone organism, that ensure its survival in low tide and explain how.	<ul style="list-style-type: none"> <li>▪ Understanding adaptation - correct feature and correct explanations 2 points</li> <li>▪ Either one or the other 1 point</li> <li>▪ Vague, incorrect, no response 0 points</li> </ul>	
2. Define the type of relationship concerning food or space (competition, predation, mutualism, parasitism), between three tidal zone organisms.	Six cells table = correct response for each cell contribute 1 point score. maximum score 6 points.	
	<b>Food relationship</b>	<b>Space relationship</b>
<ul style="list-style-type: none"> <li>▪ Patella – feeds on algae prefers the wave side of the rocks</li> <li>▪ Monodonta – feed on algae prefers back side of the rocks</li> <li>▪ Barnacle (Balanus) – feeds on plankton prefers wave side of the rocks</li> </ul>	Competition	Mutualism
	Mutualism	Competition
	Mutualism	Competition
3. What will happen if a predator fish who feeds on monodonta invades the Mediterranean Sea?	One causal relationship – 1 point Chain of causal relationships – 4 maximum points Vague, incorrect, no response – 0 points	
4. What will happen if building a new breakwater causes the sea level in the tidal zone to drop 10 cm.?	One causal relationship – 1 point Chain/net of causal relat. max 3–4 points Vague, incorrect, no response – 0 points	

In addition, unstructured data collection about students' interaction with the modelling environment was conducted, using a think-aloud approach. The teacher and research assistant observed and interviewed the students, recording their questions by them and tape-recording whole conversations. The student protocols handled with the different modelling tasks, and the taping of the interviews and questions, allow to assess procedures and difficulties that arise in using the software in the class.

### 3.2.5. Data analysis

Data analysis procedures were developed for the elaboration of the different types of materials collected in the study. The first stage in the process consisted in defining appropriate scoring guides for the students responses, products, and observed performance. These were partially presented in this section and will be detailed in the results section. Analyses conducted included between group comparisons and within (experimental group) process-data analyses.

## 3.3. Results

### 3.3.1. Students' conceptual understanding of a set of key ecological system concepts

Students were asked to explain and provide an example that fits their explanation to a set of 20 key concepts in ecology, at the beginning, and at the end of the course. Student responses were coded according to the level of understanding they reflected, as shown in Table 3.4:

**Table 3.4:** Scoring guide for the concepts quiz

Fully correct answer	Scientifically correct explanation with an appropriate example 3 score points
Partially correct answer	Either a scientifically correct explanation or an appropriate example 2 score points
Vague answer	A weak explanation with or without an example 1 score point

The maximum score that could be obtained for the full set of concepts was 60.

The following are results of paired samples t-test of the two groups (Table 3.5):

**Table 3.5:** Group comparison for answers to the concepts quiz

Group	<i>n</i>	Pre-Test		Post-Test	
		Mean (SD)	Mean (SD)	Paired Pre-Post Differences	<i>t</i> & sig.
Experimental	8	22.9 (13.0)	32.8 (14.5)	-9.9	-5.3**
Control	13	13.5 (6.9)	22.0 (5.6)	-8.5	-4.7***

Both groups gained significantly and similarly during the summer course intervention. The effect size in both groups was large (0.8 in the experimental group and 0.65 in the control group). However, the relatively low average scores obtained in both groups indicate that the short intervention that was not specifically targeted toward this type of achievement (i.e., learning generic ecological concepts), was probably not sufficient for attaining their full conceptual understanding.

### 3.3.2. Students' ability to represent the complexity of an ecological system

As mentioned in the methods section, two sets of instruments supplied data concerning our second research question: assessing students' ability to model a complex ecological system and represent it at different levels of complexity: Concept Maps and students' models and documentation. In this section we will present the results of the analyses of the Concepts Maps and in the next section our analyses of the models and documentation.

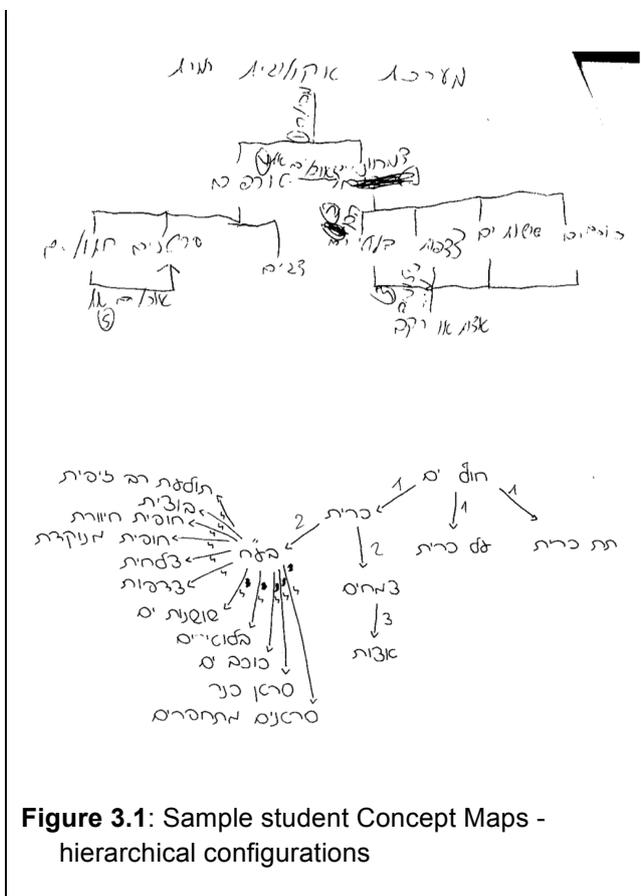
Five criteria were used to assess the level of complexity-understanding as represented in the student concept maps (codes applied appear within the parentheses):

1. The configuration of the concept map
  - a. Hierarchical type ('H' with a number that relates to the number of hierarchical levels)
  - b. Net/Web type ('N')
2. Focus on the system's structural configuration ('S' or 's' depending on the intensity) or focus on representing processes in the system ('P' or 'p' depending on their intensity).
3. The organizing principle used to arrange the components of the map:

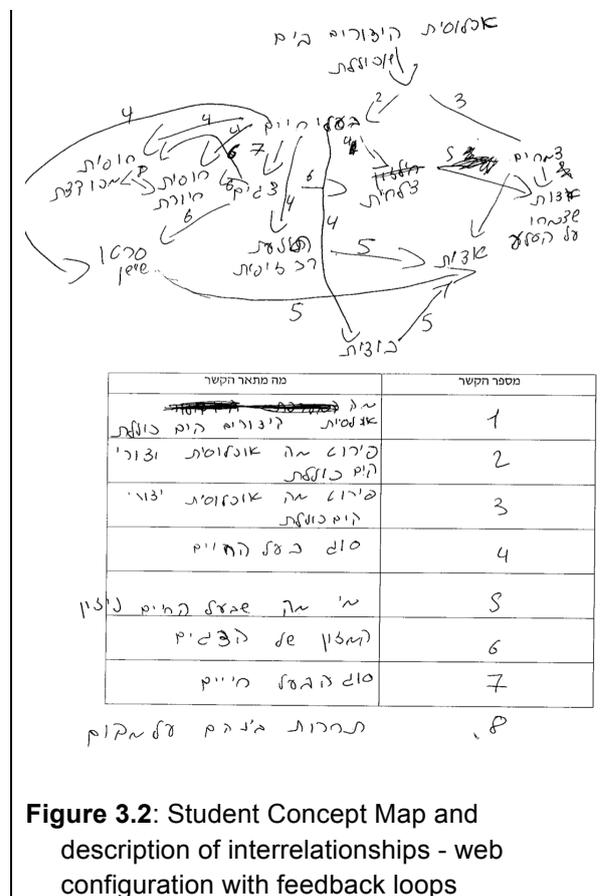
- a. Biological-systematic principle – that relates to formal classification systems of living organisms ('Sys').
  - b. Ecological principle that relates to the distribution of living organisms and non-living elements in their habitat ('E').
4. The type of relationship between the entities of the ecosystem that are represented in the concept map.
- a. Mostly inclusive ('R1')
  - b. Mostly indicating causal or process relationship ('R2')
  - c. Both inclusive and causal processes ('R3')
5. Level of scientific accuracy of the representation.
- a. High scientific accuracy ('Ac3')
  - b. Medium scientific accuracy ('Ac2')
  - c. Low scientific accuracy ('Ac1')

A combination of net-web type of configuration, which combines structural and process elements guided by ecological principles, representing causal or mixed type of relationship (inclusive and causal processes), that also demonstrates high level of scientific accuracy is regarded as a favourable response that show high level of complexity understanding.

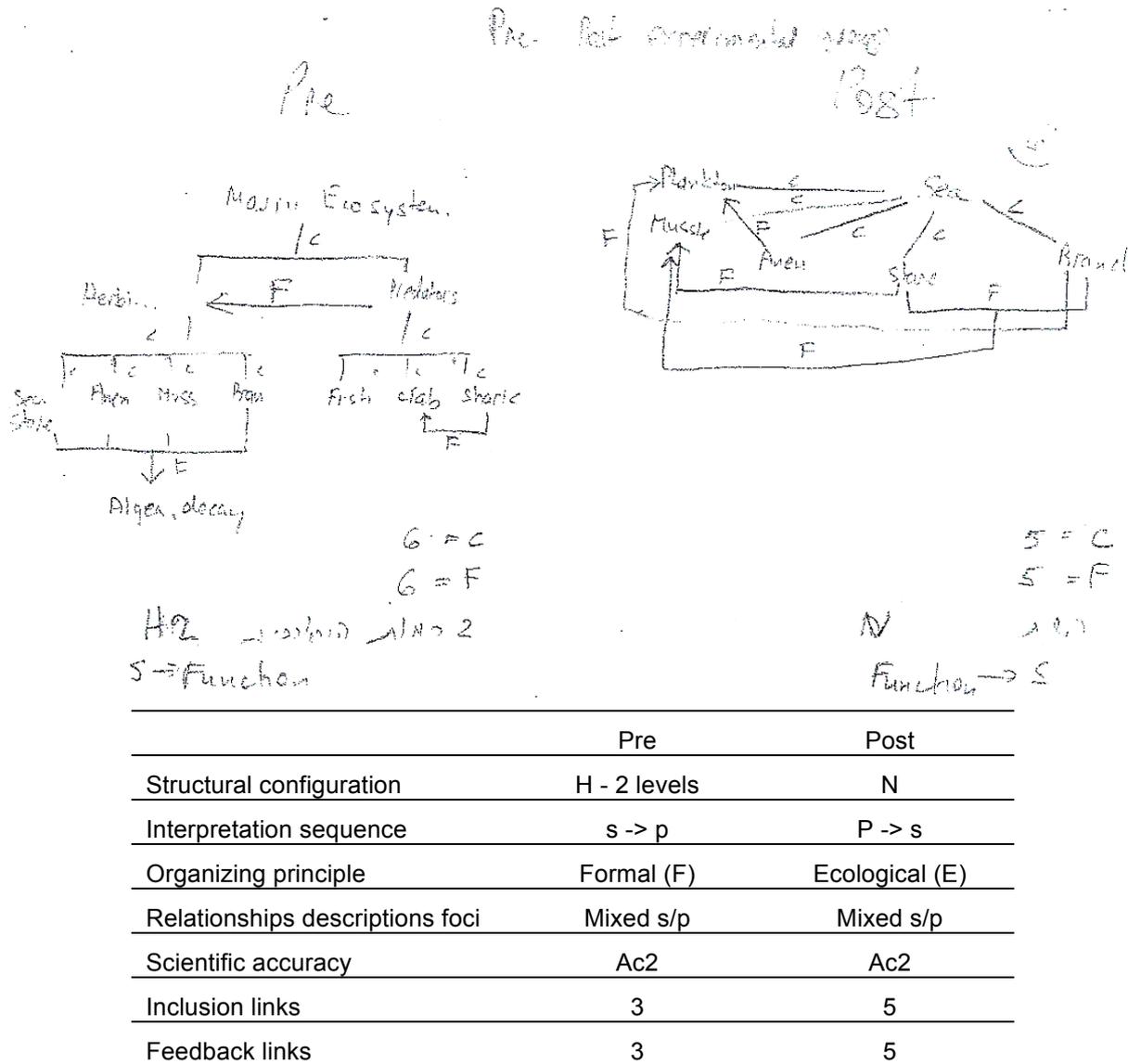
The following are samples of concept maps (Figures 3.1 to 3.3) drawn by the students in the experimental group (pre and post drawings) and the control group (post drawings only). Analyses of the concept maps using the criteria described above follows.



**Figure 3.1:** Sample student Concept Maps - hierarchical configurations



**Figure 3.2:** Student Concept Map and description of interrelationships - web configuration with feedback loops



**Figure 3.3:** Sample scoring procedures of a student Pre- and Post- Concept Maps

In Figure 3.3 two Pre- and Post- concept maps and their scoring are presented. In the example, the student's transition towards a perception of the phenomena modelled in systemic terms is evident in the system's net-like representation, its ecological organizing principle, the inclusion of feedback loops and representation sequence emphasizing processes.

Ten concept maps were produced by the participants of the experimental group at the beginning of the summer course activity (pre concept maps). Seven of the students also provided an additional concept map at the end of the activity (post concept maps).

Thirteen concept maps were drawn by the participants of the control group. All maps were drawn in the late stages of the activity and are regarded as a post measure. The following are the analysis results of the maps.

Table 3.6 provides analysis data for the experimental group, Table 3.7 provides analysis data for the control group, and Table 3.8 summarize pre- and post- scorings of the concept maps of the experimental group and the control group.

**Table 3.6:** Analyses of Concept Maps Drawn by the Experimental Group

Student Id.	Structure		Focus On		Organizing Principle		Relationship (Ratio between inclusive/process Relationship)		Scientific Accuracy (Ac)		
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	
1	H2		S		E			R(4/3)		Ac3	
2	H2		S		E			R1(6/0)		Ac3	
3	H2	N	sp	Ps	Sys	E		R3(3/3)	R3(5/2)	Ac3	Ac3
4	N	N	P	P	E	E		R3(8/10)	R3(6/10)	Ac3	Ac3
5	H3	H2	S	Sp	Sys	E		R1(7/0)	R1(5/2)	Ac1	Ac2
6*	H3	N	sp	sp	E	E		R3(7/5)	R3(4/4)	Ac3	Ac3
7*, **	N	N	sP	Ps	E	E		R3(16/12)	R3(10/7)	Ac3	Ac3
8**	N	H	sP	sp	E	E		R3(9/12)	R3(5/2)	Ac2	Ac3
9	N	N	sP	sp	Sys	Sys		R3(4/7)	R1(10/3)	Ac3	Ac2
10	H		sp		Sys			R1(8/3)		Ac3	

\*external agent

\*\*reduced no. of entities in the post map

**Table 3.7:** Analyses of Concept Maps drawn by students in the control group

Student Id.	Structure	Focus	Organizing Principle	Relationship (Ratio between inclusive/process Relationship)		Scientific Accuracy (Ac)
				Pre	Post	
1	H	S	E		R1(5/0)	Ac1
2	H	sp	?		R 3(5/3)	Ac2
3	H	?	?		R 1(5/2)	Ac1
4	H2	sp	E		R 1(9/3)	Ac3
5	H3	S	E		R 3(4/4)	Ac3
6	H2	S	Sys		R 1(10/0)	Ac1
7	H3	Sp	Sys		R 1(5/2)	Ac2
8	H2	s	Sys		R 1(4/0)	Ac1
9	H2	Sp	E		R 3(4/3)	Ac1
10	H3	Sp	E		R 1(1/0)	Ac1
11	H1	Sp	E		R 3(3/2)	Ac1
12	H3	Sp	E		R 1(5/2)	Ac1
13	H2	Sp	Sys		R 3(3/2)	Ac3

In the next table we compare the concept maps of the two groups, using data pertaining to three criteria: the configuration of the concept maps, the organizing principle characterizing the construction of the maps, and the scientific accuracy of the representation.

**Table 3.8:** Scoring of Concept Map Representations in the experimental and control groups

Pre- Post- in Experimental Group		Post- in Control group
Pre	Post	Post
H = 6/10 = 60%	2/7 = 29%	13/13 = 100%
N = 4/10 = 40%	5/7 = 71%	0/13 = 0%
Sys = 4/10 = 40%	1/7 = 14%	4/13 = 31%
E = 6/10 = 60%	6/7 = 86%	7/13 = 54%
R1 = 3/10 = 30%	2/7 = 29%	8/13 = 62%
R2 = 0/10 = 0%	0/7 = 0%	0/13 = 0%
R3 = 6/10 = 60%	5/7 = 71%	5/13 = 38%
Ac1 = 1/10 = 10%	0/7 = 0%	8/13 = 62%
Ac2 = 1/10 = 10%	2/7 = 29%	2/13 = 15%
Ac3 = 8/10 = 80%	5/7 = 71%	3/13 = 23%

**Key:**

H = Hierarchical configuration; N = Net configuration; S = Organizing principle – Systematic; E = Organizing principle – Ecological; R1 = mostly inclusive relationship; R2 = mostly process relationship; R3 = Mixed relationship; Ac1 = Low level of scientific accuracy; Ac2 = Medium level of scientific accuracy; Ac3 = High level of accuracy

A synthesis of the data from the last three Tables indicate that:

- 1. Concerning Pre- Post- changes in the experimental group's concept maps the trends observed were:**
  - a. Increase (40% → 71%) in Net-type, and decrease (60% → 29%) in hierarchical types of representations
  - b. Increase (60% → 86%) in the use of ecological organizing principles and decrease (40% → 14%) in using formal-classification organizing principles
  - c. Increase in representing inclusive relations (10% → 29%) and mixed inclusive/process relationships (60% → 71%)
  - d. Slight decrease in scientific accuracy (80% → 70%)
- 2. Concerning the comparison between the Experimental (E) and Control (C) groups' post-Concept Maps the following trends were observed:**
  - a. None of the representations in the C group was Net-like
  - b. Less use of ecological type organizing principles in the C group (E-86% vs. C-54%)
  - c. Most representations in the C group were of structural type (E-29% vs. C-62%)
  - d. Less representations in the C group combined structural/process relationships (E-79% vs. C-38%)
  - e. Less scientific accuracy in C group's representations (E-71% vs. C-23%)

### 3.3.3. Students' ability to construct models of a complex marine system

For assessing students' evolving ability to construct models of ecological systems we analysed the models as well as students' documentation of their work. The students were asked to report on each of their modelling experiences (including the initial concept map) using a similar questionnaire. The questions posed were:

- What was the phenomenon represented in the model?
- Which entities were chosen to represent the phenomenon? and why?
- Which properties of the entities were chosen to be quantified? And what were the quantities selected?
- Which relationships were essential for representing the phenomenon?
- What insights were gained through the modelling experience?
- Which additional insights were gained from the previous modelling step to the current step?

A detailed account of the students' responses appear in the Table in Appendix x. Here we will summarize the analyses of the data obtained from the models and the questionnaires. The analyses focus on three main themes.

The first theme concerns changes in the way **students' understanding of the modelled phenomena is expressed** in their representations and explanations. At the beginning of the modelling sessions, half of the students phrased the modelling aim in the format of a question, for instance: "How much effort the patella exerts in attaching the rock in the varying intensities of the waves?" or "How do the wind and the waves affect the patella attachment to the rock?"

At the end of the modelling sessions, most students (80%), described the aim of the activity in a more generic way, i.e., "The relationship between crabs, barnacles and the limpet"; or "The effect of jellyfish on the Israeli marine shore".

The changes in the description of the aim of their modelling activity imply a change in perspective: from a focus on the local and specific aspects to be modelled to a more systemic view of the phenomena. The more generic descriptions imply also the students were able to view the phenomena as particular instance of broader categories, in which multiple-variables causal relationships take place.

The second key theme relates to **students' perception of the diverse types of relationships within the system**. The patterns observed in the data collected are summarized in Table 3.9.

**Table 3.9:** Configurations of relationships in students' models and representations.

Single/unidirectional	$A \rightarrow B$	Wind affects the attachment of the patella to the rock
Single/unidirectional/parallel/independent	$A \rightarrow B$ $B \rightarrow C$	Wind affects the power of the waves The power of the waves affects the attachment of the patella
One-to-many		The wind affects the power of the waves, the attachment of the patella and the number of barnacles
Chain of relationships	$A \rightarrow B \rightarrow C$	The wind affects the power of the waves that affects the attachment of the patella
Feedback loops	$A \leftrightarrow B$	The more predators, the less prey; the less prey, the less predators

Comparing the relationships included in students' early modelling attempts with those from late stages, the following changes were observed:

- Decrease in single/unidirectional relationships (40% → 10%)
- Decrease in parallel/unidirectional relationships (20% → 10%)
- Increase in one-to-many relationships (0% → 10%)
- Increase in chain-relationships (30% → 50%)
- Increase in feedback-loop relationships (0% → 20%)

The inclusion of "chain" and "feedback" type of relationships among entities in most representations and explanations at the end of the course (70%) are clearly indicative that students' perception of the phenomena advanced towards perceiving the complex configuration of relationships among its multiple variables. In addition, it is indicative of students' understanding of the complexity of the system and the type of causal configurations required to explain its behaviour.

The third theme focuses on the **insights gained from the modelling activities** as expressed by the students in their reports along the different phases. Sample expressions by the students:

- *"The modelling activity enabled predictions"*
- *"The modelling activity enabled to know what was at the beginning"*
- *"The modelling activity enabled to understand the dynamics of the system"*
- *"The modelling activity enabled to change things in the model"*
- *"The modelling activity allowed to study many variables and many relationships"*
- *"The modelling activity taught me about direct and indirect effects (I,P)"*
- *"The modelling activity taught me that some changes have long-term and far effects – If you touch one thing, everything can change"*
- *"The modelling activity taught me that nature is in an equilibrium state"*

All our observations provided clear evidence about students' modelling capability at two levels: mastery of the modelling environment, and conceptual understanding of modelling as approach to the inquiry of ecological phenomena. At the first level, students' rapid acquisition of knowledge and skills related to modelling with DynaLearn could be observed from the very first stages of the course. At the conceptual level, the analyses of the models and explanations along the course showed clear advance towards systemic perceptions and understandings of the complexity and causal relationships (chains and loops) standing behind the systems' behaviours.

### 3.3.4. Capability to apply gained knowledge for approaching new phenomena

A set of questions administered at the end of the activity to students in both groups comprised a challenging test that was aimed to trace the application of system thinking in a new context. The questions required students to use the ecological knowledge they gained for providing descriptions, explanations, and predictions in regard to a marine ecosystem. The questions were:

1. Describe features, morphological or behavioural, of one tidal zone organism, that ensure its survival in low tide and explain how.
2. Define the type of relationship concerning food or space (competition, predation, mutualism, parasitism) between intertidal organisms.
  - Patella – feeds on algae prefers the wave side of the rocks

- Monodonta – feeds on algae prefers back side of the rocks
  - Barnacle (Balanus) – feeds on plankton prefers wave side of the rocks
3. What will happen if a predator fish who feeds on Monodonta will invade the Mediterranean Sea?
  4. What will happen if building a new breakwater causes the sea level in the tidal zone to drop 10 cm.?

The questionnaire's scoring guide is detailed in Table 3.3 in the method section. The results of the analysis and scoring of students' responses are presented in Table 3.10.

**Table 3.10:** Students' responses to the challenging questionnaire by group

		<b>Question &amp; (maximum score)</b>					
	Student ID:	1 (2)	2 (6)	3 (4)	4 (3)	Max score 15	Total % (rounded)
EXPERIMENTAL GROUP	1	2	2	4	3	11	73
	2	-	-	-	-	-	-
	3	2	4	1	1	10	66
	4	2	3	4	2	14	93
	5	2	3	1	1	10	66
	6	2	3	2	2	12	80
	7	2	3	3	1	12	80
	8	2	4	2	2	12	80
	9	2	5	3	1	12	80
	10	2	5	3	2	13	87
	Aver. Group score	2	3.6	2.1	1.3	10.5	78.3
CONTROL GROUP	1	2	1	1	0	4	27
	2	2	1	1	0	4	27
	3	2	0	1	1	4	27
	4	1	4	1	0	6	40
	5	1	3	2	1	7	47
	6	2	0	1	0	3	27
	7	2	0	1	1	4	20
	8	2	0	1	0	3	33
	9	2	1	1	1	5	27
	10	2	0	1	1	4	80
	11	2	6	2	2	12	80
	12	2	6	2	2	12	80
	13	2	6	2	1	11	73
	Aver. Group score	1.8	2.2	1.3	0.8	6.1	45.8

Students' responses to the first question (in all cases in the experimental group and some in the control group) reflected attendance to what Goel & Chandrasekaran (1989) described as a Structure-Behaviour-Function Mental Model (SBF), i.e., explanation that relates structural features to a certain behaviour that fulfils a certain function. In this sense, these responses are teleological.

The second question required understanding of different types of food and space relationships. Here the understanding demonstrated by students in the experimental group was much better than that of students in the control group (attaining 59% correct responses vs. only 36%).

The third and fourth questions required students to demonstrate their ability to predict chains of changes that might occur in a system in response to interference (effect of external agent, change in conditions, etc.). Most of the students in the experimental group (60%) succeeded in delineating long

chains of three or four events linked to each other, e.g., "*The invasive predator fish will eliminate the population of monodonta. This will increase the supply of algae for patella causing the patella population to grow*". In contrast, in the control group delineation of such long chains did not occur. Most of the relationships revealed, linked only one event to the other and in some cases (30%) two events.

The average total score obtained by students in the experimental group was much higher than that obtained by the control group (78.3% versus 45.8%).

Responses of the experimental group to the different questions, revealed students' better conceptual understanding and higher ability to predict chains of causal relationships in an ecosystem. However, few responses related to features such as web-like relationships or complex feedback loops.

In summing up these results, it is clear that concerning the dynamics of the system, the modelling activity affected the way students represent relationship in a system, and are capable of perceiving it in a more dynamic and interconnected way.

### 3.3.5. Students' motivation and attitudes towards Learning by Modelling

At the end of the course students were required to answer to a motivation and attitudes questionnaire. Students' responses (in a scale 1 to 4) are presented in Table 3.11.

The experimental group responses indicated their higher evaluation of the contribution of modelling with DynaLearn to their understanding of systems and complexity concepts, and their capability to inquire about ecosystems using DynaLearn features.

Next are the values attributed to the contribution of modelling and running simulations to their learning of ecological systems concepts.

In addition, the experimental group scored high the claim indicating their willingness to use the Learning by Modelling approach also for learning additional subjects areas in the curriculum.

**Table 3.11:** Students' responses to attitudes questionnaire

	Experimental Group	Control Group
Using DynaLearn contributed to my better understanding of the complexity of an ecosystem.	3.6	-
DynaLearn opened new ways of exploring the ecosystem which I would not have reached without it.	3.5	-
I learnt mostly through building the models on my own.	2.6	-
I learnt mostly through running simulations.	2.75	-
I learnt mostly through watching the teacher demonstrating on how to build a model.	2.25	-
I learnt mostly during the field trip.	2.6	3.0
I learnt mostly through the laboratory experiences.	3.5	3.0
I learnt mostly through the lectures given.	3.5	2.9
Most of my learning occurred during the Web-quest task.	-	2.9
I would like to learn by modelling in other subject areas.	3.4	-

In the control group, the field trip and the Laboratory tasks were the most highly valued by the students, and in less extent the lectures and computer-based task.

### 3.3.6. Focal stories

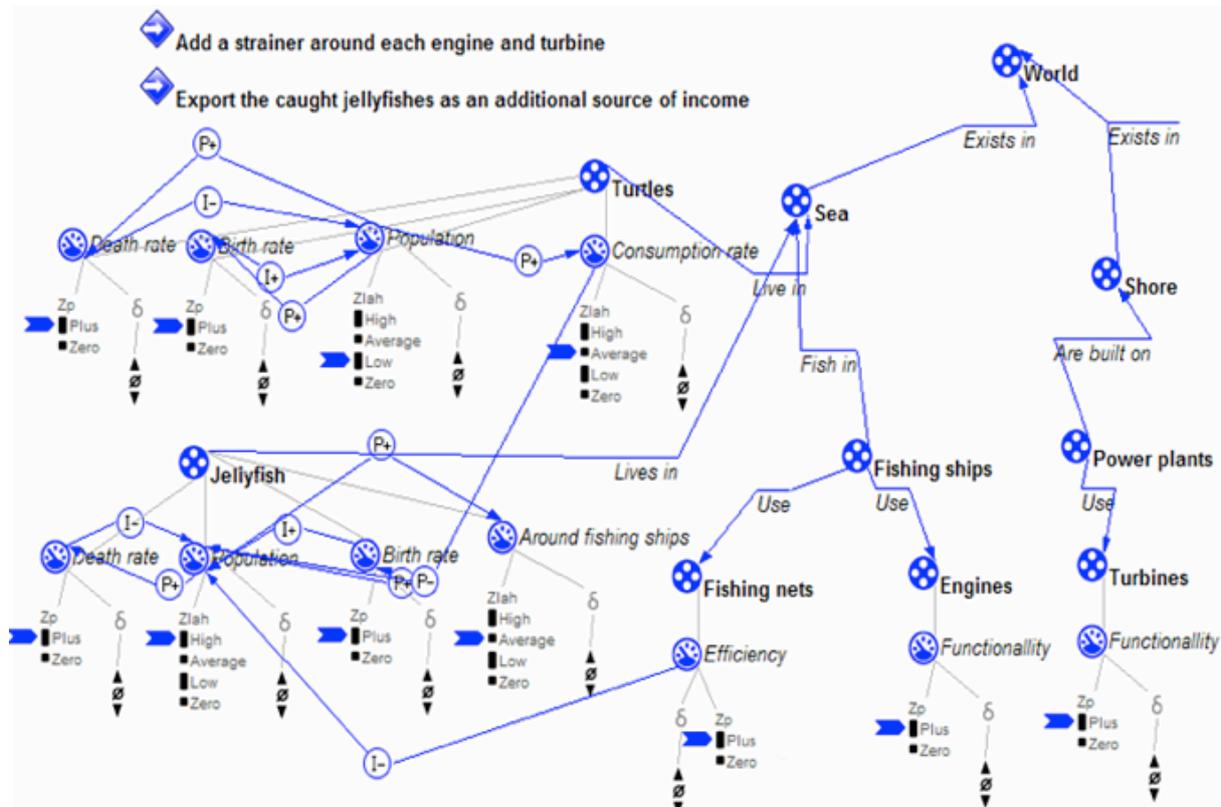
In the final activity of the course with the experimental group the students were asked to model the effects of the invading Indo-Pacific jellyfish *Rhopilema nomadica* on the Mediterranean Sea ecosystem, based on material they found on the internet. Students were also asked to present a possible solution to the jellyfish project and to demonstrate this solution on their models.

The following effects were modelled by the students:

- Jellyfish population leading to an increase in jellyfish-eating predatory fish.
- Jellyfish population leading to an increase in plankton by feeding on plankton-eating fish.
- Jellyfish population leading to a decrease in the fishing industry by clogging fishing nets.
- Jellyfish population leading to a decrease in the tourism industry by stinging swimmers.
- Jellyfish population leading to an increase in jellyfish-eating predatory sea turtles.
- Jellyfish population leading to a decrease in the power-plant industry by clogging cooling turbines.

Students' suggested solutions to the jellyfish problem included processes such as "increasing their predator populations" and "exporting the jellyfish as food".

An example of a student's model is presented in Figure 3.4.



**Figure 3.4:** A student's model for the "Jellyfish population" task

Students' suggested solutions for the problem -actually their hypotheses and predictions of the behaviour of the system in changing conditions- were implemented and tested in their models, as in the above example.

The modelling task was part of a class assignment. However, the students asked to take the software home and do further work on their models in their free time.

### **M.'s story**

#### ***"An Outstanding Presentation: Saving the Sea Turtles"***

M. with a childish appearance arrived with his mother to the presentation day. Although very shy and smaller in stature than the other students, he presented his work with a lot of confidence and behaved like an experienced lecturer. His PowerPoint presentation contained many pictures that enriched the information he provided. His presentation started with acquainting the audience with *Rophylema monadica* – the jellyfish that invaded the Mediterranean Sea through the Suez Canal . Belonging to the *Coelenterata* and armed with special toxic cells called "nematocysts" the jellyfish preys on small animals and plankton which are paralyzed when being in contact with the toxin that was exerted from the toxic cells. M. then went on to describe the explosion of the jellyfish population in the Mediterranean Sea as a result of over fishing that cause many of the predators of the jellyfish to disappear.

As a result, the jellyfish today, in their numerous number, become an obstacle for the fishing industry as they block the fishing nets.

How should we solve this problem without destroying the delicate biological equilibrium and harm the economy?

*"Importing a new predator of the jellyfish will be another threat to the already shaky biological equilibrium. Thus we should count on local predators that feed on the jellyfish. One of them is the Sea Turtle – *Caretta caretta* – common in the Mediterranean Israeli seashore. However, this species is endangered by people who collect the eggs, destroy the nests by driving 4 X 4 vehicles on the seashore. Turtles are also attracted to lights near to human settlements and many of them are run over by cars when they move toward the source of light at night".*

*"We need to take several actions, continued M. in his presentation: to prohibit cars from driving on the shores, prohibit people from collecting the eggs, and educate. If these measures are only undertaken in Israel, it will not be enough, as we need the support and cooperation of other countries along the shores of the Mediterranean Sea to participate as well. If we succeed in the recovery of the turtle population, we will see a decrease in the jellyfish population as predicted in the simulation M. demonstrated on his model".*

### **3.4. Concluding remarks**

In this evaluation activity Junior-High School students attended a summer course in Marine Biology, which included everyday sessions of modelling with DynaLearn. A control group attended a similar course, however performing computer-based inquiry activities instead of modelling. Our main observations are summarized in the following.

Upon the detailed description of the data collected presented in the previous sections, we might briefly summarize the key issues observed:

- Overall, the students acquired rapid mastery of the skills and procedures required for constructing models with DynaLearn. as the modelling sessions advanced, their products reached high levels of complexity
- At the end of the course, an increase in experimental group students' ability to represent a system's structural, functional and behavioural features was observed. This observation was obtained in relation to the groups initial performance, and in comparison with the control group's performance.
- At the end of the course, an increase in students perceptions and representations of multiple-variables causal relationships, causal chains and feedback loops was observed. This is indicative of students' evolving understanding of the complexity of a system and of the type of causal configurations provoking its behaviour.
- Student comments (qualitative account of the group's work) reinforced the conclusions from the data. On this, a representative comment by a student asserted: "*The modelling activity taught me that some changes have long-term and far effects – If you touch one thing, everything can change*"
- Knowledge and systemic approach gained during the course supported students' capability to apply these for addressing challenging questions about a system in a new context. The experimental group clearly outperformed the control group in this task.
- Students demonstrated high motivation towards the modelling activities, and towards the possibility to use DynaLearn for learning other subjects. They also perceived positively its contribution to their system thinking.

## 4. Evaluation activity 3: The contribution of "grounding" to Learning

### 4.1. Introduction

In December 2010 an evaluation activity focusing on DynaLearn's "grounding" feature was conducted. The context for the evaluation activity is a regular course in Marine Biology at Tel Aviv University. Complementing the course, a hands-on workshop using DynaLearn is being conducted along the Fall-Winter semester once a week for 2 hours, a total of 28 hours. Participants (15 students) are accredited 2 additional points for the workshop. Within this context, we conduct focal evaluation activities such the one on which we are reporting here.

The "grounding" feature in DynaLearn, relies in the use of a background Ontology (currently based on DBpedia). The feature enables learners to learn by themselves contents yet unknown to them and to relate the terminology used in their models to definitions and information contained in the semantic repository and/or in external knowledge sources. The process of grounding itself aims to serve as support for self-directed learning, and contribute to improves the quality of the students' models due to a better understanding of the phenomenon being modelled.

The main goal of this evaluation activity was **to assess the contribution of the grounding process to students' model construction process**, and **to the facilitation of self-regulated learning**. The questions addressed were:

**Does students' involvement in grounding models contribute to:**

- Their construction and revision of a model of a marine system?
- Their self-directed learning of concepts and causal relationships within the modelled system?

### 4.2. Method

#### 4.2.1. Participants

Participants were 14 students attending a Marine Biology course at Tel Aviv University, and a complementing modelling workshop with DynaLearn (14 classes, 2 hours each class). The "grounding" evaluation activity was conducted during one 2 hours class, and completed by the students as homework task.

#### 4.2.2. Variables

The variables for which data were collected and analyzed were defined in correspondence with the research questions:

- Understanding the phenomena to be modelled
- Use of previous/acquired knowledge to construct a model
- Quality of model before/after grounding
- Observations on self-directed learning

### 4.2.3. Implementation instruments: The Grounding task

The evaluation of the grounding process took place in class 6 of the modelling workshop. Students were already acquainted with the QM language and experienced constructing models in learning spaces 2, 3, and 4.

The task was conducted in two phases. In the first phase they received a "blind model" (in the sense of a "blind map"), in which the skeleton of a model appears without indication of entity names, quantities, etc. In addition they received a list of terms, many unknown to them, to serve as ingredients for the completion of the model (see Appendix B).

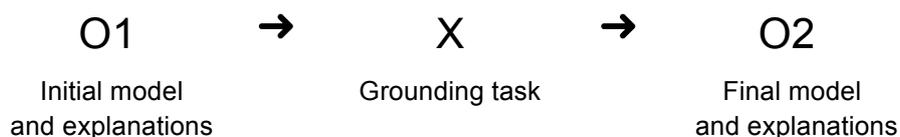
The terms included in the list were: *Ships; Antifouling Paint; Organotins; Gastropod; TBT; Concentration; Sediment; Mediterranean Sea; Number of; Population growth rate; Female fertility; Amount transferred to seawater.*

In this phase the students were requested to incorporate the terms in the appropriate (as considered by them) parts of the model, to determine the relationship between the terms, and to provide a description of the ecological phenomenon the model represents. Further on they were asked to predict the behaviour of the ecosystem under certain conditions. Finally they were also asked to run the simulation and provide several paths concerning their predictions.

In the second phase of the activity the students were asked to ground the main terms (concepts) they used for completing the blind model. This activity aimed to assess whether the grounding process broadened students' conceptual understanding of the phenomenon captured by the selected terms. Next they were asked to reconsider and revise the model they have created, to modify it if needed and to describe the additional insights they gained in the grounding process.

### 4.2.4. Study's design and Data collection instruments

The evaluation activity followed a "One-group Pre- Post-test" design (Creswell, 2003). The pre-test situation (O1) was the building and interpretation of the initial model upon the "blind" template before the grounding process (X). The post-test situation was the revision of the first model and the new explanation obtained following the grounding activity (Figure 4.1).



**Figure 4.1:** the study's design

Data collected comprised the students' initial and final models, and their answers to the following questions ("grounding task worksheet"):

**Part 1** (after completing the initial model)

- What are the phenomena and processes represented in the model?
- What do you predict will be the behaviour of the modelled system?
- Run the simulation - explain the results for selected paths.

**Part 2**

- Perform the grounding of the model terms.

- Evaluate your initial model - revise and modify it if needed.

The answers to the questions and the results of the simulation were delivered by the students as a digital file.

#### 4.2.5. Data analysis

For data analysis the following criteria were developed (the specific aspects measured appear between parentheses):

- Understanding of the ecological phenomenon from the set of given terms (telling the story)
- Ability to apply this understanding to complete a model that represents this ecological phenomenon (identifying relevant entities and relationships; identifying their correct configuration in the model; number of elements in the causal chain; and their correct ordering).
- Ability to predict the behaviour of the ecological system under certain conditions and confirm their prediction and explanations by running a simulation (simulation) and providing a scientific correct interpretation (explanation).
- Gained content knowledge of concepts (known terms).

Data for these criteria were scored using an impressionistic quality scale (1 low; 2 medium, and 3 high). Scoring was done twice, before and after the grounding process.

### 4.3. Results

#### 4.3.1. Students' assignment of terms in models and explanations

The students were asked to incorporate the set of 12 terms mentioned in 4.2.3 into the "blind model", and to generate explanations about the system modelled and its behaviour. The number of terms correctly assigned before and after the grounding is shown in Table 4.1:

**Table 4.1:** Terms correctly assigned before and after grounding

Students	Terms correctly assigned in model		Terms correctly assigned in explanation	
	Before grounding	After grounding	Before grounding	After grounding
1	12/12	11/12	12/12	12/12
2	9/12	11/12	10/12	11/12
3	12/12	12/12	12/12	12/12
4	11/12	11/12	10/12	11/12
5	11/12	12/12	11/12	12/12
6	12/12	12/12	11/12	11/12
7	12/12	11/12	12/12	12/12
8	12/12	12/12	11/12	11/12
9	12/12	12/12	11/12	12/12
10	12/12	12/12	11/12	12/12
11	12/12	12/12	10/12	11/12
12	10/12	11/12	8/12	10/12
13	10/12	11/12	8/12	10/12
	147/156 (94%)	150/156 (96%)	137/156 (88%)	147/156 (94%)

This first set of data relates to the number of terms correctly assigned, indicating the existence of previous knowledge or alternatively, the ability to infer about the role of a term in the model while building it. It appears that for these Life Sciences students, most terms were known with the exception of a small subset relating to each other, i.e., "TBT", "Organitin", "Antifouling paint". After the grounding process most terms were appropriately recognized and assigned.

#### 4.3.2. Students' assignment of terms in models and explanations

The previous is a summative account of term recognition and assignment. A deeper account on the quality of the models created, students understanding of the phenomenon modelled and the causal relationships, processes and behaviours in the system was obtained by further analyses of the data. All different aspects are summarized in Table 4.3.

**Table 4.3:** students' understandings as reflected in four data sets

	Before grounding task					After grounding task				
	story	model	simulation	explanation	Total	story	model	simulation	explanation	Total
1	2	1	3	2	8	2	1	3	2	8
2	3	2	3	2	9	3	3	3	3	12
3	3	3	3	3	12	3	3	3	3	12
4	2	2	3	2	10	3	3	3	3	12
5	2	2	3	2	10	-	-	-	-	-
6	2	2	3	2	10	3	3	3	3	12
7	3	2	3	3	11	-	-	-	-	-
8	2	2	3	3	11	3	3	3	3	12
9	3	3	3	3	12	3	3	3	3	12
10	3	3	3	3	12	3	3	3	3	12
11	3	3	3	3	12	3	3	3	3	12
12	3	3	3	3	12	3	3	3	3	12
13	2	2	3	3	10	3	3	3	3	12
$\bar{X}$	2.54	2.30	3	2.46	10.7	2.91	2.81	3	2.91	11.6
%	84	76	100	82	89	97	94	100	97	97

The first aspect considered was students' ability to recognize and understand the "main story" - the phenomenon modelled. Before the grounding only half of the students got the highest mark (3) for an accurate and complete description of the system. After the grounding all but 1 student got this mark. It appears that the activity supplied the information required to generate an appropriate description of the phenomenon.

The aspect most benefited from the grounding activity was the quality of the model built and then revised by the students. As mentioned above, the aspects analysed were: relevant entities and relationships; their correct configuration in the model; number of elements in a causal chain; and their correct ordering. Before the grounding activity only about 40% of the students created a quality model of the highest mark by these parameters. After the grounding all but one students' models got the highest mark.

Running the simulation, selecting a path and presenting an appropriate interpretation was already accomplished at the highest level before the grounding activity. It appears that the students, due to their experience in the course so far, already mastered the interpretive skills required to work with the simulation results of their models.

Overall, students explanations for all issues examined were contributed by the grounding activity. Although all explanations before grounding were of reasonable level, only 60% of the students got the highest mark. After grounding the model all but one student supplied complete explanations.

### 4.3.3. Observations on self-directed learning

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An important goal pursued by DynaLearn is to foster independent and self-directed learning (SDL). SDL was defined by Gibbons (2002, Pp. 2) as *"any increase in knowledge, skill, accomplishment, or personal development that an individual selects and brings about his or her own efforts using any method in any circumstances at any time"*. This, in contrast with Teacher-directed learning (TDL) in which the increase in knowledge and skills is brought about by teacher initiatives, who determines the selection of the contents, the learning activities, and testing procedures. A key question for the development of curricular solutions and learning environments is how to build appropriate balances among SDL and TDL with the purpose of supporting the gradual construction of independent learning skills and strategies by the students.

In the grounding activity we have collected several observations with clear connection with SDL processes (about a more general discussion on SDL with reference to the whole set of evaluation activities conducted see the final discussion section of this deliverable). Overall, for which no external (teacher) support was offered other than guidance in procedural aspects of the activity. The task demanded to address the problem at hand and construct knowledge at different levels: knowledge of content (concepts definition), identification of the essence of an ecological phenomenon ("telling the story"), depicting it as a system of ingredients and relationships, including causal interdependences, representing it using the modelling environment, and formulating hypotheses and making predictions about the system's actual and possible behaviours under changing conditions.

Specifically for the grounding, and in particular for the unknown terms, they were requested to evaluate alternative definitions; to select what they consider the most appropriate ones by activating criteria and weighting the appropriateness of a piece of information in relation to the whole context - the system and the processes in it; to develop strategies for dealing with the unknown terms. An example of a strategy: as a term's "neighbourhood" in the representation becomes "populated" (grounded), and fragments of it turn into a clear enough context, the insertion of the new term is facilitated.

Additional evidence of students' independent decision making while grounding is related to given constraints in the grounding mechanisms in the current early versions of their implementation. For some terms, in their original wording either no information was obtained or irrelevant information appeared. In some cases a mere technical solution was used (e.g., entering the term in its singular rather than plural form). However in other interesting cases, content-related considerations had to be applied (e.g., are "sedimentation" -for which information was shown- and "sediment" -no information was obtained- equivalent in relation to the required grounding in the context of the model?). Once again these situations demanded the devise of ad-hoc solutions by the students.

Finally the task, which demanded more work time than the allocated in the class, was completed as homework by the students (they were also requested to update the version of DynaLearn in their home computers with the features included in a recent release). Without doubt the features relying on the semantic technologies are promising for pursuing the goal of supporting the independent and self-directed learner.

## 4.4. Concluding remarks

In this evaluation activity students in a DynaLearn workshop accompanying a course in Marine Biology were requested to perform a learning activity focusing on the "grounding" feature. The main questions addressed related to the contribution of this feature to students' understanding of concepts, of the system's structural configuration, its processes and behaviour, as well as to students' capability to learn independently. Our observations are summarized in the following.

- The students, performing independent work, reached success in the completion of all components of the task.
- Most candidate terms for grounding were appropriately handled by the students with their previous knowledge. However, there was a cluster of unknown terms which required to be identified and defined. The grounding activity contributed to the understanding of these terms and concepts and to the successful incorporation of them into the models constructed.
- The main effect of the grounding activity was on the students' model construction and revision processes. Data collected on various parameters of students' work (i.e., identifying relevant entities and relationships; identifying their correct configuration in the model; number of elements in the causal chain; and their correct ordering) indicate an increase in students' capabilities following the grounding activity.
- Next on the extent of effect of grounding on students' performance relates to their ability to recognize the phenomena (to "tell the story of the system") and on the completeness of the explanations supplied by them.
- Observational data was obtained indicating the potential role of the activity to support self-directed learning, reinforcing all previous data on students' success in completing a complex task requiring independent work.

## 5. General discussion

This section summarizes a series of issues integrating the results and conclusions from the different evaluation activities. The specific observations behind the issues were already discussed in their relevant context for each of the evaluation activities. Here we will adopt an overarching perspective to sum up the first phase of evaluation main issues.

### 5.1. Conceptual understanding

An essential focus for our examinations was the contribution of DynaLearn to students conceptual understanding of ecosystems, and of concepts in Environmental Science. Evidences collected within both Undergraduate and Junior-High School students are clearly indicative of this contribution.

Concerning DynaLearn's curriculum in Environmental Science, the activities planned and conducted focused on contents pertaining to three of the seven main themes: The living world, land and water use, and pollution. More specifically, the contents addressed included the topics : Marine ecosystems, species interactions, the chemistry and physics of marine environments, invasive species and migration, food chain, human intervention effects. The pedagogical model chosen for the design of the learning situations was based in all cases in the use of scientific papers and/or textual descriptions about ecosystemic phenomena, as basis for the further modelling activities. Overall, all the topics addressed were appropriate for conducting DynaLearn-based learning activities. The approach adopted, consisting in the use of scientific papers describing actual questions and experiments about real problems and systems (situated and authentic problems in the topics), has been proven as rich and motivating curricular setting for students' learning.

In the case of the undergraduate students, we were able to observe the gradual change in understanding and increase in meaningful learning along the learning process, as reflected in the differences between their initial representations of the phenomena under study (in the intuitive concept maps) and the complex models of the same phenomena developed and presented at the end of the course.

The specific "grounding" feature, although examined in its current stage of development, clearly supported students acquaintance with unknown concepts. In the course, the participant Life Sciences students had strong background in the discipline and were familiar with most concepts already at the beginning of the activity. However for the unknown concepts, students' inquiry of their meaning while grounding them allowed their appropriate integration in the models being constructed.

In the case of the Junior-High School students, the modelling work contributed to their conceptual understanding of ecological systems, and in less extent to their understanding of specific concepts. This understanding of the systemic aspects of the phenomena was evident in the students' models and explanations, and in their ability to apply the acquired understanding for addressing new phenomena (in the "challenging questions") compared with the control group.

Overall, two main conclusions can be drawn from the observations in the evaluation activities. The first is that the main gain at the conceptual understanding level relates to students' perception of the phenomena modelled from a systemic perspective - considering the ecosystems structure and behaviour. The second is that previous content-knowledge plays a crucial role in the model construction activity. Alternatively, the acquisition of the new knowledge and concepts required for complex modelling demands and extended learning process. This was facilitated by the long-term interventions (as in the undergraduate course) in contrast with the limited effect of the short-term intervention (School students).

## 5.2. LbQM and System thinking

Students' system thinking and ability to represent a system's structural and behavioural features were clearly contributed by the work with DynaLearn. Along the learning processes, growth of skills and abilities was observed. Examples of observed performances indicative of this growth are students':

- Progressive ability to define and refine the foci (the essential properties) of the model to be constructed
- Defining criteria for reducing the amount of model ingredients while preserving its meaningfulness
- Balancing between goal-oriented and trial-and-error (exploration) approaches
- Translating among representations (e.g., from textual descriptions of a phenomenon to its expression in a DynaLearn model)
- Hypotheses formation and testing
- Generation of new questions and inquiry processes beyond the original information used for generating the model
- Perceiving the value of the models constructed not only in terms of the specific phenomena modelled, but as paradigmatic examples of complex systems in the area under study

Overall, the students acquired rapid mastery of the skills and procedures required for constructing models with DynaLearn. As the modelling sessions advanced, their products reached high levels of complexity. At the end of the courses, an increase in students' ability to represent a system's structural, functional and behavioural features was observed.

We have also observed growth in students' skills referred in the literature as comprising system thinking (e.g., Draper, 1993; Assaraf & Orion, 2005), such as: the ability to identify components of a system and processes within a system; the ability to organize the system's components within a framework of relationships; understanding the hidden dimensions of a system; or thinking temporally - retrospection and prediction.

However, the development of system thinking implies an essential transition in students' learning: a transition in paradigmatic approach towards the inquiry of phenomena in the world. The vast majority of science teaching curricula and learning materials (particularly at the school level) aims to teach "classical science" and its methodology. Novel theoretical and methodological approaches in development in the sciences community for several decades, that view phenomena from the perspective of complexity and systems theories, is almost absent from existing curricula. This transition is not a trivial one, and demands the development of novel pedagogical approaches and essentially - it requires time, or long-term involvement in learning processes involving system thinking.

## 5.3. Causality

A central question while assessing students' modelling processes of systems relates to their perception of causal relationships and configurations within the system, and between the system and its environment. DynaLearn demands the definition of these as part of the model construction process, facilitating the progressive approach of causal aspects of the system being modelled while traversing the different learning spaces. However, a characterization of students' perceptions and ability to compose causal configurations is essential. In our evaluation activities we developed analysis criteria and coding schemes aiming to depict such a characterization.

Basically we considered two main layers. The first for mapping students' different ways of expressing "explicit" causal relationships, namely, those that are attached to the components represented in the model (e.g., direct relationships between quantities or causal chains). The other is the "hidden" layer, understanding how the overall behaviour of the system results (emerges) from the causal configuration of its components.

For the first layer, we defined on the basis of our observations the progression of causal constructs shown in Table 3.9. Our set ranges from single/unidirectional relationships, through different configurations of one-to-many and many-to-one relationships, causal chains, to simple and complex feedback loops. For the second layer, we based our analyses on students descriptions and explanations to assess their understanding of the overall system's behaviour. Our main observation was that along the modelling activities, students' perceptions (hence representation) of causal patterns and configurations became more complex. Even in the School students group, most of them succeeded in expressing long causal chains in their models (in contrast with the non-modellers group). Also in most cases students' showed high ability to predict causal chains and loop in alternative scenarios for the systems modelled.

Of greater difficulty however for School students were more complex causal configurations, and few web-like configurations were found in their models and explanations. It is obvious that mastering this level requires more learning time, more interaction with models, and more involvement in modelling activities than the afforded in the course conducted.

For the higher layer - understanding of the overall behaviour of the system- we found ample evidence in students explanations. For example, undergraduate students' generation of inquiry questions beyond the questions in the scientific paper used by them as reference to build their models, is clear evidence not only of their understanding of the causal configurations among factors in the original experiment, but also of their ability to suggest and explore alternative causal configurations. One School student's comment is illustrative of the insights gained: *"The modelling activity taught me that some changes have long-term and far effects – If you touch one thing, everything can change"*.

However, these are only initial observations on the way the modelling activities with DynaLearn empower students to approach and understand causal configurations in a system, and obviously more research work should be planned and conducted in the next phase of evaluation activities.

## 5.4. Motivation issues and self-directed learning

Overall, the marks for motivational issues related to learning with DynaLearn were high. Looking at specific aspects, the the higher scores were related to the students perception of the software's motivational value for building ecological models (in the course and in the future as well), and to the contribution of the work with the software to their system thinking. At a lesser extent the modelling work was perceived by the students as contributing to their conceptual understanding.

One of the aims of DynaLearn as constructivist learning environment id to foster students' self-directed learning (SDL). As discussed in the chapter related to the 3<sup>rd</sup> evaluation activity, appropriate balance should be achieved between SDL and teacher-directed learning (TDL), aiming to create the necessary motivation and perception of self-confidence for the student to take control of her learning. Numerous observations of the gradual transition towards a more independent learning modality were collected. However, these situations should be formally and systematically devised as pedagogical process in the future as a model for the pedagogical implementation of DynaLearn. And obviously these models should be assessed in future evaluation activities.

Still in the dimension of the interaction between pedagogical approaches and students' motivation and attitudes towards learning, an important transition is required. For years the main teaching modality

which students are involved in is the lecture-based or information-delivery modality. Learning about systems with DynaLearn demands a clearly different approach: learning by constructing models, and learning by inquiring phenomena represented in models. This transition implies once again a pedagogical model in which the "model constructor" responsible for her own learning stands at the centre of the scene. The constructionist idea stating that the students construct their inner world by constructing in the outer world demands a supporting pedagogy. Our preliminary observations of learning processes with DynaLearn serve as promising background for the development of these pedagogies.

## 5.5. Future work

Concerning the next phase of evaluation, future work includes activities at several levels.

The first level is obvious and relates to the planning and conduction of evaluation activities. During the first phase the activities were conducted using the released version of the software at the time of the evaluation. For obvious reasons in an ongoing development project, only given features were available at the different times. In some cases, some of the features were still in preliminary form or were unstable. For the next round of evaluation we will be able to design activities based on the implementation of a more complete configuration of the software, making possible to address the remaining questions in our evaluation framework (see Figure 1.1 and list of questions in page 9). More specifically, we expect to address in the next round questions related to the implementation of features related to the semantic technologies and the motivational and learning roles of the Virtual Characters. As well, we expect to be able to address the more general questions and deepen our questions on motivational aspects and self-directed learning. Finally, on the basis of the methodological approaches and instruments developed, we will be able to deepen our examination of students thinking about complexity.

Another dimension concerns the identification of stakeholders for DynaLearn. We see three main groups as target population for DynaLearn. The first are College and University Students (within the current scope of the project mainly pertaining to the environmental science related disciplines). In TAU, given our successful experience in incorporating DynaLearn as integrated component in the Marine Biology course for the second year, we see the prospect of replicating this model in other courses and in other faculties (for example, in courses in the School of Education's graduate program in "Technology & Learning", in the department of Science Education).

The second target population are High School students, both in formal as well as in informal education settings. This year's experience with the Institute for Excellence in Education and the University's Unit for Science Oriented Youth was successful, and we were requested already to conduct a more comprehensive course for young students in the second part of the year. Expanding these activities with early High-School students is also a promising venue.

The third population group is undoubtedly highly important for disseminating the integration of DynaLearn for learning science: teachers in pre-service and in-service formation courses. Teachers are the key mediators between the learners and the curriculum, and their training in using DynaLearn as learning environment for environmental science topics implies the potential for a multiple-sites dissemination of DynaLearn approach and tools. For this population, we have already initiated conversations with a Teachers College in the area, and with staff involved in teacher training programs at TAU.

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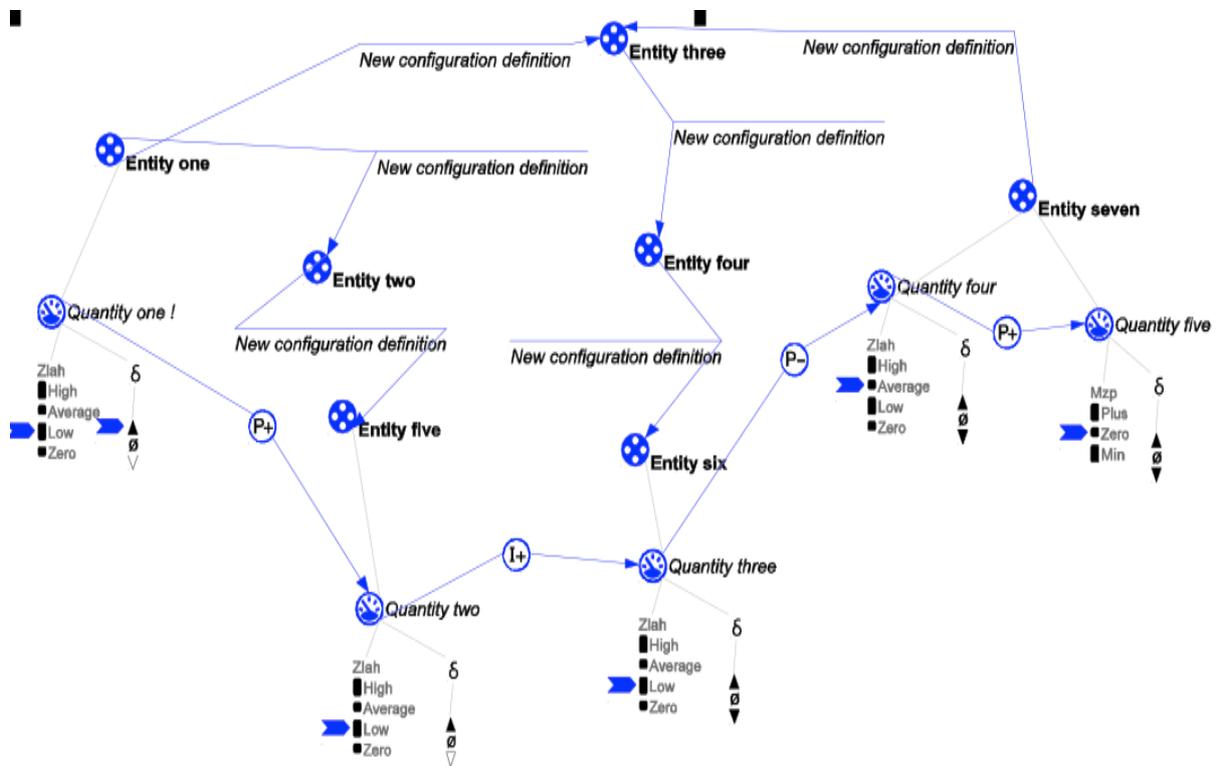
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## Appendix A: Questionnaire on main concepts of the course

The following is a list of concept and terms related to ecological systems. State whether you recognize the concept, and if you have been taught about it at school (Yes / No), and provide a short explanation and an example for each concept.

Concept	I Know about the Concept	Learnt at School	Explanation and Example
Biotic and a-biotic factors			
Renewable and non-renewable resources			
Biodiversity			
Material cycles			
Food chain			
Food pyramid			
Food web			
Consumers			
Producers			
Decomposers			
Competition			
Predation			
Parasitism			
Mutuality			
Symbiosis relationship			
Ecological equilibrium			
Invasive species			
Adaptation			
Extinction			
Zonation			

## Appendix B: "Blind Model" and list of terms for the grounding activity



### Terms to be grounded and integrated in the "blind model":

Ships  
 Antifouling Paint  
 Organotins  
 Gastropod  
 TBT  
 Concentration  
 Sediment  
 Mediterranean Sea  
 Number of  
 Population growth rate  
 Female fertility  
 Amount transferred to seawater

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