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Abstract

This deliverable provides the framework for the development of courses and lessons integrating DynaLearn into teaching and learning processes in environmental sciences.

At the core of the document are three main components: (1) the rationale and conceptual framework underlying the development of lesson plans, (2) templates for the formalisation and presentation of the lesson plans and the detailed description of their sections and categories, and (3) a set of sample course and lesson plans developed following these guidelines.

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Contents

1. Introduction

The main purpose of this document is to set the generic formats for the development of courses and lessons focusing on the implementation of DynaLearn, and qualitative modelling, for teaching and learning environmental sciences.

The development of appropriate pedagogical plans and didactic solutions is essential for the successful integration of DynaLearn into a curriculum. To achieve this, the implementation plan for DynaLearn presented here comprises:

a. The definition of a common and shareable set of categories and criteria for the development of course and lesson plans integrating DynaLearn.

b. The definition of a common and shareable generic schema to guide teachers and lesson developers in planning DynaLearn-based courses and lessons.

c. The presentation of sample lesson plans devised using the above schema, categories and templates.

The following sections comprise a summary of background issues, the research questions addressed, detailed description of the course and lesson plans schemas, sample lesson plans developed according to the proposed guidelines, and a discussion on building a DynaLearn-based lesson-plans repository.

2. Background

Course and lesson plans are the natural platform for generating fruitful encounters between learners and knowledge within the context of formal teaching/learning processes. Foremost, course and lesson plans detail the target curricular knowledge and skills to be taught, and the procedures for teaching and assessment. However, the plans also represent, either implicitly or explicitly, the planners' conceptions and beliefs concerning the nature of teaching/learning and the role of the proposed pedagogical solutions (including the use of technology) for supporting students' learning. The following sections comprise a presentation of the components of the conceptual and pedagogical framework for defining learning objectives and developing DynaLearn lesson plans.

2.1. Learning with DynaLearn - overall approach

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; Vygotzky, 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. Each of these conceptual components is briefly presented below, and their implications for DynaLearn lesson plans development are considered.

Constructivist theories state that human knowledge is *constructed*: by reflecting on their experiences learners construct their understanding of the world they live in. Learning is a search for meaning, and learners participate actively in the construction of that meaning.

Two important principles stand at the basis of the constructivist approach. The first is that new understandings are constructed using what learners already know. Learners come to new learning situations with conceptions, knowledge, schemas and mental models formed from previous experience, and all these influence what new or modified knowledge they will construct. The second principle is that learning is an *active* rather than passive process. When facing a new learning situation, if what learners encounter (e.g., a piece of knowledge, a phenomenon, a required performance) is inconsistent with their current understanding, their understanding can change to accommodate new experiences. Active learners apply current understanding to new situations, identify gaps to be bridged, note relevant elements in new learning experiences, judge the consistency of prior and emerging knowledge, and modify and construct new knowledge. An important outcome related to learners' active role is their control over their own learning process. *Learner-control* has been characterised at different levels, in correspondence with the target of the decisions made and actions taken during a learning process. These include: learner control of contents, of pace and sequence, of activities (and the strategies involved). All of these concern external stimuli from the learning environment, and most importantly, control of internal or cognitive strategies for interacting with the stimuli.

Constructionism is conceived as both a theory of learning and a pedagogical approach. The Piagetian conception of the learner as active constructor of her/his own knowledge adds the need for an external construction of personal meaningful artefacts (e.g., a poem, a robot, a sand castle, a computer program or a model). The constructed artefact acts as a "public entity" becoming an object for reflection, inquiry, peer critical discussion, or a building block for further learning.

Another important approach complementing constructionism is the view of knowledge as being *socially constructed*. One aspect is the view that current human knowledge (e.g., scientific disciplines) is the integration of many humans' constructed knowledge over time. All fields of knowledge represents actual evidence of the gradual construction, development, enrichment and event shift milestones contributed by people over time. Another highly relevant aspect for the DynaLearn approach is the view of knowledge construction as a result of intellectual transactions among learners, and between learners and "more knowledgeable others" (e.g., peers, teachers, experts, computer environments). In Vigotzky's view (1978), a powerful resource for potential intellectual development is the space he calls the "Zone of Proximal Development" (ZPD): a region of activities that individuals can navigate with the help of more capable peers, adults, or artefacts. In Vygotsky' view, peer interaction, scaffolding, and modelling are important ways to facilitate individual cognitive growth and knowledge acquisition. The ZPD can be composed of different levels of expertise of individuals (students and teachers), and can also include artefacts such as books, computer tools, and scientific equipment. *Scaffolding* is the powerful teaching/tutoring mechanism by which differential support is offered to the learner along the learning process. In general the high levels of support given at the beginning of the process are gradually "faded" as the learner consolidates her/his knowledge and gains confidence about her/his understandings and mastery of knowledge and skills.

Another key component of the framework concerning learning is the *situationist* perspective. This perspective stresses the idea that meaningful learning takes place with reference to a context (e.g., physical, social, cultural, epistemological). Learners should work on authentic tasks that take place in real-world settings, serving as the platform for the construction of formal (and in latter stages generalised) knowledge. Working in authentic tasks promotes the activation of real-world knowledge-construction processes (as opposed to abstract and de-contextualised traditional school-based processes) as performed by scientists and experts. In this case the emphasis is on doing, sharing, apprenticeship, participation in "communities of practice" (with peers and colleagues) and collaboration, leading to the further articulation of generalised knowledge grounded in learners' situated understandings.

Upon this background, DynaLearn is conceived as powerful learning environment, supporting learners' own construction of knowledge and mastery of scientific reasoning skills by qualitative modelling of systems. The learning environment supplies a comprehensive toolbox allowing the interaction with models and their construction. As a working environment, it supports the gradual progression from initial levels focusing on descriptive aspects of a system's structure, to more complex levels dealing with within-systems relationships and processes, up to levels requiring high-order reasoning and thinking skills (e.g., planning inquiry process for exploring a system, formulating hypotheses about a system's predicted behaviours). As a *constructionist* based environment DynaLearn presents a highly rich learning playground for the construction and exploration of complex systems. As well, the models (and model parts) built by experts and learners serve as "public entities" fostering collaboration and interaction at many different levels, e.g., re-use of other people's model parts, collaboration in the model building process and discussion of alternative interpretations of a model's behaviour.

Scaffolding is offered by several of the DynaLearn features, such as the general help features, the interactive feedback and personalised recommendations based on the **ontology-based** technology, or by the interaction with **Virtual Agents** fulfilling a wide range of functions. A challenging question to be addressed by lesson plans developers is to define appropriate integration between human and computer-environment tutoring/scaffolding support. The immediate implication of this is the need to define the role of the human tutor in leading the constructivist learning process.

The *situationist* approach is highly relevant to DynaLearn's rationale. The challenging real-world environmental issues studied in Environmental sciences, and the systemic approach with which they are addressed, provide fertile ground for the development of learning opportunities in which scientific knowledge, scientific inquiry and real-world situations are intertwined. Attention to these issues has reached a high level both in the scientific community and in the general public awareness. DynaLearn offers appropriate tools for learning in an active and participative way about these challenges, the scientific knowledge involved and the consequences of alternative solutions.

2.2. Learning-by-modelling with DynaLearn

A second set of approaches in the conceptual framework relate to learning-by-modelling (and close pedagogical associates such as problem- and project-based learning and case-based learning, see Kolodner, Camp, Crismond, Fasse, Gray, Hollbrook, et al., 2003; Hmelo-Silver, 2004).

The DynaLearn approach and paradigm are grounded in the learning-by-modelling 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. 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 (Bredeweg and Forbus, 2003; Levy and Wilensky, 2009; Raghavan and Glaser, 1995).

Research indicates that involvement with models of scientific phenomena and complex systems can play a powerful role in science education (Gobert and Buckley, 2000; Gilbert and Boulter, 2000; Louca and Constantinou, 2003; Resnick and Wilensky, 1997; Yehezkel, *et al.*, 2005). Learning with/by-building models (Lw/bM) might provide students with the power to understand and explore systems that were previously difficult to trace and predict. Moreover, Lw/bM might facilitate the development of powerful intellectual tools for meaningful learning, such as the abilities involved in generating questions, theories and hypotheses about given phenomena, or in running simulations and/or creating models to explore these theories and hypotheses (Stieff and Wilensky, 2003; Wilensky and Resnick, 1999).

Previous research focusing on learning materials from the print technology (e.g., textbooks), has already examined the claim that diagrams and models facilitate learners' understanding of complexity, e.g., by simply "adding" a diagram or a model to the textual materials. However, the studies showed that simply adding diagrams and models did not facilitate learning because it increased cognitive load on learners (see Gobert, 2003). Also, students lacked the necessary domain knowledge to guide their search processes through diagrams/models in order to understand the relevant spatial, causal, dynamic, and temporal information represented (Gobert and Clement, 1999; Gobert, 2003).

Existing research on students' ability to cope with complexity also indicates that students experience difficulties in learning concepts relevant to understanding complex systems as currently taught in existing science courses. Student thinking may be counter-intuitive or might conflict with scientific models (Chi, 2005; Jacobson, 2001; Jacobson and Wilensky, 2006; Wilensky and Resnick, 1999). Hmelo-Silver and Pfeffer (2004) argue that the characteristics of complex systems make them difficult to understand, since they comprise multiple levels of organisation and cause/effect relationships that cannot be easily identified, leading to an increase in cognitive load on students (see Gobert, 2003).

It seems evident that a different approach, based on the development and implementation of powerful interactive modelling tools, is required for teaching the structure and dynamics of complex systems. DynaLearn's rationale is based on such an approach, adopting Qualitative Reasoning (QR) and qualitative modelling as key theoretical and technological foundations for the development of the learning environment. Indeed, recent publications report on the contribution of the qualitative modelling approach to learning (e.g., Dresner, 2008). In a recently published study, results indicate that students were able to understand model representations of system structure, causality, and dynamics; apply this understanding to real-world situations; evaluate model content compared to real-life experiences or outside knowledge; and were able to abstract model content to general principles in a domain (Nuttle and Bouwer, 2009).

As for the project-, problem-, and case-based pedagogical approaches, these are of interest for their potential to serve as powerful pedagogical envelopes for DynaLearn lesson plans. Although these approaches are described in the literature as differentiated models, this framework will focus on a set of features that is common to all of them. The trigger for the learning process could be a question to be answered, a solution to be designed or a case to be explored. The learning process might comprise inquiring, gathering information, making informed decisions, recognising structural and dynamic aspects of a system, building models, formulating and testing hypotheses and/or predicting behaviours. These features allow the development of motivating learning opportunities, e.g., reconstructing a "case" described in a scientific paper and exploring questions not included in the paper, or designing an alternative "ecologically-sound" solution for an affected area ("project").

Following the learning-by-modelling pedagogical approach, DynaLearn is an interactive learning environment in which students have the possibility to explore, manipulate and construct models of systems. This provides a unique opportunity to understand the dynamics of the modelled system, the causal relationships among its components, the underlying processes and the possible scenarios that result from these relationships and processes. By examining the different conditions in which these systems work, it allows learners to raise questions, formulate hypotheses and test the effect of the different conditions on the behaviour of the system. In this way, the pedagogical approach fosters analytical skills, qualitative reasoning and scientific reasoning skills.

DynaLearn relies on elaborated artefacts (qualitative conceptual models) to represent knowledge about physical and conceptual systems. The DynaLearn software consists of a conceptual modelling workbench, pedagogical agents and semantic technology. Within the modelling workbench, teachers and students may create qualitative models at six levels of complexity. These models may be included in an open repository that can be used to drive the communicative interaction of the software among different learners.

Learners will be able to browse and download existing models in the repository and use these for inspiration or to borrow parts (model fragments, scenarios) to build their own models. Teachers who want to develop their own material for environmental science courses may use the models either to explore specific topics or to build a complete model-based curriculum. Virtual characters in DynaLearn can use these as expert models to support comparison with learners' models and, using the semantic technology, provide feedback for the learners whilst they formalise their own knowledge by constructing their own models. In doing that, DynaLearn may support students working alone or in groups, in the classroom under the teachers' supervision or on their own.

The advantage of using conceptual models that are stored in the models repository is that the learning outcomes become valuable knowledge assets that can be further improved by the learners to enhance their competence, skills and performance. In order to achieve these goals, DynaLearn adopts the following premises:

- Curricula should focus on student competences, such as acquiring vocabulary, understanding scientific concepts, applying knowledge in problem solving, developing decision-making and argumentation capabilities, and improving the capacity of formulating proposals aiming at sustainability and human development.
- Curricula should be open such that environmental science themes are organized as a web of topics that can be navigated via different routes, according to the learners' needs and interests.
- Learning tasks should follow a project-based methodology, for the students to develop their skills on (autonomously) seeking learning resources and organising their studies.
- Provide grounding to construct meaning through contextualised facts and accompanying didactic materials.
- Develop model-based lessons and courses, including activities of exploring ready to use models, and building models from scratch or by combining parts of existing models.

2.3. DynaLearn lesson plans components - conceptual account

This section completes the description of the conceptual framework for the definition of learning objectives and lesson plans, focusing on specific aspects of the planning process. These aspects relate to the general and specific objectives for courses and lessons, the organisation of teaching, learning modes, modelling levels, assignments and assessment activities.

2.3.1. General and specific objectives

Two main sources serve for the definition of course and lesson plans objectives: The curriculum and the target set of scientific-reasoning and modelling skills.

The area of knowledge addressed by the DynaLearn project is Environmental Sciences. The curricular foci were presented in the Description of Work (DoW, 2008) and the elaborated curriculum is detailed in deliverable D6.1 (2009). It comprises seven main themes, for which sets of topics were defined. The following table (Table 1) presents the seven main themes, sample topics for each theme and sample learning objectives (for a detailed account of the curriculum see D6.1, 2009).

Table 1. DynaLearn curriculum - themes, topics and sample objectives

Themes	Sample topics	Sample Objectives
Earth systems and resources	Climate factors	To identify relevant climate factors for understanding the dynamics of a specific ecosystem
	Natural processes forming riverine landscapes and habitats	To compare different types of rivers and verify how natural processes have affected their formation
	Mining	To discuss mitigation measures for the damage caused by mining, in a specific case-study
The living world	Evolution	To represent in qualitative models case studies that show how evolutionary concepts justify topics in Environmental science
	Biodiversity	To model basic principles required for representing biodiversity in the context of the impact of human actions, including conservation activities
	Meta-populations	To demonstrate how basic concepts related to meta-populations can be used to design conservation practices
Human population	Education	To establish causal relations among relevant elements from society, culture, economy and environment related to the education
	Urbanisation	To model typical urban environmental problems and possible solutions for them
	Reduce, reuse, recycle	To compare situations in which each of the 3 Rs may contribute to achieve more sustainable conditions
Land and water use	Flood protection	To identify the main elements necessary to reduce the damage caused by flood in catchment areas
	Deforestation	To identify causal relations between society, culture, economy and environment aspects related to forest exploitation
	Irrigation	To compare different approaches to irrigation with respect to productivity and environmental impacts
Energy resources and consumption	Photosynthesis	To identify the most relevant factors involved in autotrophic energy metabolism and establish causal relations among photosynthesis and the nutrient cycling and energy flow
	Secondary production	To identify the most relevant factors involved in storage of biomass at higher levels of the trophic structure and establish causal relations involving environmental factors with secondary productivity
	Hydropower generation	To compare fossil fuels to non-conventional sustainable sources of energy with respect to socioeconomic output and environmental impacts

Pollution	Diffusion and osmosis Organic water pollution Soil pollution	To establish causal relations among the forces that drive the movement of molecules either or not through membranes To identify elements associated production and decay of organic pollution and establish causal relations that may be used for management actions To compare possible solutions to soil pollution in order to define sustainable solutions in specific case studies
Global changes	Atmospheric oxygen and ozone Climate change Ballast water discharge	To formulate and test hypotheses about how human actions may improve or make worse the production and consumption of oxygen and ozone in the atmosphere To represent causal relations among human-made systems, climate factors, atmospheric temperature and the consequences of temperature variation for environmental issues To represent hypotheses about how to contain the spread of exotic species and reduce the damage caused by these species in specific case studies

The examples of topics in the seven curricular themes (Table 1) illustrate the way DynaLearn's curriculum guides the definition of objectives at different levels of generality for complete courses and for each particular lesson plan.

The second criteria for the formulation of learning objectives are the **scientific reasoning and modelling** skills to be developed by using DynaLearn. In the science education arena there is a long tradition of curricular and research efforts focusing on the development and learning of scientific reasoning (e.g., see Lawson, 2004; Schun & Anderson, 1999; Zimmermann, 2000). In the literature, it is consensual to refer to scientific reasoning as a complex capability, involving a diverse collection of cognitive activities rather than a single cognitive process.

Generally, the set of processes and skills that a learner should be expected to develop includes the ability to (a) define a scientific problem; (b) state a hypothesis; (c) design an experiment; (d) observe, collect, analyse and interpret data; (e) apply the results; and (f) make predictions on the basis of the results. A committee at George Mason University has published recently (2008) a scientific reasoning assessment framework in which they have identified key components/learning goals of scientific reasoning (although indicating that each discipline might emphasise these goals to varying degrees):

a. Students will demonstrate that they understand the ways of scientific knowing, including inductive and deductive, empirical and theoretical.

b. Students will demonstrate the ability to develop and test a hypothesis.

c. Students will demonstrate the ability to read and interpret data.

d. Students will demonstrate the ability to interpret both primary and secondary sources.

e. Students will demonstrate their knowledge of both quantitative and qualitative methods.

f. Students will demonstrate an awareness of both the power of the scientific process and its limitations.

g. Students will demonstrate an awareness of communication as an integral part of the scientific way of knowing, both between and among scientists, and between scientists and the rest of society.

h. Students will demonstrate the ability to understand and value the role of science in both personal and public/societal decision-making.

Kuhn et al. (2006) identify three additional key components of mature scientific reasoning that should be considered important targets for learning: (1) the ability to reason about multiple causal effects on an outcome, rather than the effects of just a single variable, (2) the development of a constructivist understanding of the nature of scientific knowledge, and (3) the ability to engage in skilled scientific argumentation.

In addition, some authors reflect on what they consider another paradigm shift in scientific thinking as embodied in complexity science (Phelan, 2001), stressing the demand for new conceptual tools and skills for understanding complex systems. It is fairly obvious that the development of these novel tools is closely related to knowledge technologies that allow scientists to explore and redefine explanations about world phenomena as complex entities. Jackson (1996) claims that science is undergoing the above metamorphosis as a result of the possibilities generated by the digital computer, which adds to the use of physical experiments and mathematical models (characteristic of the first metamorphosis which began about four centuries ago), the use of computer experiments as a powerful resource for scientific inquiry. Whilst new theoretical approaches, methodologies and tools have been generated, adapting these methods and tools from the scientific to the educational milieu is a challenging endeavour (Mioduser et. al, 2009).

For the DynaLearn framework a specific set of competences and skills were defined. This comprises:

(S1) Understanding natural and technological phenomena, intellectual production related to cultural, artistic, political and social activities, as well as relevant philosophical, historical, and moral issues.

(S2) Mastering natural languages (national and foreign languages) and specialised languages (mathematical, scientific, artistic languages), understanding the multiple uses of languages, and mastering the capability to translate among languages (both formal and representational).

(S3) Identifying central and peripheral information, presented in different contexts (texts, literature, models).

(S4) Integrating knowledge from different areas (for example, natural sciences and humanities) by developing interdisciplinary projects.

(S5) Making inferences (inductive, deductive and analogical).

(S6) Applying adequate methods for problem analysis, formulation of suitable solutions, critically evaluate alternative solutions, selecting and implementing an optimal solution.

(S7) Interpreting and/or constructing models of phenomena (natural, artificial), formulating hypotheses and predicting results.

(S8) Formulating and articulating adequate and consistent argumentation.

(S9) Elaborating well structured reports (essays, presentations).

(S10) Elaborating proposals of intervention on reality, based on ethical principles and citizenship; these proposals take into consideration socio cultural diversity as inherent to the human condition in space and time.

The DynaLearn interactive learning environment offers powerful tools for supporting the development of this complex configuration of skills, methods, processes and traditional and novel approaches towards understanding phenomena. Examples of these supporting features are:

a. the model-construction environment which demands the activation of a wide range of skills (e.g., analytic as well as synthetic; inductive as well as deductive; interpretive as well as predictive) and methods (e.g., representing all relevant structural and dynamic components of a system; designing an experiment);

b. the supply of knowledgeable feedback and contextualised information allows critical, reflective and argumentative processes to take place; and

c. features such as the sharing and re-use of models and model-parts, or integrating Virtual Characters' functions into group (or class) assignments, foster the development of skills essential to collaborative knowledge-construction processes.

The appropriate integration of the various skills and processes in the formulation of lesson plan objectives is critical to the planning process and the consequent development of learning assignments.

In summary - the integration between DynaLearn's curriculum and the compound of scientific skills and processes provide a rich ground for the definition of course and lesson plans addressing the appropriate educational objectives.

2.3.2. Course organization

C**ourse organisation** relates to decisions made by the planner at the course level, before the specific planning of lessons. In the DynaLearn scheme, it refers to the configuration and sequencing of the teaching process during the planned course, focusing on the kind of model-use and/or model-building activities to be implemented. Possible configurations of the teaching process within a course are:

a. **Independent-models**: Each lesson is focused on one specific model dealing with a given topic. The course is built as a sequence of lessons using or requesting to build a different model in each lesson.

b. **Evolving-model**. This pedagogical mode is a long-term and multiple-stage activity, accompanying the instructional process of a course over several weeks. At each stage of the course's progression, and according to the pedagogical plan, a new component of a model is added. Thus, as the course's topics are presented, the modelling activity and the resulting model become more comprehensive and complex in structure and behaviour. Another option for the evolving modality is to move through the different modelling use-levels (e.g. starting with the concept map level and gradually moving to more complex levels).

c. **Collaborative-modelling**. This mode implies devising learning assignments that compromise the interaction of several students (from small groups to the whole class) while activating, exploring, and/or constructing models. Work can be conducted in either a collaborative or a cooperative fashion. The division of labour/foci can be made along several lines, e.g. by sub-populations in a system, by levels of aggregation (e.g., individuals, sub-populations, system), etc. The models grow along with the students' ability to contribute to them - implying increasing understanding, knowledge acquisition and skills acquisition, etc. as well as understanding the role/contribution of particular components to the systems behaviour and development (e.g. growth, competence, equilibrium, etc.).

d. **Combination of teaching modalities**. This refers to a pedagogical/organisational decision combining different modalities in a course. For example in the course plan on the topic of marine biology included in Appendix I, the course comprise a **lecture** modality (14 lectures in an academic semester) for teaching and elaborating on theoretical and research issues, and a workshop modality implementing the **evolving-model** mode (14 hours during the last seven weeks of the course), in which the theoretical concepts and topics became embedded in the actual modelling and hands-on activities.

These are but a few examples and by no means exhaustive of the different considerations that may guide decisions about the organisation and sequencing of the teaching along a course. It is expected that other pedagogical configurations will be defined by teachers and developers, according to the course's objectives and needs, the target population's characteristics, or other pedagogical considerations.

2.3.3. Qualitative Modelling levels

The actual modelling activity consists of constructing qualitative models that capture the concepts explaining physical or conceptual systems. Starting materials for such an activity may consist of other media such as spoken or written natural language, mathematical equations, and diagrammatic representations. Such materials capture descriptions of the behaviour of such systems and possibly the mechanisms/processes involved (and possibly even direct observation of the system behaving). To build a model, the learner should be able to design a modelling plan and then to implement it (Bredeweg et al. 2008). First, the learner identifies an interesting problem (or receives some indication) to address. Often, this first approach consists of a textual description of the system and its behaviour, from which the learner abstracts the most relevant aspects in order to re-write the knowledge available using a specific modelling language. One of the most important steps of any modelling effort is to adopt a system thinking approach: recognise the objects that compose the system of interest, understand the relations among these objects and identify the elements involved in the dynamics of the system. Table 2 presents how some elements of real systems may relate to ingredients in a qualitative reasoning model.

Table 2: Correspondence between a system's features and ingredients of its model

SYSTEM SUBJECT OF LEARNING	QUALITATIVE AND CONCEPTUAL MODEL OF SYSTEM
As any system, environmental systems consist of objects connected to other objects so that the system has a boundary	Entities and configurations
Reasoning about the system requires following changes in certain (relevant) properties of the objects	Quantities
Changes in relevant properties lead to significant different states of the objects. Combining the simultaneous states of all the system objects it is possible to recognise qualitative states of the system	Qualitative values of the quantities represent the qualitative states of each entity; combining the qualitative values of the quantities results in the qualitative states of the system captured by the model
Changes in a system's object are characterised by two types of variation: change in the 'amount' of the object's property and in its direction of change	Each quantity value consist of a pair of descriptors <magnitude, derivative>, that captures changes in the "amount of a quantity" and the direction of change, respectively
Making sense of the functioning of the system requires identifying cause-effect relationships that relate changes in its object's properties	DynaLearn qualitative models provide explicit representation of causality by using two primitives: direct influences (I+ and I-) and qualitative proportionalities (P+ and P-)
Initial changes in the object properties are due to processes; changes caused by processes may propagate and affect other properties, of the same or of different objects	Direct influences are used to capture the notion of process, and represent the initial cause of change; these may propagate to other quantities via proportionalities
Quantification of changes require measuring the amount of change in specific properties within a determined time period, so that the total change can be obtained after some elapsed time	Some quantities of interest are considered state variables. They inform about the state of the (whole) system. The amount of change in state variable during a certain time is represented by a special kind of quantity, the rate of change. Direct influences always connect the two quantities, rate of change → state variable, providing a representation for the processes.
Certain situations the system (and its parts) can be found in are typical and can	Model fragments are reusable ingredients that can be used to capture specific

be used to describe the system. Some of these situations may reappear under certain conditions of the system	situations of the system, and to combine modelling primitives to represent processes and other causal dependencies.
Some other situations describe conditions for the system to enter in continuous changes	Scenarios are representations of the system under certain initial conditions that may start simulations.
Real systems can be found in specific situations that last for some time, during which a specific combination of states of each object's property hold. Such states constitute the behaviour of the system.	Qualitative simulations show states and possible state transitions. Each sequence of states constitutes a trajectory of the system (a behaviour path); all the behaviour paths form an envisionment and represent the all possible states the system can be found and, therefore, the system behaviour.
Changes in the system are perceived without using numbers or mathematical functions and the predictions and explanations can be done by the non-expert persons	Qualitative models and simulations support predictions about the future of the system given a representation of the system's structure (using only symbolic representations of quantities, and modelling primitives that capture causal relations). Based on the causal relations, it is also possible to generate explanations about why certain results were obtained.

The system ingredients presented in table 2 are general enough to become applicable to any kind of physical or conceptual system.

Following this framework for the development of lesson plans, one critical aspect for the development of learning assignments is the choice of modelling level to be used. A brief overview of the different modelling levels facilitated by the modelling environment is given below (for detailed a description of the use-levels in Dynalearn (and all technical specifications of the software) see Deliverable D2.1, and D6.1(2009). In each use-level learners deal with models at increasing level of complexity, working with an increasing number of modelling primitives and features, up to the re-use and re-configuration of model parts for building new models. With DynaLearn the students interact (e.g., build, explore, explain, interpret, hypothesise, etc.) with qualitative models at six levels:

a. **Concept map**: The initial and simplest level of model building. This level allows the expression of the initial perception of a system under study, and its representation by indicating its key components (as nodes), and the linkage or relationships among these (as links and arrows). Further analytical and reflective work, and recruitment of additional knowledge, might lead to the progressive refinement and enrichment of the initial representation.

b. **Basic causal model**: The 2nd level of modelling using DynaLearn primitives and methods. Entities and quantities are defined, relationships are designated by arrows, and causal influences indicated by + and – signs. Students deal mainly with causal relationships. In this level, the simulations typically show information such as "if quantity 'a' is increasing then quantity 'b' is increasing", and other similar relationships.

c. **Basic causal model with state-graph**: In addition to the previous level, one or more quantities have values for the qualitative magnitudes (e.g. concepts such as small, below the normal, greater than the threshold, etc.). The notion of quantity space, an ordered set of magnitudes with all the possible qualitative values a quantity may assume, is introduced. With the quantities having different magnitude values, simulations at this use level produce behaviours with sequential states and state transitions where quantities change magnitude. Only arrows with the signs + and – indicate the type of influence. The simulation typically shows information such as that "if quantity 'a' is increasing, then quantity 'b' is increasing and the value of 'c' is changing from small to medium, from medium to large" and so on. This level provides richer semantics for the representation and the interpretation of the system's behaviour. Also, the notions of state, state-space and state transitions appear.

d. **Causal differentiation**: In this use-level even more tools and definitions are added to the model-building environment, particularly to express the notion of a process. Among them are the direct influences (I+ and I–) and the qualitative proportionalities (P+ and P–) modelling primitives that express causal relationships. Educational activities in this level typically explore the notion of process as the mechanism that causes the system to change.

e. **Conditional knowledge**: In this use-level, models can be read as "IF – THEN" statements, and it is possible to represent the conditions and consequences in dynamic systems. Conditions for processes to start and to stop, and for changes to propagate throughout the system, via causal chains, are at the centre of the learning issues explored at this use-level. Though some statements may be always true, without any condition to be satisfied, it may happen that during the simulation, some statements that were true will no longer apply, whereas others may become applicable and specific processes or proportionalities will become active. The idea of representing conditions and consequences is very rich, and provides reality to the model. From the educational point of view, this is an important step towards understanding the functioning of complex systems.

f. **Generic and reusable knowledge**: At this level models are built out of model parts from a library of model fragments and scenarios. Combinations of reusable knowledge contained in the model fragments are used to create each state of behaviour during the simulation. In this way, different, and even opposite views on the same topic may coexist in the library of model fragments, and the knowledge captured can be reused to create more complex representations of a system. This use-level differs in many aspects compared to the previous use-levels. The use of generic and reusable knowledge facilitates work aiming at higher-level educational goals, such as formulating and representing hypotheses to explain how a system works, providing representations for comparison of alternative hypotheses, or predicting a system's behaviour in varied conditions.

While developing a lesson plan, decisions as to the modelling level are made vis-à-vis the objectives defined by both the contents to be taught as well as the scientific reasoning (competencies and skills) required. An example of how the qualitative modelling process can be used to address high level educational goals related to the target competences and skills appears in Appendix I, focusing on the construction of a simple model about water pollution.

2.3.4. Learning modes

The next issue on which decisions have to be made in each lesson plan refers to the **learning mode** to be implemented in the lesson. This dimension relates to different modes of interaction of the students with the models (at all different **modelling levels** in DynaLearn). DynaLearn considers three main learning/interaction modes:

a. **Description/interpretation mode**. Models are used to illustrate/demonstrate a particular concept, process or phenomenon, as a trigger for further discussion and elaboration of a topic, or as first encounter with a topic to be developed further. Students get acquainted with models ("ready-mades"), activate them, formulate questions/hypotheses and generate explanations.

b. **Exploration/manipulation mode**. Models and modelling processes are used to deal with substantial scientific questions and/or concepts. Didactically, the learning activity is devised around a key question for which students have to design an investigation plan using DynaLearn. The plan comprises all relevant stages: formulation of hypotheses, design of the DynaLearn based experiments, etc. Students work with models in which parameters, variables, properties, etc. can be manipulated. Models are used for inquiry activities such as investigating scenarios, anticipating a system's behaviour, exploring extreme configurations, etc.

c. **Model-building mode**. The more comprehensive mode - students build models either using model-parts from a repository, or plan and develop a complete model, at any of the 6 use-levels.

As with the framework for course organisation, these modes can be implemented in various configurations, either as individual or collaborative work. It is also expected that, following the gradual incorporation of the DynaLearn approach into the teaching and learning process, many more learning modes may emerge as a result of the innovation of potential developers in the community of educators.

2.3.5. Assignments

Assignments are the building blocks of the lesson plans, the actual learning tasks or piece of work part of a course of study. The definition of the learning assignments is based upon the integration of several resources, e.g., the learning objectives (for conceptual understanding as well as reasoning skills acquisition), the modelling level addressed, the DynaLearn features considered (e.g., using the repository of model-parts or interacting with a specific Virtual Character), and the learning configuration adopted (individual, collaborative).

General guidelines for the development of learning assignments can be found in the vast existing literature on Instructional Design, e.g., Jonassen, 1997; van Merrienboer et al., 2003; or comprehensive review repositories in the Web (e.g., by Ryder, 2010).

As the repository of lesson plans grows in the future, a comprehensive classification scheme will be developed. However at this point, preliminary classification criteria can be defined based on lesson plans under development and existing experience. As shown in the following table, assignments can be characterised by:

Criterion	Examples: assignments focusing on
Learning objectives - contents	Any curricular theme, topic and/or concept addressed
Learning objectives - skills	Identifying a scientific problem; designing an experiment
Pedagogical function	Introducing a concept; expanding a topic; assessing learners knowledge
Performance expected	Theoretical; information gathering; hands-on/ construction
Integration of learning resources	DynaLearn-only tasks; Integration of external resources (print or Internet materials); integration with real-world experiments
Level of complexity	Focus on one [concept, skill, etc.]; constructing a simple model; testing hypotheses with a complex model
Degree of anchoring	Abstract; situated; implemented within a real-world task
Learning configuration	Individual; dyads; group work
Structure	Closed (e.g., perform the following steps…); open-ended
Sequencing	One-time & self-contained; evolving assignment

As noted, this preliminary list of classification criteria is expected to expand with the growth of the lesson plans repository. Additionally, the development of innovative formats of learning assignments built on DynaLearn's unique features is encouraged. Examples are: class learning situations in which each student/dyad's Teachable Agent is challenged by other students' or by the quizmaster's questions; or cooperative assignments, in which a "division of labour" approach is applied: a complex model is assembled out of fragments constructed by different groups, demanding insightful discussions on issues such as required flow of information among fragments, mutual effects, conflicts, inconsistencies, missing processes, etc. The design of these innovative formats is an exciting challenge at the assignment development level.

2.3.6. Assessment tasks

Assessment is the process of collecting, analysing, interpreting and using information on student achievement and performance. The assessment process reveals what a student understands, knows and can do. Assessment information provides the basis for decision-making regarding teaching and learning.

A first distinction will be made between summative and formative assessment.

Summative assessment is made at the conclusion of a unit of work to assess student skills, knowledge, and understandings at that particular point in time. This assessment focuses on learning products or outcomes of various sorts, e.g.

- *Knowledge outcomes*: material to be mastered as regards to the subject matter
- *Reasoning Outcomes*: ways to use knowledge to meet specific problem-solving challenges
- *Skill outcomes*: things that students should be able to do as a result of mastering the material presented
- *Affective outcomes*: feelings students might experience as a result of study

Formative assessment refers to all those activities undertaken by teachers, and by the students themselves, which provide information to be used as feedback to modify the teaching and learning activities in which they are engaged. Such assessments become formative when the evidence is actually used to adapt the teaching to meet the needs of students (see Black and William, 1998). When conceived as constructive **feed-back**, it highlights important aspects of the observed performance to focus on. As **feed-forward** it provides an outline of the steps to be taken (scaffolding) towards achievement. This assessment is focused on **processes** rather than products, and aims to collect data on students' performance, evolving understanding, knowledge and skills acquisition, products production process (e.g., models), during the learning. It is widely and empirically argued that formative assessment has the greatest impact on learning and achievement.

Another relevant distinction relates to the persons involved in the assessment activities. The most common modality is teacher assessment, in which the administration of the instruments and the analysis of the collected data are done mainly by the teacher. Alternative possibilities comprise **self**- and **peer-assessment** activities. In these, students engage in a systematic review of their progress and achievement (either concerning their own or another's work), the purpose of improvement. It may involve reflective activities, comparison activities with an exemplar, success or other criteria. It may also involve critiquing their work or generating a critical report of the achievement obtained.

Recent years theoretical and research work on assessment promotes moving from the epistemology of the intelligence to that of the mind, and from a culture of testing to that of assessment (Wolf, Bizby, Glenn & Gardner, 1991; Pellegrino et al., 1999). This trends support the implementation of assessment tools that reveal increased sophistication gained through building conceptual models, from static-spatial to causal and dynamic (Gobert, 2000).

Assessment also becomes integral part of the learning cycle. Swarz and White (2005) define a scientific model as a set of representations, rules and reasoning structures that allow one to generate predictions and explanations. The modelling activity is part of an inquiry cycle students are engaged with and thus can by itself serve as an assessment task (Kinchin et al., 2000). The process of modelling leads to an inquiry cycle of question generation, prediction, investigation and model revision, done both individually and collectively.

In correspondence with these approaches, the idea of **alternative assessment** is central to the DynaLearn planning framework. Alternative assessment is normally defined in contrast to traditional and standardised testing, using a wide range of definitions, e.g., performance-, authentic-, situated- (or contextualized) assessment. Alternative assessment is embedded in the instructional process, and supplies data collected stage by stage through it. Most importantly it uses a wide range of techniques that are well documented in educational literature, e.g., portfolios, diaries, performance tasks, student products analyses, concept mapping (Buhagiar, 2007). As authentic tasks, they are characterised by: their connection to the world beyond the classroom; the presentation of challenging (and sometimes ill structured) complex tasks; the demand for problem-solving and high-order thinking; for the production (rather than reproduction) of knowledge; and for performance (Harrington & Herrington, 2006).

The **alternative assessment** approach is favoured for assessing students' learning with DynaLearn. The goals stated for the learning with the modelling environment explicitly refer to contents of high levels of complexity and to reasoning skills of the highest order. Assessing the students' performance and achievements at these deep levels require the use of instruments and procedures other than traditional knowledge-testing tools - i.e., new instruments from the alternative assessment field. Examples of these are embedded in the sample lesson plans included in this document, and the repertoire of these is expected to increase significantly with the contributions of new educators joining the DynaLearn community.

2.3.7. Concluding remarks

Developing effective pedagogical strategies for learning complex science concepts is a substantial challenge for researchers and instructional designers. This challenge requires careful elaboration concerning pedagogical decision-making on many different issues. Among these issues are: the extent to which the modelling activities convey the essence of the contents and support learning; how they support the gradual mastery of modelling skills, methods and tools; how they support the gradual mastery of (scientific) reasoning skills via the modelling process; how the different features of the software environment is effectively integrated in the activity's plan; and many other questions.

In this section we presented the overall framework for the development of courses and lessons - from the general perception of learning with DynaLearn (2.1) and learning-by-modelling with DynaLearn (2.2), to specific elaboration on conceptual aspects of lesson plans components (2.3).

The following section presents guidelines for the concrete development of lesson plans using DynaLearn. The guidelines refer to actual features and parameters in several dimensions: DynaLearn’s modelling modes, pedagogical modes, learning modes, knowledge and skills, evaluation modes and resources required. All of these components are discussed and integrated into a template for guiding the development of lesson plans.

3. Schemata for the development of course and lesson plans

This section centres on the schemata for the development of course and lesson plans. For this a brief description is given of how the framework components presented in the previous section nurture the design of DynaLearn course and lesson plans.

The constructivist approach - DynaLearn is a powerful learning environment aiming to support the self-directed student in their active construction of knowledge. It supplies a rich construction environment for the interpretation, exploration and/or building of models of systems. These features promote the development of lesson plans including components such as: active model-building assignments, exploration tasks (e.g., of unexpected or counter-intuitive behaviours of a system), or prediction tasks (e.g., exploring solutions for undesired outcomes of human activities in an ecosystem by modifying model parts).

Situationist perspective – The DynaLearn rationale and curriculum are clearly focused on the environmental sciences and the systemic approach. Currently, environmental issues are part of the world's agenda at many different levels: scientific, social, political, economical, and moral levels. DynaLearn lesson plans represent the opportunity to integrate scientific content, modelling methodologies and real-world phenomena in support of meaningful learning processes.

Scaffolding - DynaLearn comprises varied features in support of scaffolding process, e.g., interactive feedback, personalised recommendations (ontology-based), supply of model-parts relevant to the topic or phenomena under study, or Virtual Agents fulfilling various roles. Lesson plans can be developed following the classic scaffolding model: providing support via interaction with the Virtual Agents in the first stages of the learning process, fading this support as the learners gain in mastery and confidence (e.g. concerning contents or modelling capabilities). Or assignments can be planned focusing on a specific scaffolding feature (e.g., grounding).

Learning by modelling - DynaLearn's working space, the conceptual modelling workbench (together with the pedagogical agents and the semantic technology), is custom built for learning by modelling. Lesson plans are typically built considering aspects such as the use-level, the resources in the repository, or the gradual mastery of the language and methods of qualitative modelling with DynaLearn.

Learning modes - DynaLearn allows then implementation of a range of model-based learning modes: from assignments based on the interpretation, description or explanation of an existing model up to complex model-building tasks. As well, learning assignments can be designed for individual, small group or class collaborative learning. Lesson plans will be developed upon this rich repertoire of learning modes, all anchored in DynaLearn's unique approach: qualitative modelling of systems.

Alternative assessment - contrasting with traditional and standardised tests, alternative assessment is embedded in the instruction making use of various data sources, e.g., the student products, documented processes for solving a task, or students' self-reports. Lesson plans should favour this type of assessment according to the main goals pursued by DynaLearn such as supporting knowledge construction, facilitating understanding of the behaviour of complex systems, or fostering the gradual mastery of qualitative modelling language and capabilities. For example: assessment tasks in the lesson plans can focus on the analysis of the students performance (e.g., models created in each use-level, or the set of hypotheses formulated while exploring a model); alternatively, assessment tasks can take the form of a report generated upon experiments conducted with DynaLearn models (e.g., a paper or a presentation).

Following these premises, a common and shareable practical template for describing the course plan and corresponding lesson plans has been developed.

The items (or slots) in the templates relate to the decisions made by the planners on several dimensions of the course or lesson concerning its content, pedagogical formats and implementation issues. It is expected that for each course the teacher or lesson developer will produce a set of completed templates comprising: one plan for the whole **course** containing appropriate general information, and a series of **lesson** plans, one for each lesson containing lesson-specific information.

In the next two sections a description and explanation on the different items in each template is provided.

3.1. Course plan template

The template for the course plan:

COURSE PLAN ID	
Topic:	
General Objectives:	
Target population:	
Procedure	
Duration:	
Implementation plan and schedule:	[procedure, stages, timetable…]
Course organisation:	
Assessment:	[formative, summative]
Resources	
DynaLearn resources:	[e.g., repository of model-parts, Virtual Agents in varied roles, …]
Learning materials:	[e.g., readings, worksheets, model requirement specifications, evaluation forms…]

The first section of the template relates to **general information** about the planned course: its topic, general objectives and target population.

The second section refers to the courses overall **procedure**, i.e., its duration (in terms of lessons or time slots required or recommended) and implementation procedure (e.g., stages, timetable, differentiation between class- and home-work).

The **course organisation** item relates to the configuration and sequencing of the teaching process along the course, focusing on the kind of model-use and/or model-building activities. As mentioned in the previous section, possible configurations of the teaching process along a course are:

a. **Independent-models**

b. **Evolving-model**

c. **Collaborative-modelling**

d. **Combination of teaching modalities**

The last section of the course plan template relates to the **resources and materials** necessary to run the course. The first item details DynaLearn resources, such as models, model parts, or help materials. The second item focuses on general instructional materials, such as scientific papers, worksheets, or evaluation forms.

In summary, the course plan template supplies an overall perspective of a planned course, and is normally required whenever a planned DynaLearn-based teaching cycle exceeds the scope of a few lessons, becoming a complete course. In this case the course template supplies the teacher or the potential adopters of a course plan, with an overall perspective of the unit's goals and procedures before getting into the details of the individual lessons.

3.2. Lesson plan template

The information included in the plan for each specific lesson pertains to three main sections: the lesson's objectives, contents skills and modelling level addressed; the procedure for the lesson implementation, and the resources required.

The template for each lesson plan:

LESSON PLAN ID	
Topic:	
Specific Objectives:	
Content knowledge and skills:	
Modelling knowledge skills:	
Prerequisite knowledge and skills:	
Learning mode/s:	
Use level/s:	
Procedure	
Duration:	
Implementation plan and schedule:	[procedure, stages, timetable…]
Assessment (if planned):	
Resources	
DynaLearn resources:	[e.g., repository of model-parts, Teachable Agent, …]
Learning materials:	[e.g., readings, worksheets, model requirement specifications, evaluation forms…]

3.2.1. Lesson ID

The first item in this section details the specific-lesson's **topic** (e.g., diffusion and osmosis, renewable energy, marine biology - invasive species, photosynthesis, the use of renewable resources etc.).

The second items defines the lesson's **specific objectives**, e.g., "Understand causes/effects of ozone depletion", "Identify predator-prey interactions in a marine system" or "Identify important processes influencing riverine landscapes being relevant for an integrative catchment management".

The next two items detail the **target knowledge and skills** for the lesson relating both to content as well as to modelling/scientific-reasoning abilities. Examples of these at the content level are: "Integrative river management", "Influence of an agent external to the system", or "The biological, chemical and physical processes moving nutrients between reservoirs". Examples of target modelling/scientific-reasoning skills are: "Specification of concept maps into level 2 model", "Address processes, conditions, consequences in dynamic systems", or "Testing hypotheses by running an appropriate simulation".

In the following item, the lesson developer is requested to indicate the **prerequisite knowledge and skills** (if any) that are necessary to cope with the target knowledge and skills.

The next item on which decisions have to be made refers to the **learning mode** to be implemented in the lesson. As presented in the framework section (2.3.4), this dimension relates to different modes of interaction of the students with the models (at all different use-levels in DynaLearn). Three main learning/interaction modes are foreseen:

a. **Description/interpretation mode**

b. **Exploration/manipulation mode**

c. **Model-building mode**

Completing the first category of items, the lesson planner is requested to indicate the DynaLearn **use-level** (or levels) on which the students' activity focuses (see 2.3.3).

3.2.2. Lesson procedure

The second section of items in the lesson plan template relates to aspects of the lesson implementation. Firstly, its **duration should be defined**; whether the topic is covered in a single lesson or in a sequence of lessons, including the planned period of time the students will be working on the topic.

In the next item the **implementation plan and schedule** are detailed - indicating the stages of the implementation, kinds of activities to be performed at each stage (e.g., reading a scientific paper, sketching the first conceptual model, gathering additional information for the development of a model, model-building progression of activities with DynaLearn).

Of particular importance is the typology of activities developed upon the unique features of DynaLearn. The most obvious category relates to assignments designed around DynaLearn as modelling environment, e.g., focus on a specific use-level, on the distinction between direct and indirect influences (I's and P's) within a model, or on the de-bugging process of a (deliberately supplied) faulty model. Less obvious types of activities relate to the other components of DynaLearn, e.g., assignments focusing on the interaction with the Teachable Agent, either as individual task or as part of a competitive group activity involving agents taught by several students.

Finally, learning **assessment** means and methods are to be detailed. This category is essential for the planning of the learning unit, as it refers to the means and instruments which will serve to asses students' learning at all the different levels targeted. As mentioned previously, the DynaLearn approach suggests formative as well as summative assessment, acknowledging that in some lessons either one or both could be relevant. The description in the template should include indication of the various aspects involved, such as the **target** of the assessment activities (e.g., conceptual understanding, scientific reasoning skills, modelling capabilities); the **type of assessment** planned (e.g., accompanying the learning process at all its stages or summative assessment at the end of a learning cycle), the **kinds of activities** included (e.g., diagrammatic representations, open-ended questions, transfer tasks); the **criteria** for assessing the learning gain.

3.2.3. Resources required

The third component of the lesson plan specifies the required resources, within and outside the DynaLearn environment, for the implementation of the lesson.

DynaLearn resources may include indication of necessary materials (digital or printed) such as manuals, tutorials, sample models, specific model parts, semantic technology or virtual character resources.

Other required materials include items such as readings, articles, textbook chapters, materials or data located in the Web or internet repositories, worksheets, or evaluation forms.

3.3. Research questions

DynaLearn aims to enhance learning by means of an engaging interactive learning environment allowing students to construct their conceptual system knowledge either individually or in a collaborative setting (DoW). DynaLearn seeks to attain this goal by means of the integration of three technological developments - the diagrammatic approach, virtual pedagogical agents and semantic technologies. As well, by reformulating the curriculum and fostering learning about systems via qualitative modelling.

Course and lesson plans fulfil two main roles: they are the instrument for the actual implementation of DynaLearn's rationale and tools in real world learning situations, and they are the context in which the contribution of DynaLearn to enhance learning can be examined.

For the first role, the main question to be addressed related to the ways DynaLearn might be integrated in teaching/learning processes of topics and concepts in environmental science. For this general question many specific questions can be formulated when taking in account different variables, e.g., the educational objectives addressed, the learning mode favoured, the age-level of the target population, the learning context (e.g., High School, University students, informal education settings), or the DynaLearn features used (e.g., focus on the interaction with a pedagogical agent). These and other instructional design questions will be at the centre of the gradual construction of an increasing repertoire of course and lesson plans during the project.

For the second role, DynaLearn's contribution to the enhancement of learning, a preliminary framework or inquiry space has been defined for the formulation of specific questions to be addressed while implementing the lesson plans in research case studies. According to the expressed in the DoW, DynaLearn's contribution to learning enhancement is considered at three main levels: students' conceptual understanding of systems and topics in environmental science (CU), acquisition of reasoning and modelling language and skills (R/M), and motivation (M). Specific features of the learning environment to be considered include the diagrammatic approach (DA), the virtual pedagogical agents (VA) and the individualisation of learning via the semantic technologies (ST). An additional important variable considered for study is the learning mode implemented (from interpretive to constructivist) in the lesson plan (LM).

The above set of variables is depicted in the following general inquiry space:

	1 DA	2 VA	3 ST	4 LM
a CU				
b R/M				
c M				

From this general framework focused questions will be defined and localised upon the specifics of particular lesson plans. For example:

- Question of type 1b (DA on R/M) will focus on assessing the contribution of modelling at level 2 on students' ability to describe causal relationships within systems
- Question of type 3a (ST on CU) will focus on assessing the contribution of the "grounding" feature on students' mastery of a given set of concepts
- Question of type 2c (VC on M/A) will focus on assessing the contribution of a "teachable agent" on students' willingness to persist on task for a considerable period of time

The main goal is to generate research data on the different cells of the matrix with the aim to complete a comprehensive answer to the main question of how DynaLearn acts as a tool for enhancing learning.

4. Sample Course and Lesson Plans

Some examples of course and lesson plans are presented in Appendix I. These examples are illustrative of the various kinds of course and lesson plans that can be developed following the templates and guidelines presented above. Some of these plans, supplied by the partners in WP6 and WP7, will be actually implemented during the evaluation cycles of DynaLearn. As well, they will serve as initial set in the repository of lesson plans, which is expected to evolve and grow as a result of the expansion of the community of educators adopting DynaLearn in their teaching while developing new plans and pedagogical solutions.

The examples are of various formats. They differ from each other obviously in terms of content, but also in terms of extent and scope (from few lessons to complete courses), level of modelling with DynaLearn, kind of integration with various pedagogical modalities (e.g., integration within a course, self-contained plan, workshop), or target knowledge and skills related to modelling and scientific reasoning.

In the near future, as the repertoire of lesson plans increases in quantity as well as in diversity, a classification scheme will be developed to assist users in their selection and adoption for instruction. As well, the classification scheme will assist developers looking for possible formats and pedagogical solutions for creating new plans. It is expected that initial categories for a classification scheme are derived from the planning template, e.g., categories relating to content; to target skills; target population; modelling level; learning mode; or assessment methods. Other categories will be developed relating to the rationale of teaching given topics in particular modelling levels and activities. Additional categories could refer to the role of specific DynaLearn features (e.g., a specific Virtual Character, informed feedback) in the learning situation.

The sample course and lesson plans included in Appendix I are:

Course **and** lesson plans:	Green House gases and climate change[#] Nutrient cycling[#] Marine biology Renewable energy and related concepts Aquatic ecology and river management Conservation Biology
Lesson plans:	Photosynthesis[#] Diffusion and osmosis[#]

these course and lesson plans were developed as examples of how modelling could be integrated into existing teaching approaches in UK A level/undergraduate institutions. Curricula, content and suggested scheduling are drawn from example course descriptions for A level Biology and Environmental Studies (AQA 2007a,b; 2008a,b).

It should be noted here that part of the sample plans in the Appendix are examples of course and lessons designed for use in the evaluation case studies included in the projects work plan, e.g., the Marine Biology course or the Conservation Biology course. Other plans were designed as exemplars of how modeling might be used in non-research learning situations, e.g., the photosynthesis or Diffusion and osmosis lessons.

5. Concluding remarks and future work

The design of course and lesson plans requires the integration of all the dimensions described in sections 3.2 and 3.3 focusing on the planning templates. The planning process proceeds by defining the corresponding “values” for each dimensions - by making content and pedagogical decisions about the different aspects included in the plan. It is expected that the templates will serve as guiding instruments for planning of learning activities. As well, they are expected to serve as a concise representation of the learning units thus facilitating the gradual construction of a shareable repository of pedagogical units using DynaLearn.

The planning of courses integrating qualitative modelling with DynaLearn is not a trivial task. The challenge resides in the need to integrate components from all relevant levels into a coherent pedagogical unit - an assignment, a lesson, or a complete course. These components include: the technological resources, i.e., the workbench, the pedagogical characters and the ontology-based features; the qualitative modelling language and approach; the pedagogical approach, i.e., a learner-centred constructivist approach; the curricular approach, i.e., a systemic perspective on environmental science topics and concepts. The amalgamation of aspects pertaining to these levels result in unique lesson formats with DynaLearn as platform and facilitator of the expected learning processes.

With the aim to support teachers and developers in the planning process, we formulated the rationale for the development of DynaLearn course and lesson plans presented in section 2, and following it the templates presented in section 3. Using these schemata, Work Package participants are already engaged in the development of assignments, lessons and courses. These serve not only as practical exploration of the possible formats and modalities for integrating DynaLearn in teaching and learning processes, but also as plans to be implemented in the coming evaluation phase.

The future work at the lesson-plans level comprises the gradual development of lesson plans for the different curricular issues defined for DynaLearn (see D6.1). This process is foreseen as a collaborative one involving all WP partners where additional plans are developed alongside the modelling and evaluation activities. As more educators become involved in using DynaLearn, it is expected that novel pedagogical implementations, for different content areas, learners’ age-level, academic context, and educational objectives will emerge.

As this process takes form, it is expected that there will be a need to review and enrich the presented framework for lesson planning, to include new aspects, ideas and approaches for the benefit of the community of educational users.

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Appendix I: Sample Course and Lesson plans

The sample course and lesson plans included in this section are:

Course **and** lesson plans:	Green House gases and climate change[#] Nutrient cycling[#] Marine biology Renewable energy and related concepts Aquatic ecology and river management Conservation Biology
Lesson plans:	Photosynthesis[#] Diffusion and osmosis[#]

[#] these course and lesson plans were developed as examples of how modelling could be integrated into existing teaching approaches in UK A level/undergraduate institutions. Curricula, content and suggested scheduling are drawn from example course descriptions for A level Biology and Environmental Studies (AQA 2007a,b; 2008a,b).

The texts and diagrams accompanying the following course and lesson plans are examples of items included in the "additional resources" category of the course and lesson templates

Course and Lesson plans: **Green House Gases and Climate change**

COURSE PLAN ID - GREEN HOUSE GASES AND CLIMATE CHANGE	
Topic:	**GREEN HOUSE GASES AND CLIMATE CHANGE**
General Objectives:	Present the green house effect as a natural phenomenon Identify the role of atmospheric gases in heat balance and global climate Present the major anthropogenic sources, changing concentrations and relative effects of the main green house gases Consider causes/effects of ozone depletion Explore the likely effects of global climate change – develop scientific reasoning skills Identification of positive and negative feedback mechanisms altering the rate of global climate change
Target population:	A Level / Pre – Certificate / early undergraduate
Procedure	
Duration:	4 weeks (4-5 hours per week)
Implementation plan and schedule:	<u>Week 1</u> *Atmospheric structure, solar radiation and heat balance* Introductory lecture 1hr Group seminar to identify main entities, quantities and processes 1hr Construction of heat balance model (level 3 model) to explain effects of green house gas concentration 2hrs <u>Week 2</u> *Ozone depletion* Introductory lecture 1hr Group seminar to identify main entities, quantities and processes 1hr Construction of ozone model (level 3 model) to explain influences and impacts 2hrs <u>Week 3</u> *Global climate change* Introductory lecture 1hr Group seminar to identify main entities, quantities and processes 1hr Development of previous heat balance and ozone models to explore predictions for global climate change 2hrs <u>Week 4</u> *Global climate change* Discussion session of positive and negative feedbacks to climate change 1hr Development of existing models (into level 4 model)

	to test hypotheses on feedbacks in global climate change 2hrs Discussion session on Gaia hypothesis 1hr
Teaching/Learning organisation:	Evolving model
Assessment:	Summative
Resources	
DynaLearn resources:	Expert level 2 model on Atmospheric heat balance and Ozone
Learning materials:	Diagrammatic representation of atmosphere and earth Lecture handouts Text books

LESSON PLAN	
Topic:	Atmospheric Structure, Heat Balance And Ozone
Specific Objectives:	Learn the structure and function of the atmosphere Learn the concept of heat balance Learn the concept of dynamic equilibrium of oxygen forms and ozone Provide the basis to develop concepts of global climate change
Content knowledge and skills:	Structure and functioning of the atmosphere Processes involved in global heat balance Green house gases, their origins and relative effects Dynamic equilibrium of the different forms of oxygen – relationship with UV light Skills: Scientific reasoning about the processes involved in climate change
Modelling knowledge and/or skills:	Construction of level 3 models to explore dynamic systems and test hypothesis
Prerequisite knowledge and skills:	Experience of model building and causal differentiation
Teaching/learning mode:	Evolving – Collaborative mode Model building and exploration
Modelling level/s:	Level 3
Procedure	
Duration:	2 weeks
Implementation plan and schedule:	<u>Week 1</u> *Atmospheric structure, solar radiation and heat balance* Introductory lecture 1hr Group seminar to identify main entities, quantities and processes 1hr Construction of heat balance model (level 3 model) to explain effects of green house gas concentration 2hrs <u>Week 2</u> *Ozone depletion*

	Introductory lecture 1hr Group seminar to identify main entities, quantities and processes 1hr Construction of ozone model (level 3 model) to explain influences and impacts 2hrs
Evaluation	
Summative Submission of models Written assignment of hypothesis testing using the models Final written exam (assuming this contributes to an overall module).	
Resources	
DynaLearn resources:	Expert level 2 model of heat balance Expert level 2 model of ozone equilibrium
Learning materials:	Diagrammatic representation of atmosphere and earth Lecture handouts Text books

Course and Lesson plans: **Nutrient Cycling**

COURSE PLAN ID - NUTRIENT CYCLING	
Topic:	**NUTRIENT CYCLING**
General Objectives:	Understand the importance of the common nutrients (carbon, phosphorous, nitrogen) Recognise common features in the nutrient cycles – movement of nutrients between reservoirs Explore the processes involved in moving nutrients between reservoirs for the carbon, nitrogen and phosphorous cycle Explore in detail photosynthesis, aerobic respiration and decomposition as processes in the carbon cycle.
Target population:	A Level / Pre – Certificate / early undergraduate
Procedure	
Duration:	4 weeks (4-5 hours per week)
Implementation plan and schedule:	Week 1 *Biogeochemical cycles* Introductory lecture and exploration of concept map of nutrient reservoirs (1hr) Detailed lecture on carbon cycle – include annotating general concept map to make it specific to carbon cycle (1hr) Specification of level 2 model of carbon cycle (2 hrs) Week 2 *Biogeochemical cycles* Lecture on Nitrogen and Phosphorous cycles (1 hr) Collaborative modelling of level 4 models on either nitrogen or phosphorous cycle (2 hrs) Presentation of models to class (1 hr). Week 3 *Photosynthesis* (see lesson details) Week 4 *Respiration & Decomposition* – the role in the carbon cycle and link with photosynthesis in cycles in water quality/oxygenation
Teaching/Learning organisation:	Combination (model focused, evolving model and collaborative modelling).
Assessment:	Summative
Resources	
DynaLearn resources:	Concept maps of nutrient cycles Basic level 2 model of generic nutrient cycle for adaption Expert model of carbon cycle Expert model of photosynthesis
Learning materials:	Lectures/handouts Visualisations of each nutrient cycle Text books

LESSON PLAN	
Topic:	**NUTRIENT CYCLING**
Specific Objectives:	Learn importance and features of common nutrients Learn common features of nutrient cycles Knowledge of biological/chemical/physical processes involved in each nutrient cycle Development of level 4 modelling skills Development of collaborative working skills Development of presentation/communication skills
Content knowledge and skills:	The concept that the cycling of elements, including plant nutrients, occurs between the gaseous, hydrological, sedimentary and biological reservoirs with varying residence times. The biological, chemical and physical processes moving nutrients between the reservoirs. The concept of dynamic equilibrium produced by active processes which produce an overall balance by cancelling out the changes they cause The impact of human activities on the nutrient cycles Skills: Ability to predict consequences of human influences on the nutrient cycles
Modelling knowledge and/or skills:	Specification of concept maps into level 2 model Development of level 4 model (potentially from editing a level 2 model)
Prerequisite knowledge and skills:	Experience of level 1 and level 2 models Knowledge of causal differentiation models (I's and P's).
Teaching/learning mode:	Collaborative modelling mode Mixed (including model building)
Modelling level/s:	Level 2 and 4
Procedure	
Duration:	2 weeks
Implementation plan and schedule: 3 x 1hr lectures 1 x 1hr interactive seminar 2 x 2hr model building sessions 1 x hr group presentations seminar	<u>Week 1</u> Introductory lecture and exploration of concept map of nutrient reservoirs (1hr) Detailed seminar on carbon cycle – include class annotating general concept map to make it specific to carbon cycle (1hr) Specification of level 2 model of carbon cycle (2 hrs) <u>Week 2</u> Lecture on Nitrogen and Phosphorous cycles (1 hr) Collaborative modelling of level 4 models on either

<table>
<tr><td></td><td>nitrogen or phosphorous cycle (2 hrs)
Presentation of models to class (1 hr).</td></tr>
<tr><td colspan="2">Evaluation</td></tr>
<tr><td colspan="2">Summative
Submission of level 2 carbon cycle mode
Presentation of level 4 nutrient cycle model
Final written exam (assuming this topic would be a unit within a larger module)</td></tr>
<tr><td colspan="2">Resources</td></tr>
<tr><td>DynaLearn resources:</td><td>Concept maps of nutrient cycles
Basic level 2 model of generic nutrient cycle for adaption
Expert level 2 model of carbon cycle
Expert level 4 models of carbon, nitrogen and phosphorous cycle (for ontological matching with student models?)</td></tr>
<tr><td>Learning materials:</td><td>Lectures/handouts
Visualisations of each nutrient cycle
Text books</td></tr>
</table>

Lesson plan: **Photosynthesis**

LESSON PLAN	
Topic:	**PHOTOSYNTHESIS**
Specific Objectives:	Students should understand the process of photosynthesis as a flow of energy though a chemical reaction. Students should also understand the concept of limiting factors.
Content knowledge and skills:	Photosynthesis: The light-independent and light-dependent reactions in a typical C3 plant. *Light-dependent reaction* The light-dependent reaction in such detail as to show that • light energy excites electrons in chlorophyll • energy from these excited electrons generates ATP and reduced NADP • the production of ATP involves electron transfer associated with the electron transfer chain in chloroplast membranes • photolysis of water produces protons, electrons and oxygen. *Light-independent reaction* The light-independent reaction in such detail as to show that • carbon dioxide is accepted by ribulose biphosphate (RuBP) to form two molecules of glycerate 3-phosphate (GP) • ATP and reduced NADP are required for the reduction of GP to triose phosphate • RuBP is regenerated in the Calvin cycle • Triose phosphate is converted to useful organic substances. *Limiting factors* The principle of limiting factors as applied to the effects of temperature, carbon dioxide concentration and light intensity on the rate of photosynthesis.

Modelling knowledge and/or skills:	Carry out experiments on the effect of limiting factors on the rate of photosynthesis using water plant such as Elodea. Identification of basic causal model Exploration of model to explain causal chain behind behaviour identified in laboratory experiment.
Prerequisite knowledge and skills:	The content knowledge listed above is the knowledge taught at A-level Biology. If the concept of limiting factors is taught here (e.g. the chemistry background is not specifically handled) then the knowledge listed above could be considered pre-requisite. Software operability QR representation skills
Teaching/Learning mode/s:	Investigation/Observation/Explanation mode
Modelling level/s:	Level 2 Basic causal model; Level 3,4 or 5 to explore causality of behaviour
Procedure	
Duration:	1 week (2- 1 hour lessons, 1- 3 hours practical)
2- 1 hour lessons and an associated practical class	*Lesson 1* Lecture on the chemical basis of photosynthesis and concept of limiting factors 45 mins. Class-based discussion of key entities, quantities and processes 15 mins. *Lesson 2* Introduction of practical experiment objectives and set up 15 mins. Class-based group work to develop basic causal models to predict the outcome of lab experiment on limiting factors in photosynthesis. 45 mins. *Practical* Experiments concerning limiting factors on photosynthetic rate. 2hours. Exploration of pre-built model in use level 5 (or 3 or 4 depending on details required) to replicate lab

	experiment and explain behaviour observed. 1hour.
Evaluation	
Laboratory write up, including practical results Use of basic causal model and simulations from "expert" model to discuss the causality using QR terms in the lab write up.	
Resources	
DynaLearn resources:	DynaLearn software Model of photosynthesis built to be able to consider limiting factors
Learning materials:	Lecture notes Diagrammatic hand-out of photosynthesis systems Practical class

Lesson plan: **Diffusion and Osmosis**

LESSON PLAN	
Topic:	**DIFFUSION & OSMOSIS**
Specific Objectives:	Learn concept of diffusion Recognise osmosis as a special type of diffusion Learn fluid mosaic model of cell membranes and use to explain movement of water/solutes across membranes
Content knowledge and skills:	Osmosis is a special case of diffusion Diffusion is a flow across a gradient Effects of surface area, gradient and thickness of exchange surface on rate of diffusion Fluid mosaic model, protein channels, carrier proteins and active transport Skills: Development of a practical experiment
Modelling knowledge skills:	Hypothesis generation using expert models
Prerequisite knowledge and skills:	Knowledge about concentrations, solutes and water as a solvent Recognition of a level 6 model and ability to generate scenarios
Teaching/Learning mode/s:	Investigation mode exploration/manipulation
Modelling level/s:	Level 4
Procedure	
Duration:	1 week
Implementation plan and schedule:	Introductory lecture on concepts (using level 4 model) - 1hr Brief introduction to practical experiment and level 4 model – students use model to design their experiments and generate hypotheses - 1hr Practical on diffusion/osmosis - 2-3 hrs
Evaluation	
Summative Submission of models – write up of practical results Final written exam (assuming this contributes to an overall module).	
Resources	
DynaLearn resources:	Expert level 4 model of diffusion & osmosis
Learning materials:	Diagrammatic representation of diffusion and osmosis Lecture handouts Text books

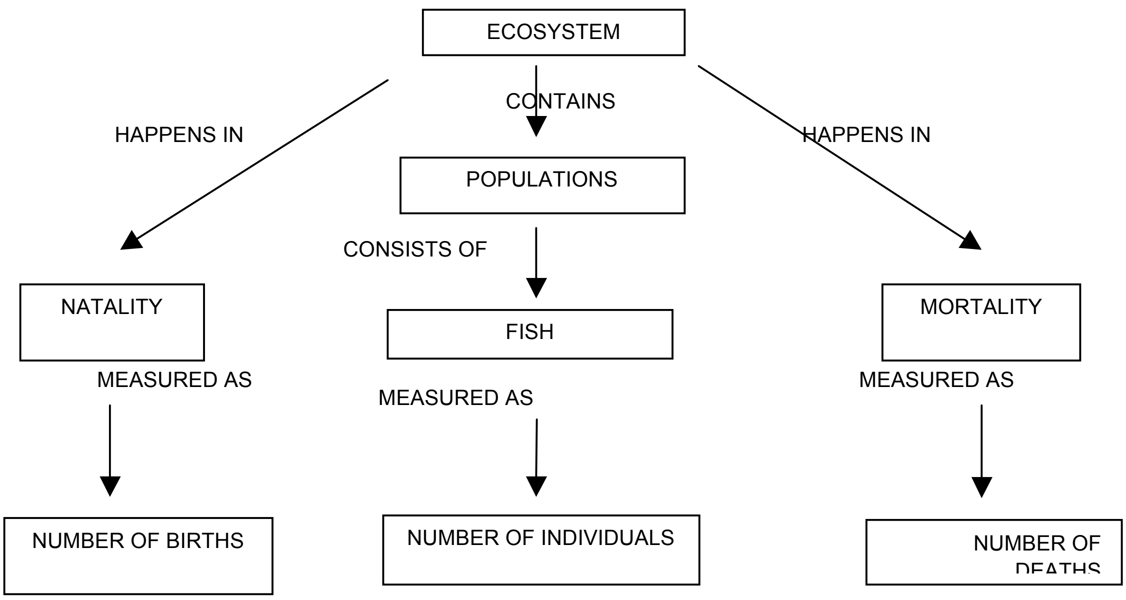
Course and Lesson plans: **Marine Biology**

COURSE PLAN ID - MARINE BIOLOGY - (MODELLING WORKSHOP)	
Topic:	**MARINE BIOLOGY**
General Objectives:	- Developing students' modelling skills in Marine Systems - Developing students' systemic view
Target population:	3rd year undergraduate students
Procedure	
Duration:	7 weeks
Implementation plan and schedule:	**Evolving-model mode:** as described in each lesson plan separately
Teaching/Learning organisation:	Life Sciences Faculty, Tel-Aviv University
Assessment:	Formative and summative
Resources	
DynaLearn resources:	User's manual, repository of model-parts, sample models
Learning materials:	Presentations, Scientific papers, exercises

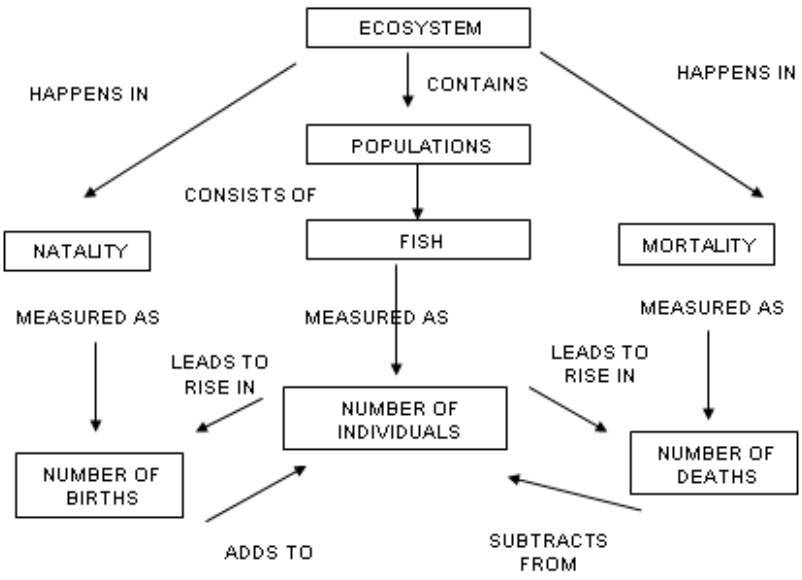
LESSON 1	
Topic:	Learning by modelling
Specific Objectives:	- Introduction to "Learning by Modelling" - Constructing a basic knowledge model of ecosystems using concept maps
Content knowledge and skills:	Fish population
Modelling knowledge skills:	Identifying a set of concepts and the labelled relationships among them in a Marine system
Prerequisite knowledge and skills:	All topics covered by the Marine Biology course: population, predator-prey interactions, symbiosis, invasive species, photosynthesis, eutrophication, pollution, over-fishing, ecological equilibrium.
Teaching/Learning mode/s:	Description/interpretation mode
Modelling level/s:	Building a concept map (level 1)
Procedure	
Duration:	90 minutes
The lesson will be composed of 3 parts: 1. Presentation on "Learning by Modelling" 2. Presentation and demonstration of	1. A presentation on the educational approach of "Learning by Modelling" and its unique contribution to understanding complex ecosystems – 30 minutes. 2. a. Creating a concept map of a fish population (CM1).

constructing a Predator-Prey interaction concept map. 3. Assigning a scientific paper to each pair of students.	b. Defining the relations between quantities (Birth adds to number of individuals, etc. (CM2). c. Expanding the concept map by adding snail population and the a predation process (CM3) - 40 minutes. 3. Students will be asked to group to pairs. Explanation of the final modelling project and assignment of scientific papers will be presented- 20 minutes. During the course, each pair of students will build a model based on a marine biology scientific paper assigned to them that discusses one of the subjects addressed by the course.
Evaluation	
Assessment task: The students will build a concept map of the processes and populations in their assigned scientific paper.	
Resources	
DynaLearn resources:	-
Learning materials:	Concept maps (CM1, CM2, CM3). Scientific papers

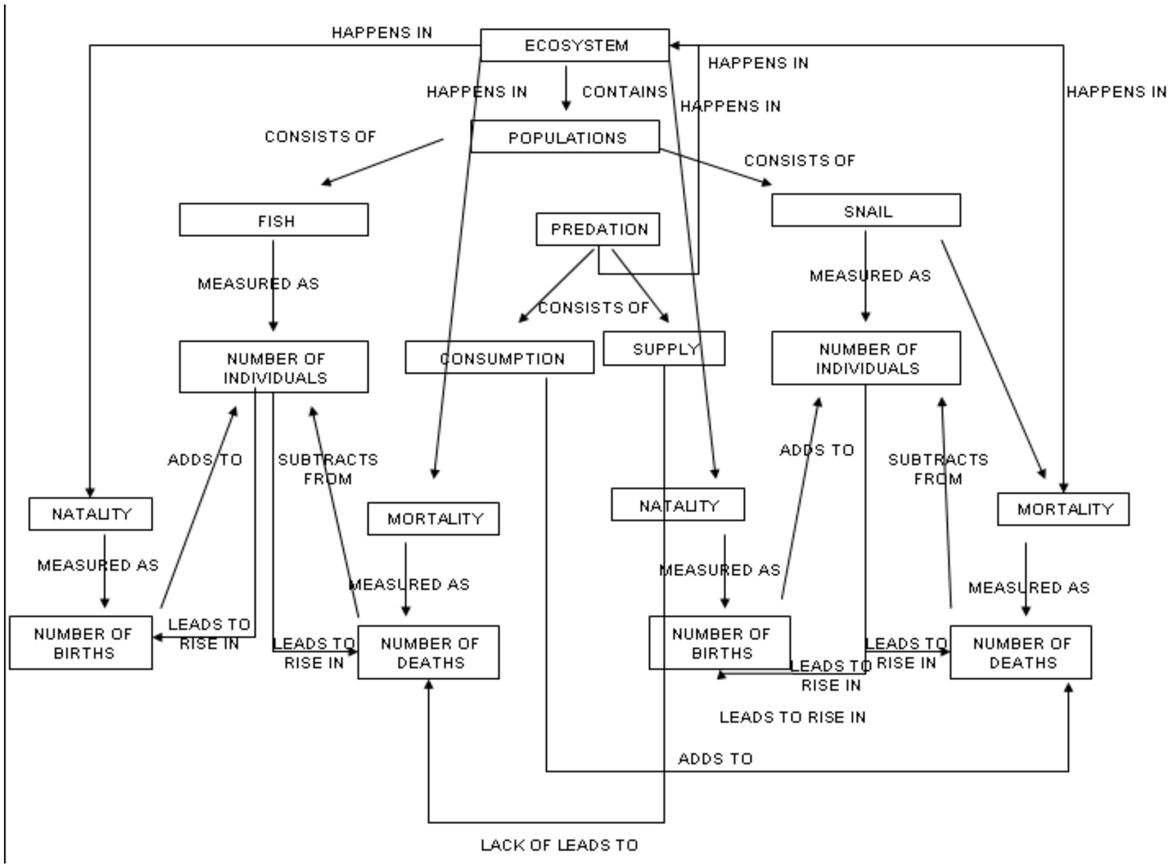
CM1- Concept map of a fish population (stage 1):



CM2 - Defining the relations between quantities (stage 2):



CM 3 – expending the concept map with a snail population and the predation process (stage 3):



LESSON 2	
Topic:	Population model
Specific Objectives:	- Introduction to Garp3 - Understanding the principle terms and concepts of Qualitative Reasoning (QR)
Content knowledge and skills:	QR terms and principles
Modelling knowledge skills:	Identifying and assigning QR terms to a Marine system
Prerequisite knowledge and skills:	All topics covered by the Marine Biology course: population, predator-prey interactions, symbiosis, invasive species, photosynthesis, eutrophication, pollution, over-fishing, ecological equilibrium.
Teaching/Learning mode/s:	Description/interpretation mode
Modelling level/s:	Building a concept map (level 1) and basic causal model (level 2)
Procedure	
Duration:	90 minutes
The lesson will be composed of 3 parts: 1. **Presentation -** an introduction to Garp3 basic features and icons. 2. **Demonstration -** modelling the basic concept of "population" from the concept maps, built during Learning unit 1, using Garp3. 3. **Presentation -** an introduction to "static" and "process" terms in Garp3.	This lesson connects between Qualitative Reasoning language and the concept map by representing the concept maps in Garp3. 1. Introduction to Garp3 basic icons (save, open model file, moving through fragments) - 20 minutes 2. Modelling fish population using Garp3: - Defining Entities (Ecosystem, population, fish) - Specifying Configurations (contains, consist of) - Defining quantity (number of, density, biomass) and quantity space After each demonstration the students will apply the material on their computer - 50 minutes (See lesson2.hgp) 3. An introduction to "static" and "process" using the concept maps from Learning unit 1 - 30 minutes (See "fish and snail basic populations" scenario in lesson2.hgp)
Evaluation	
Assessment task: The students will define, using Garp3, the basic entities, configurations, quantities and quantity spaces of the scientific papers assigned to them in Learning unit 1. Model files will be handed in and evaluated by the tutors.	
Resources	
DynaLearn resources:	Lesson2.hgp
Learning materials:	presentation

LESSON 3	
Topic:	I's and P's
Specific Objectives:	- Understanding the terms Influence (I) and

	Proportionality (P)
Content knowledge and skills:	Basic population, Natality, Mortality
Modelling knowledge skills:	Identifying the Interactions between quantities – Influence and Proportionality
Prerequisite knowledge and skills:	All topics covered by the Marine Biology course: population, predator-prey interactions, symbiosis, invasive species, photosynthesis, eutrophication, pollution, over-fishing, ecological equilibrium.
Teaching/Learning mode/s:	Exploration/manipulation mode
Modelling level/s:	basic causal model (level 2)
Procedure	
Duration:	90 minutes
The lesson will be composed of 4 parts: 1. **Presentation -** explanation of the influence (I) and Proportionality (P) terms 2. **Exercise** 3. Building the Static fragment in the basic population models built in Learning unit 2 and Assigning Proportionalities. 4. Building the Process fragments in the basic population models built in Learning unit 2 and assigning Influences.	1. Explanation of the Proportionality concepts. Class task – assigning I's and P's to a list of quantity pairs (see " Set of quantity pairs for class task" below) - 30 minutes. 2. Building the Static fragment in the basic population models built in Learning unit 2 and Assigning Proportionalities (See "Lesson 3" model)- 30 minutes. 3. Building the "Natality" Process , adding the "birth rate" quantity and the Zero Plus (Zp) quantity space into the basic population models built in Learning unit 2 and assigning Influences (See "Lesson 3" model) - 30 minutes.
Evaluation	
Assessment task: Students will add the "mortality" process to the basic population model, adding the "death rate" quantity and assign influences (I's). Additionally, static and process fragments will be added to the models based on the assigned scientific papers. Model files will be handed in and evaluated by the tutors.	
Resources	
DynaLearn resources:	Lesson3.hgp
Learning materials:	Presentation, exercise

LESSON 4	
Topic:	Building a scenario
Specific Objectives:	- Understanding the concept of "scenario" - Interpreting the state graph
Content knowledge and skills:	Basic population, Natality, Mortality

Modelling knowledge skills:	- Identifying the Interactions between quantities – Proportionality and Influence - identifying and recognising a flew in a model
Prerequisite knowledge and skills:	All topics covered by the Marine Biology course: population, predator-prey interactions, symbiosis, invasive species, photosynthesis, eutrophication, pollution, over-fishing, ecological equilibrium.
Teaching/Learning mode/s:	Exploration/manipulation mode
Modelling level/s:	Basic causal model with state-graph (level 3) and Causal differentiation (level 4)
Procedure	
Duration:	90 minutes
The lesson will be composed of 3 parts: 1. Building a scenario and defining initial values 2. Simulation of the scenario and examination of the state graph 3. Explanation of the "Inequality" concept.	1. Building a scenario on the basic population model and defining initial values – 30 minutes 2. Simulation of the scenario and examination of the state graph (see "lesson 3" model) - 30 minutes 3. This particular model has a flaw – when number of individuals = 0 the model still allows birth and death to proceed (remain "plus"). Proper examination of the graph should lead the student to find this flaw (See model flaw at the bottom). Flaw will be "fixed" using "inequalities" and "Add model fragment as condition" (see "lesson 4" model). Students will apply "inequalities" on "birth rate" and "Death rate" quantities in the scenario and run simulations of birth>death, birth=death and birth<death – 30 minutes.
Evaluation	
Assessment task: Students will build a basic scenario and apply inequalities in the model based on their assigned scientific paper. Model files will be handed in and evaluated by the tutors.	
Resources	
DynaLearn resources:	Lesson4.hgp
Learning materials:	presentation

LESSON 5	
Topic:	Process
Specific Objectives:	Linking two populations via a process
Content knowledge and skills:	Predation
Modelling knowledge skills:	Address processes, conditions, consequences in dynamic systems

Prerequisite knowledge and skills:	All topics covered by the Marine Biology course: population, predator-prey interactions, symbiosis, invasive species, photosynthesis, eutrophication, pollution, over-fishing, ecological equilibrium.
Teaching/Learning mode/s:	Exploration/manipulation mode
Modelling level/s:	Conditional knowledge (level 5)
Procedure	
Duration:	90 minutes
The lesson will be composed of 2 parts: 1. Connecting two separate populations via the "predation" process. 2. Explanation of the term "agent".	1. A model will be built based on the predation concept map from Learning unit 1. This model is different from previous models because two populations now exist in the ecosystem. The "Fish" and "Snail" entities will be added. The quantities "supply" and "consumption" will be added and assigned the ZSML quantity space. "Predator" and "prey" assumptions will be added. The "predation" process will be built (see "lesson 5" model). The "predation population dynamics" scenario will be built (see "lesson 5" model). Running of the scenario and examination of the state graphs. Applying changes to quantity parameter and running the scenario: Predator death rate>birth rate, prey death rate>birth rate, Number of predators = Large and number of prey = small. Number of predator=large and number of prey=0. Number of prey=large and number of predator=0. Every step of the model building will be demonstrated by the tutor and then repeated by the students on their computer -80 minutes. 2. A short explanation of the term "external agent" giving the examples of over fishing and pollution as external factors affecting the modelled system. The addition of an agent will be discussed in Learning unit 6.
Evaluation	
Assessment task: Students will build the basic processes in the models based on the assigned scientific papers. Model files will be handed in for examination by the tutors. Additionally, students will define the external agents in the paper.	
Resources	
DynaLearn resources:	Lesson5.hgp
Learning materials:	Presentation, scientific papers

LESSON 6	
Topic:	Agent

Specific Objectives:	Understanding the role and influence of an external agent
Content knowledge and skills:	The fishing industry, Tributyltin (TBT)
Modelling knowledge skills:	Identifying the influence of an external agent and process
Prerequisite knowledge and skills:	All topics covered by the Marine Biology course: population, predator-prey interactions, symbiosis, invasive species, photosynthesis, eutrophication, pollution, over-fishing, ecological equilibrium. In addition: TBT pollution, imposex.
Teaching/Learning mode/s:	Model-building mode
Modelling level/s:	Generic and reusable knowledge (level 6)
Procedure	
Duration:	90 minutes
The lesson will be composed of 2 parts: 1. Building the "Fishing industry" agent as a class demonstration. 2. Students building "water pollution" agent and scenario.	1. A demonstration of building the "Fishing industry" agent and applying it on the Predation model built in Learning unit 5 (See "lesson 6" model). Running the scenario and examination of the state graph - 30 minutes. 2. Tributyltin (TBT) is a biocide compound which integrates certain antifouling paints used on the hulls of vessels to prevent biological fouling - a phenomenon which has considerable economic costs and environmental risks. Although very efficient, TBT has been subject to restrictions due to its toxic effects in non-target species, detected at the end of the 1970s. One of its harmful effects is imposex – the masculinisation of females of certain marine snails in response of the exposure to TBT concentration. Students will add the "imposex" quantity, build the "TBT pollution" agent and apply it to the predation model affecting the "snail birth rate". Running the scenario and examination of the state graph. (See "Lesson 6 TBT" model)- 30 minutes. 3. During the remaining 30 minutes, the students will begin building the scientific paper models for their final project (in pairs). Tutors will assist and common questions will be addressed in front of the class.
Evaluation	
Assessment task: Model projects After this lesson, students will have a period of two weeks in which they will build their scientific paper models for their final project. Tutors will be available for assistance. Lesson 7 will consist of 15 minute presentations of the models and the topics addressed by the paper. These will be given in front of the entire "Marine Biology" course students which did not attend the modelling exercise.	

Resources	
DynaLearn resources:	Lesson6.hgp; lesson6TBT.hgp
Learning materials:	Scientific papers

Course and Lesson plans: **Renewable energy and related concepts**

COURSE PLAN ID - RENEWABLE ENERGY AND RELATED CONCEPTS	
Topic:	Renewable energy and related concepts
General Objectives:	Within the course the students should develop a deeper understanding of renewable energy sources and their use and should be able to develop a model based proposal of with regard to an increased use of renewable energy in society.
Target population:	3-4 students working as a group
Procedure	
Duration:	One week with daily activities between 15.04.-22.04.2010
Implementation plan and schedule:	**Evolving model mode**: Students will be introduced to the modelling approach with DL based on examples related to their field of experience. They will get the assignment to develop models for renewable energy use based on a set of questions (What is the difference between a renewable energy source and a fossil energy source? Which processes characterize them? Why do we need these resources? Why is it necessary to build up strategies based on renewable resources? Was has to be considered, when building up strategies based on renewable resources? Is the use of renewable resources always sustainable? Which strategies could be used to strengthen a sustainable use of renewable energy sources?). Further information can be found in the lesson plan.
Teaching/Learning organization:	Combination (model focused, evolving model and collaborative modelling).
Assessment:	**Formative**. The whole process will be guided and the attitude of the students towards DL will be assessed continuously via interviews and questionnaires.
Resources	
Dynalearn resources:	Short summary of the most important features of the DL software with examples (written); a short structured description/framework of how to build models within DL software from level 1 to 6 pointing out the specific features available at different use levels.
Learning materials:	Internet, literature.

LESSON PLANS 1-5	
Topic:	The use of renewable resources
Specific Objectives:	Developing a deeper understanding what renewable resources are, and developing a framework for strengthening their use in a project based approach– considering environmental, social and political issues.
Content knowledge and skills:	Important environmental, social, technical and economic issues related to the use of renewable resources.
Modelling knowledge skills:	Features of the DL software, structured way of building models of increased complexity.
Prerequisite knowledge and skills:	Knowledge related to the importance of renewable resources, of how to use the internet for searching information, presentation skills. An important issue is to develop an understanding of how DL modelling language links to the UML language that has been used by the students to develop their models so far.
Teaching/Learning mode/s:	**Evolving-model mode and collaborative modelling ™ -** collaborative development of models with increasing complexity along with the student's model building abilities. The work of students is based on a set of key questions delivered to them at the beginning of the project, and is guided along the course by regular learning and feedback units. **Model building mode (LM)** - students will start with concept maps developing models on different use levels based on existing model fragments, other sources like Wikipedia, internet and scientific literature. **Project based** approach supported by the DL software with **final presentation**.
Modelling level/s:	Modelling should follow a framework for model building, and will focus on levels 1 to 5.
Procedure	
Duration:	1 week
Implementation plan and schedule:	1. First Day a) In an introductory unit the learning by modelling approach & the DL software with its main features and elements will be introduced (1,5 h) to the students based on examples linked to the field of their experience (engineering and UML language). b) Then the software is explored in a collaborative mode (DL software running on individual laptops) (2 h) based on existing models on different DL levels. Then the target for their project will be developed together with the teachers (presenting the questions and developing an understanding of the working progress along the whole week). c) The rest of the day (afternoon) will be spent conducting literature research and use other internet sources for developing a deeper

	understanding of their topic related questions. This information is transformed into concept maps (level 1) and simple models (level 2 or level 3). 2. Day 2- day 5 a) Additionally 4 units (2.5 h) will be held daily to accompany the project based approach for feedback and introducing ideas for building models on higher use levels of the DL software. Within each of these units: i. they will present their approach and their models produced so far ii. the results will be discussed and questions of the students will be answered iii. Possibilities of DL software are further explored in a collaborative mode based on existing expert models providing them with ideas of how to implement their own ideas. 3. Day 6 a) Final official presentation at the e-day at the IHTL at 22.04.2010

Evaluation

Mainly formative by questionnaires for collecting information during the whole model building process (at the end of each of learning unit - daily) and at the end of the project that allow to identify if the DL software

- provides useful vocabulary to capture complex problems,
- enables students to address more complex problems (done by comparing the first results to the final model),
- supports individual learning behaviour and self organization of knowledge (questionnaire),
- able to attract students towards environmental sciences (questionnaire).

Resources

DynaLearn resources:	Short summary of the most important features of the DL software with examples (written) that show the relationship between the DL modelling concept and vocabulary and the UML modelling language in use not to overload students with similar vocabulary with different meanings. A short structured description/framework of how to build models within DL software from level 1 to 6 pointing out the specific features available at different use levels.
Learning materials:	Internet, literature.

Course and Lesson plans: **Aquatic ecology and river management**

COURSE PLAN ID - AQUATIC ECOLOGY AND RIVER MANAGEMENT	
Topic:	4 main topics: 1. Basics of river landscapes and river management 2. Large river systems - examples from the Danube 3. Benthic invertebrate ecology and water quality assessment 4. Fish as Indicators for Ecological integrity of running waters
General Objectives:	Developing and improving students understanding of processes in aquatic ecology and river management. The selected topics should cover the range of aquatic ecology and river management. A variety of examples will be presented.
Target population:	20 Bachelor and Master students
Procedure	
Duration:	5 lessons with duration of about 4h.
Implementation plan and schedule:	**Demonstration and investigation mode** Each of the 4 topics will be presented without DynaLearn software, each in one afternoon lasting for about 4h using a traditional power point teaching approach. In the fifth lesson (workshop - duration 5h) an applied example in river management (topic 1) will be developed and discussed by means of the DynaLearn software.
Teaching/Learning organization:	Combination (model focused, evolving model and collaborative modelling).
Assessment:	**Summative** At the end of the course there is a written assignment, with relatively open questions; this probably has to be adopted to fulfil our evaluation requirements; we think it would be good to have a common structure of the assessments for all 4 topics, that allows us to measure the effect of the DL software. **Formative** Interviews & questionnaires, observational notes.
Resources	
DynaLearn resources:	Users manual, Expert models, short summary of the most important features of the DL software with examples (written); a short structured description/framework of how to build models within DL software form level 1 to 6.
Learning materials:	printed ppt presentation as a basis to formulate models, scientific papers, textbook “Angewandte Fischökologie an Fließgewässern” Jungwirth et al. 2003 Facultas UTB 2113 ISBN 3-8252-2113, Pictures as starting points for discussions.

LESSON 1	
Topic:	Basics of river landscapes and river management.
Specific Objectives:	• Natural processes forming riverine landscapes and habitats • Impacts on riverine landscapes • Integrative river management • Restoration measures
Content knowledge and skills:	Identify important processes influencing riverine landscapes being relevant for an integrative catchment management.
Modelling knowledge skills:	-
Prerequisite knowledge and skills:	Basic knowledge of river ecology.
Teaching/Learning mode/s:	Demonstration/Observation/explanation mode.
Modelling level/s:	
Procedure	
Duration:	4 hours
Implementation plan and schedule:	3h traditional power point teaching approach - 1h discussion
Resources	
DynaLearn resources:	-
Learning materials:	printed ppt presentation, textbook

LESSON 2	
Topic:	Large river systems - examples from the Danube
Specific Objectives:	• Natural processes forming large river systems • Flood protection • Hydropower generation
Content knowledge and skills:	Identify important processes influencing large river systems embedded in intensive used landscapes.
Modelling knowledge skills:	-
Prerequisite knowledge and skills:	Basic knowledge of river ecology.
Teaching/Learning mode/s:	Demonstration/Observation/explanation mode.
Modelling level/s:	-
Procedure	
Duration:	4.5 hours
Implementation plan and schedule:	3h traditional power point teaching approach - 1h discussion

Resources	
DynaLearn resources:	-
Learning materials:	printed ppt presentation textbook

LESSON 3	
Topic:	Benthic invertebrate ecology and water quality assessment
Specific Objectives:	• Benthic invertebrate ecology • Key species • Biological water quality assessment • EU water framework directive
Content knowledge and skills:	Knowledge on benthic invertebrates; identify their influence in the biological water quality assessment.
Modelling knowledge skills:	-
Prerequisite knowledge and skills:	Basic knowledge of river ecology.
Teaching/Learning mode/s:	Demonstration/Observation/explanation mode.
Modelling level/s:	-
Procedure	
Duration:	4 hours
Implementation plan and schedule:	3h traditional power point teaching approach - 1h discussion
Resources	
DynaLearn resources:	-
Learning materials:	printed ppt presentation textbook

LESSON 4	
Topic:	Fish as Indicators for Ecological integrity of running waters
Specific Objectives:	• Biological water quality assessment • EU water framework directive • Key species
Content knowledge and skills:	Knowledge on fish as key species; identify their influence in the assessment of biological water quality assessment.
Modelling knowledge skills:	-
Prerequisite knowledge and skills:	Basic knowledge of river ecology.
Teaching/Learning mode/s:	Demonstration/Observation/explanation mode.
Modelling level/s:	-
Procedure	
Duration:	4 hours
Implementation plan and schedule:	3h traditional power point teaching approach - 1h discussion
Resources	
DynaLearn resources:	-
Learning materials:	printed ppt presentation textbook

LESSON 5	
Topic:	Applied example in integrative river management
Specific Objectives:	• Catchment management • Natural processes forming riverine landscapes and habitats • Flood protection
Content knowledge and skills:	Important processes influencing riverine landscapes being relevant for an integrative catchment management
Modelling knowledge skills:	Model building based on DL modelling principles introduced by an introduction.
Prerequisite knowledge and skills:	Basic knowledge of river ecology
Teaching/Learning mode/s:	**Demonstration mode (TM)** – models are used as a basis to explore the potential of the DL software and the modelling approach itself **Investigation mode (TM)** – the learning activity is devised around a key question (reflected in a picture of a riverine landscape) **Collaborative modelling mode (TM)** – students will build models in small groups and finally present results **Model building mode (LM)** – students will start with concept maps developing a model using model parts from the repository.
Modelling level/s:	Modelling follows a general framework for model building, and will focus on levels 1 to 4 (eventually 5).
Procedure	
Duration:	5 hours
Implementation plan and schedule:	1. Features of the DL software, introduction of a structured way of building models. The lesson will start with a short introduction of the project and the DynaLearn software with its main features and elements (0.5h); 2. the software is explored in a collaborative mode demonstrated on an expert model (DL software running on individual laptops) (0.5h); 3. The students should explore in small groups (2-3 students) different topics with the DL software that have been presented (3 h). 4. Discussion (1h) - possibility to contrast the students models with expert models and analyzing the differences
Evaluation	
Formative: Interviews and questionnaires for collecting information during the model building process; final questionnaires; **At a later date: summative assessment** - content related questions that allow to identify the effect of the DL software on model building and learning/understanding capabilities/effects (Topic 1: lecture and DynaLearn Workshop; topics 2-4: only lectures	
Resources	

DynaLearn resources:	Short summary of the most important features of the DL software with examples (written); a short structured description/framework of how to build models within DL software form level 1 to 6. Expert models
Learning materials:	printed ppt presentation as a basis to formulate models, pictures that reflect key questions

Course and Lesson plans: **Conservation biology**

Introduction

The conservation of nature is considered important for three reasons: nature´s intrinsic value, its instrumental or economic value, and its emotional, spiritual and psychological values. Here follows some concepts required to the understanding of the principles of conservation biology:

An understanding of the important components of nature that should be conserved is based on an understanding of many key biological concepts, including those of taxonomy, ecology, genetics, geography and evolutionary biology.

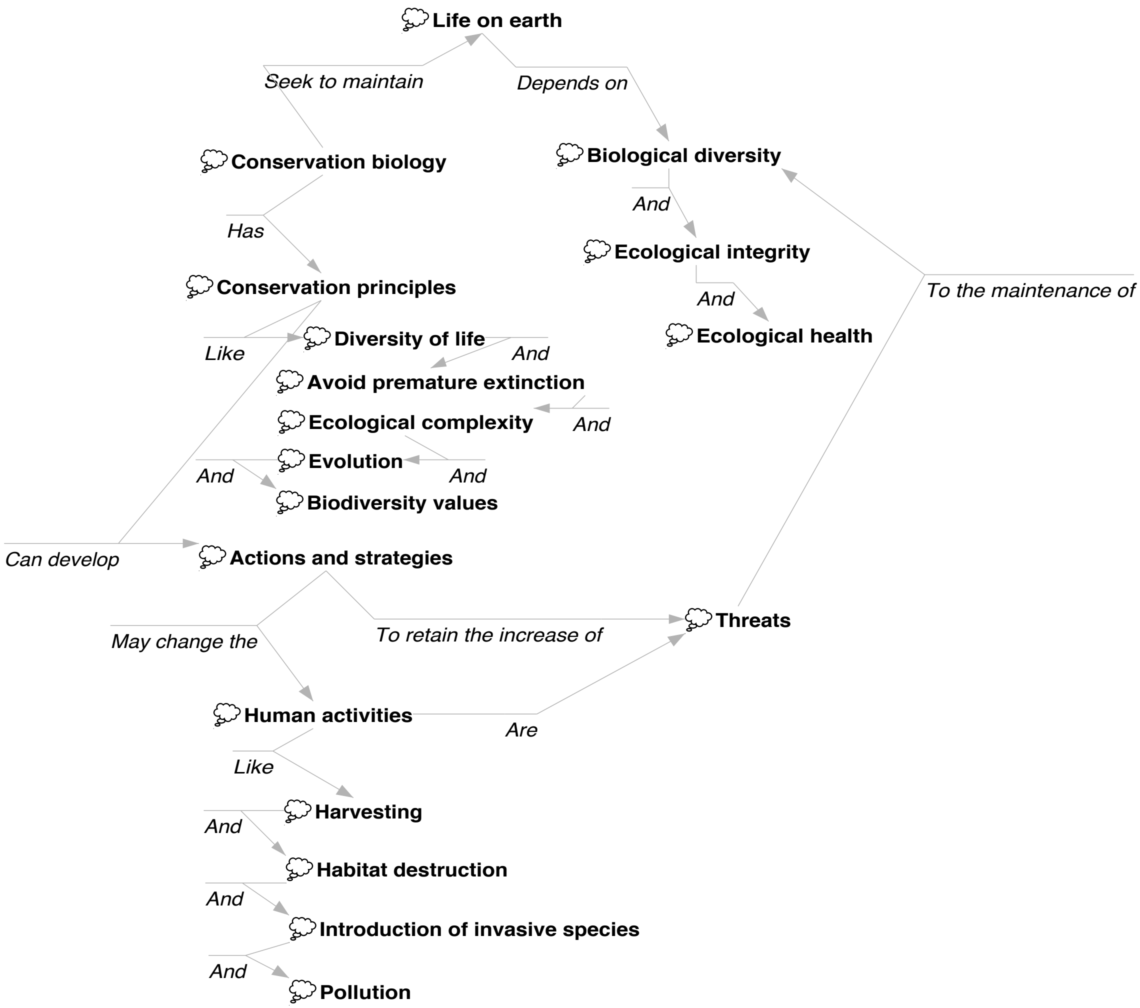
Some essential concepts are:

- Taxonomic hierarchy
- Ecological hierarchy – the organization of life from genes, sub-populations, populations, meta-populations, communities, ecosystems and landscapes.
- Genetic diversity
- The species concept – there´s a variety of definitions for species, but from the perspective of conservation, a species is considered a group of organisms that share common traits and common descent. It´s also important knowing that species are not unchanging over time, rather, they evolve in response to the forces of selection, gene flow and chance.
- Population size – the size of a population depends on the trade off between the tendency of a population to grow exponentially and the limitations imposed by biotic factors (e.g., density dependence, predation) and abiotic factors (e.g., climate) in the environment. The size of a population is, in general, inversely related to the probability of inbreeding, the loss of genetic information due to chance events associated with survival and reproduction, and susceptibility to extinction. Therefore, small populations are, in general, at greater risk of extinction than large populations.
- Communities and Ecosystems
- Stochasticity – the operation of chance in nature from one time period to another
- Extinction – extinction refers to the termination of an evolutionary line. It´s important that students comprehend that extinction is a long-term expectation for all populations
- Global climate change: the earth is currently experiencing an increasing average temperature caused by human addition of greenhouse gases into the atmosphere. This change in temperature will have severe consequences for life on Earth through rapid changes in climate, geographic range, and ecological processes, increasing the risk of extinction (McCarthy et al., 2001). Regional and seasonal changes in climate will have many effects on species, including changes in geographic distributions, risk of extinction, community composition and ecosystem function.

COURSE ID	
Topic:	Conservation biology aspects related to the maintenance of the biodiversity of life
General Objectives:	To represent the main principles of conservation biology, its meaning and importance to the protection of the biodiversity and practice to promote a sustainable behaviour. To represent the greatest causes that threats the global biodiversity. Help students better understand the basis for effective conservation policies.
Target population:	Secondary school students
Procedure	
Duration:	6 lessons of 50 min each (5hours)
Implementation plan and schedule:	(a) In the first lesson, the learner is introduced to the theme and the task is to build a generic diagrammatic representation based on the given text (b) next, the learner is introduced to the modelling primitives and build a simple causal chain in use-level 2; (c) then, in the use-level 3, the student introduces a quantity space and explores a simulation; (d) in use-level 4 the student discuss the concept of process, in the context of the processes that involves the influence of human activities into species conservation; (d) the student explores the conditions for things to happen in use-level 5; (e) finally, in use-level 6 the student creates model fragments and learns how to use conditional representations in order to explore the model
Teaching/Learning organization:	A combination of teaching modalities, including the evolving-model mode, as the learner has to build a model in each use- level, and the model-focused lesson, in order to explore the models with alternative initial values representing different situations.
Assessment:	Formative, in each step of the modelling process (b – e); at the end, a summative evaluation in order to assess the whole model usage. Ask the student for a prediction of the outcomes direction of change of the quantities given a scenario with influences of human activities upon the extinction of species. It is expected that the student will be able to answer what are the main drivers of the decline and loss of biodiversity.
Resources	
DynaLearn resources:	A text about the conservation biology goals facing the diminished ecological diversity. This text contains too some of the consequences of the human activities demand for overexploitation of

	the nature resources.
Learning materials:	The student will receive the guidelines to build the model and an example of concept map about conservation biology. The instructions about the modelling tasks are included in the guidelines. Finally, an evaluation sheet will be given for assessment of the model created.

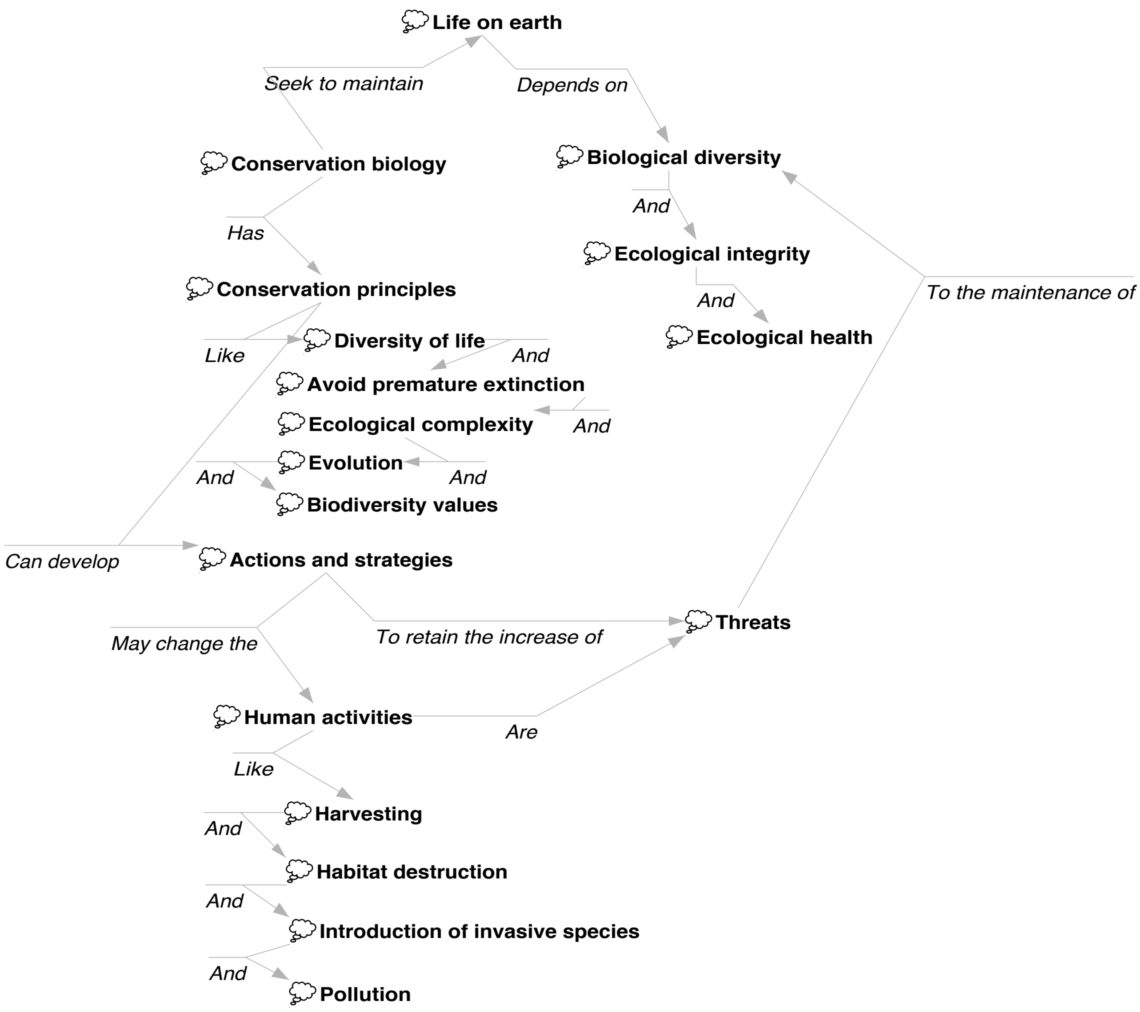
Concept map – use level 1



COURSE ID	
Topic:	Meta-populations and the conservation of the biodiversity
General Objectives:	To represent the main characteristics of the populations organized as meta-populations, its meaning and importance to the conservation of the biodiversity. To represent the main aspects of populations that is living in fragmented areas.
Target population:	Secondary school students
Procedure	
Duration:	6 lessons of 50 min each (5hours)
Implementation plan and schedule:	(a) In the first lesson, the learner is introduced to the theme and the task is to build a generic diagrammatic representation based on the given text (b) next, the learner is introduced to the modelling primitives and build a simple causal chain in use-level 2; (c) then, in the use-level 3, the student introduces a quantity space and explores a simulation; (d) in use-level 4 the student discuss the concept of process, in the context of the processes that involves the flux of individuals between the habitat patches in a fragmented landscape(d) the student explores the conditions for things to happen in use-level 5; (e) finally, in use-level 6 the student creates model fragments and learns how to use conditional representations in order to explore the model
Teaching/Learning organization:	A combination of teaching modalities, including the evolving-model mode, as the learner has to build a model in each use- level, and the model-focused lesson, in order to explore the models with alternative initial values representing different situations.
Assessment:	Formative, in each step of the modelling process (b – e); at the end, a summative evaluation in order to assess the whole model asks the student for a prediction of the outcomes direction of change of the quantities given a scenario with the influences of migrations, colonizations and extinctions between the habitat patches.
Resources	
Dynalearn resources:	A text about Meta-population importance and context. goals facing the diminished ecological diversity. A concept map built in the sketch tool showing the main aspects that involves a population structured as a Meta-population.

Learning materials:	The student will receive the guidelines to build the model and an example of concept map about meta-population. The instructions about the modelling tasks are included in the guidelines. Finally, an evaluation sheet will be given for assessment of the model created.

Concept map – use level 1



Appendix II – Setting education goals for QR modelling

The model described in this section is inspired in the following verbal model:

> Water pollution may cause human diseases. An industry located next to a lake produces effluents that may pollute this water body. Given that the lake supplies water for a human population, diseases may appear.

The approach taken for implementing (represented here in a Garp3 model) this verbal model is to decompose it in a set of models of increasing complexity, in order to explore the capabilities of different use-levels available in DynaLearn. Use level 1 (concept maps) is not considered here as the use of concept maps is well documented elsewhere and is not unique to the DynaLearn approach.

Suppose a lesson plan defined for the whole activity aims at improving learner's skill (S4) "Integrating knowledge from different areas (for example, natural sciences and humanities) by developing interdisciplinary projects". (the list of skills mentioned in this appendix is detailed in section 2.3.1 of this document). This is a quite complex learning goal, for this model involves integrating knowledge from areas such as economy (an industry produces goods, but additionally it creates some externalities, such as the water pollution), ecology (water quality decreases due to pollution) and medicine (diseases will cause harm to humans that have contact with the polluted water).

Of course, it would not be expected that all these details are included in the qualitative model. Instead, the model provides the basis for a broader coverage of the knowledge involved in the verbal model, maybe with the support of additional learning resources. However, the learning objective mentions a project based -methodology to implement such interdisciplinary task. Accordingly, the whole set of activities described in this section can be considered as being part of a single project, that should be further detailed in different lesson plans and maybe a course plan. The educational goals related to this (S4) skill will be mentioned below.

USE LEVEL 2

At this use level, the model is simple and consists of a basic causal representation. Entities and configurations are used to represent the structure of the system. Quantities with magnitude QS = {plus} are created and the influence links between quantities is represented using qualitative proportionalities. Note that exogenous quantities (Bredeweg et al., 2007) are used to give the dynamics to the system, as direct influences and proportionalities (Is and Ps) are only available in use-level 4.

Given the verbal model, in skill, '(S2) Understanding multiple uses of the language', is necessary for the learner to recognise what the objects are that constitute the system being modelled, and the properties that are associated to the dynamics of the system. Also, the learner is expected to use the correct modelling primitives for representing objects and properties.

- *Learning goal 1*. Identify, in the verbal model, what the objects are that constitute the system being modelled.
  [*the learner should identify the 'Industry', the 'Lake' and the 'Human Population'*]

- *Learning goal 2*. Create a representation for the system structure to be captured in the model.
  [*the learner should select the correct modelling primitives for entities, and create a configuration that makes sense given the verbal model; the representation of the system structure is shown in Fig. 1*]

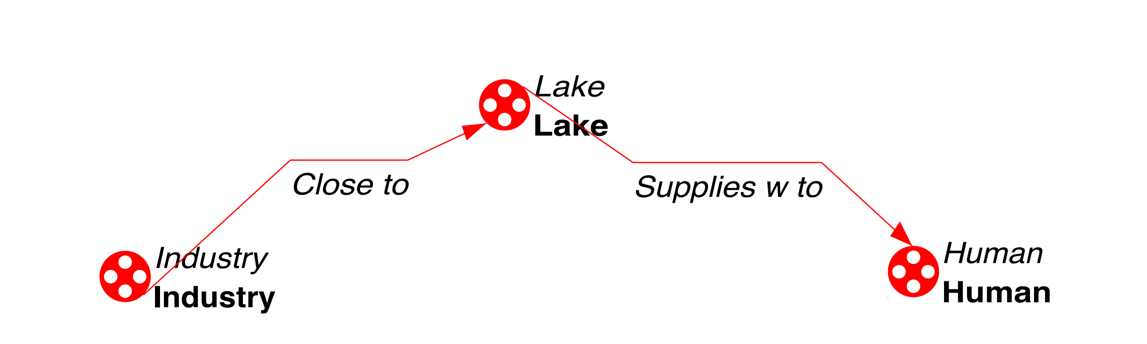


Figure 1: System structure of a DynaLearn level 2 model.

Note that to create this representation the learner was supposed to abstract the elements that capture the physical objects and use the same modelling primitive (entity) three times, with different names, and establish links between them (configuration) that was implicit in the verbal model.

Goals associated to the '(S3) Identifying central and periphery information, presented in different contexts (texts, literature, models)' are at the heart of the modelling activity. In this case, the learner was supposed to identify the properties of the objects that could represent the dynamics of the system.

- *Learning goal 3*. Identify, in the verbal model, the properties of objects that constitute the system being modelled.
  [*the learner could identify the 'production of effluents' as a feature of the object 'Industry'; the 'water quality' as the property of the 'Lake'; and the 'incidence of disease' as a property of 'Human Population'*]

- *Learning goal 4*. Create a representation for the quantities and for to be captured in the model.
  [*the learner should select the correct modelling primitives for each of the entities' properties, the quantities, and give them a quantity that is simple enough to capture only the basic references to the dynamics (changing either upwards, downwards or stable) suggested by the verbal model; the representation of the system structure is shown in Fig. 2*]

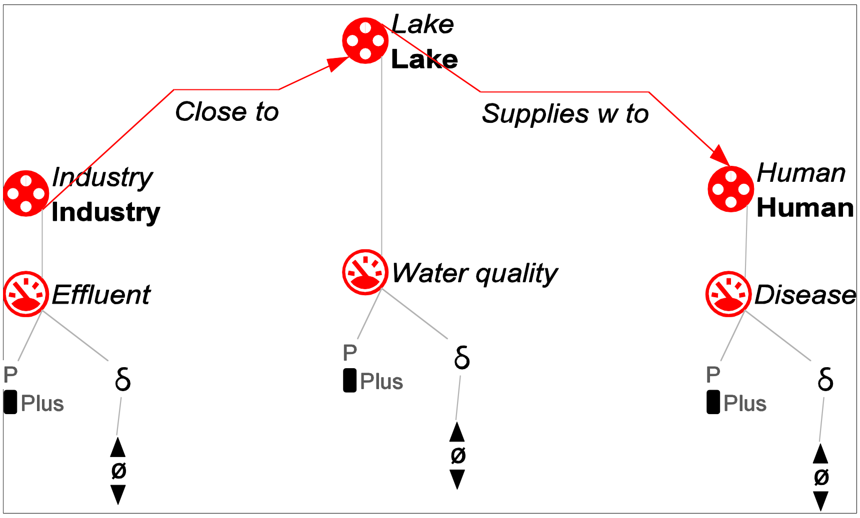


Figure 2: System structure and quantities of DynaLearn level 2 model.

To arrive at this representation, the learner should be able to differentiate between an Entity (the physical object) and a quantity (its property); also, as required in S3, the learner is expected to have the skill of selecting only the concepts of effluent, water quality and disease to express the dynamics of the system – other concepts such as the kind of industry, which pollutant could be produced and to what type of disease this could be associated would be irrelevant for the model. The names of the quantities show the only information required for the model to represent the verbal description of the system.

At this point, a learning goal related to (S4) (the interdisciplinary project about economy, ecology and medicine) could be introduced.

- *Learning goal 5*: Identify types of industrial effluents and search for legislation that defines at what concentration their presence in a lake would constitute water pollution.
  [*the learned may find the information required in a number of sources, and should keep the results for future application within the project*].

Next, the learner has to establish the links between the quantities in order to capture the causal chain involved in this situation. Goals related to the skill '(S4) Applying adequate methods for problem analysis and resolution' are required to assign causal dependencies between the quantities and this way to establish the basis to produce the adequate behaviour for the given situation.

- *Learning goal 6* Assign causal relations between the properties' objects that support the expected system behaviour for the given situation.
  [*the learner should first think about the system behaviour – what increases? decreases? when changes occur?*]

- *Learning goal 7*. Create a representation for the causal relation between the quantities in order to realise the expected behaviour of the system represented in the model.

  [*the learner should make the following reasoning: if* Effluent *is increasing, then* Water quality *is decreasing; and when* Water quality *is decreasing,* Disease *is increasing; these quantities express opposed behaviour; the representation of the causal dependencies is shown in Fig. 3*]

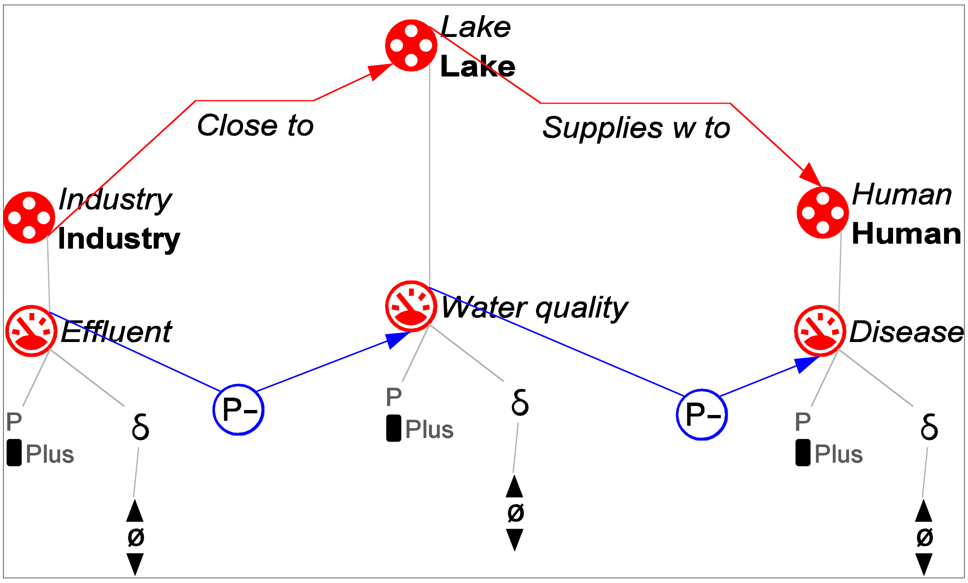


Figure 3: Model fragment of DynaLearn level 2 model.

As the student is expected to develop skill (S6) 'Applying adequate methods for problem analysis and resolution' with this activity, the correct reasoning the learner is required to perform, is to analyse the relation between the quantities in order to establish the causal. The correct causal link is the following: if *effluent* is increasing, then *water quality* is decreasing; and if *effluent* is decreasing, then *water quality* is increasing. These behaviours are exactly what the P– relation produces. The same reasoning is required to add the second P– relation in the model fragment.

- *Learning goal 8*. Test the causal chain just created to integrate the quantities using simulation as an instrument for defining the correctness of the solution.

The proof of concept is provided by a simulation starting with the scenario shown in Figure 4.

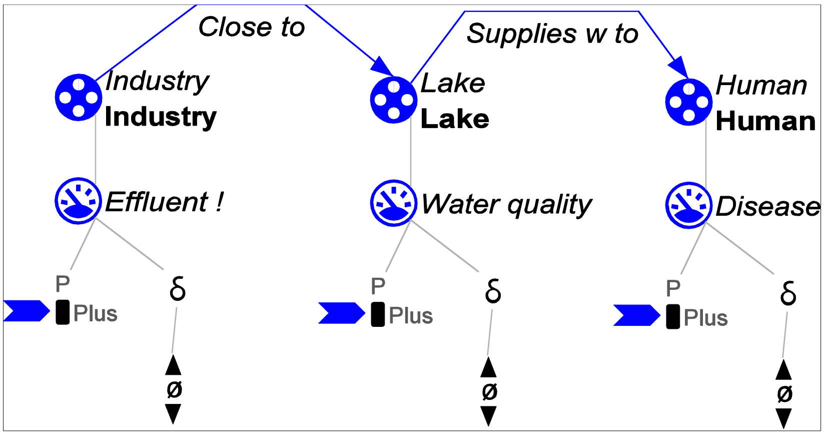


Figure 4: Scenario (sce01) of DynaLearn level 2 model.

The quantities involved in the simulation express the behaviour shown in Figure 5:

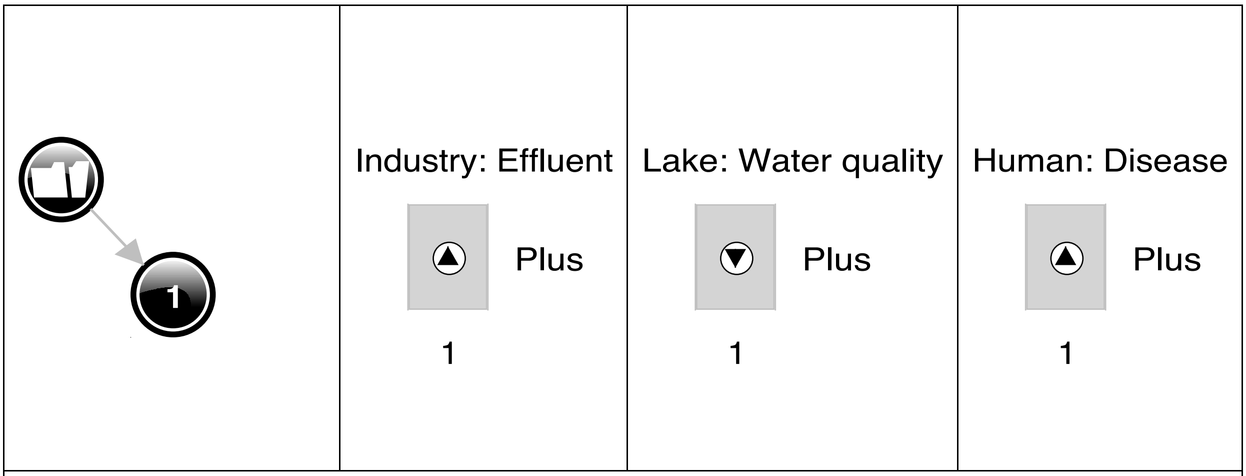


Figure 5: Behaviour graph and value diagrams showing three quantities of DynaLearn level 2 model in a simulation with Scenario 1.

The results of the simulation confirm the expectations of the learner while building the model.

As the representation shown in Figure 3 is correct, the model can be used to solve a problem given incomplete knowledge about the same system, if the learner masters the skill '(S5) Making (inductive, deductive, analogical) inferences' and is able to use it.

- *Learning goal 9*. Given a diagram with the values of some of the quantities involved in the level 2 model, infer the correct behaviour of the missing quantity.

The diagram is shown in Figure 6:

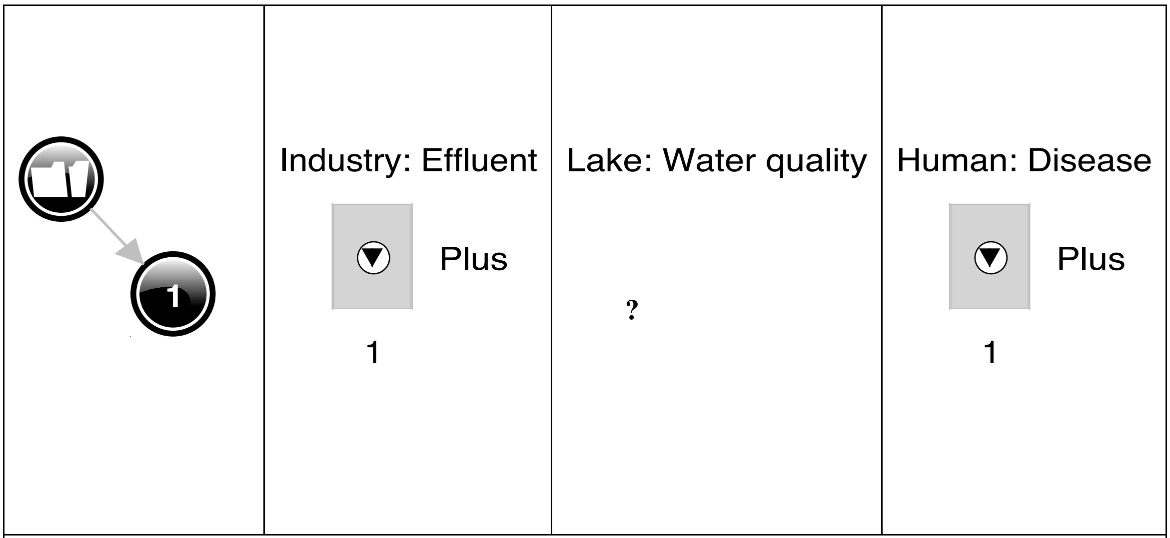


Figure 6: Behaviour graph and value diagrams showing three quantities of DynaLearn level 2 model.

To solve the problem, the learner is expected to make the following deductive reasoning: IF *effluent* is decreasing AND the relation between this quantity and *water quality* is a P-, THEN the quantity water quality is increasing (that is, changing in the opposite direction). Alternatively, the learner could infer, from the behaviour of the quantity *disease* and the existence of a P– relation with *water quality* that this quantity should be increasing.

At this point, a new learning goal related to (S3), the interdisciplinary project about economy, ecology and medicine could be introduced.

- *Learning goal 10*: Identify and describe types of water related diseases could be involved and search for medical information about them and how to avoid them.
  [*the learned may find the information required in a number of sources, and should keep the results for future application within the project*].

Getting this causal model helps to understand why human population was suffering of diseases, and to establish a causal explanation for that. However, the situation is not clear yet. For instance, at what level of water quality people become ill? A slight drop in the water quality is enough to affect a large number of people? In order to answer questions like these, we have to add more details to the model. In fact, what is needed at this point is to be more clear about the water quality and diseases possible *qualitative states*. This is still part of the development of skill (S4), improving the problem analysis and then move to a possible solution.

- *Learning goal 11*: Based on information about water quality and water-related diseases identify and describe possible states for water quality and number of people with the diseases are relevant for understanding the problem.
  [*the learner may find the information required in a number of sources and come up with the idea that states of water quality can be classified as {bad, medium, good}, and the frequency of people with diseases, {low, medium, high}*].

- *Learning goal 12*: Create a representation for the possible qualitative states of the quantities *Water quality* and *Disease* and include them in the model.

[*the learner should be aware of the notion of* Quantity Space *and then be able to create the quantity spaces required; the representation of the causal dependencies is shown in Figure 7*].

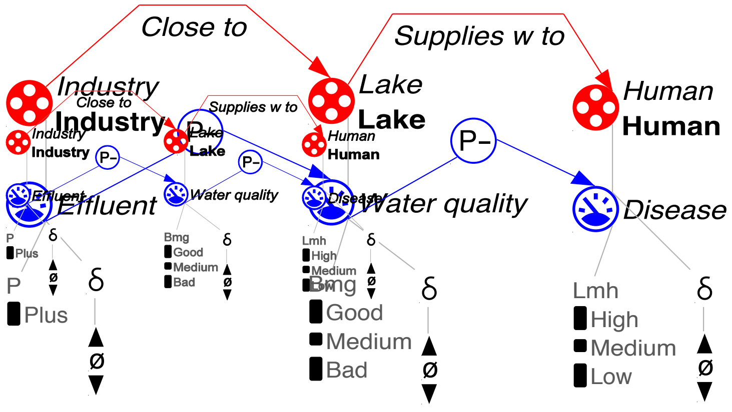


Figure 7: Model of a DynaLearn use-level 3 showing expanded quantity spaces in *Water quality* and *Disease*.

A new simulation is run with the modified model and the results are shown in Figure 8.

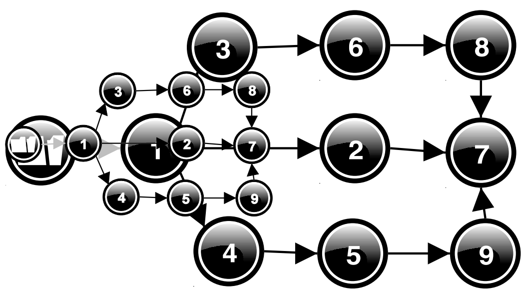


Figure 8. Behaviour graph obtained in a simulation with extended quantity spaces for *Water quality* and *Disease*

This state space produce three behaviour paths, showing all the possibilities for the development of the system, given the initial conditions described in the scenario. The values of the quantities are shown in Figure 9.

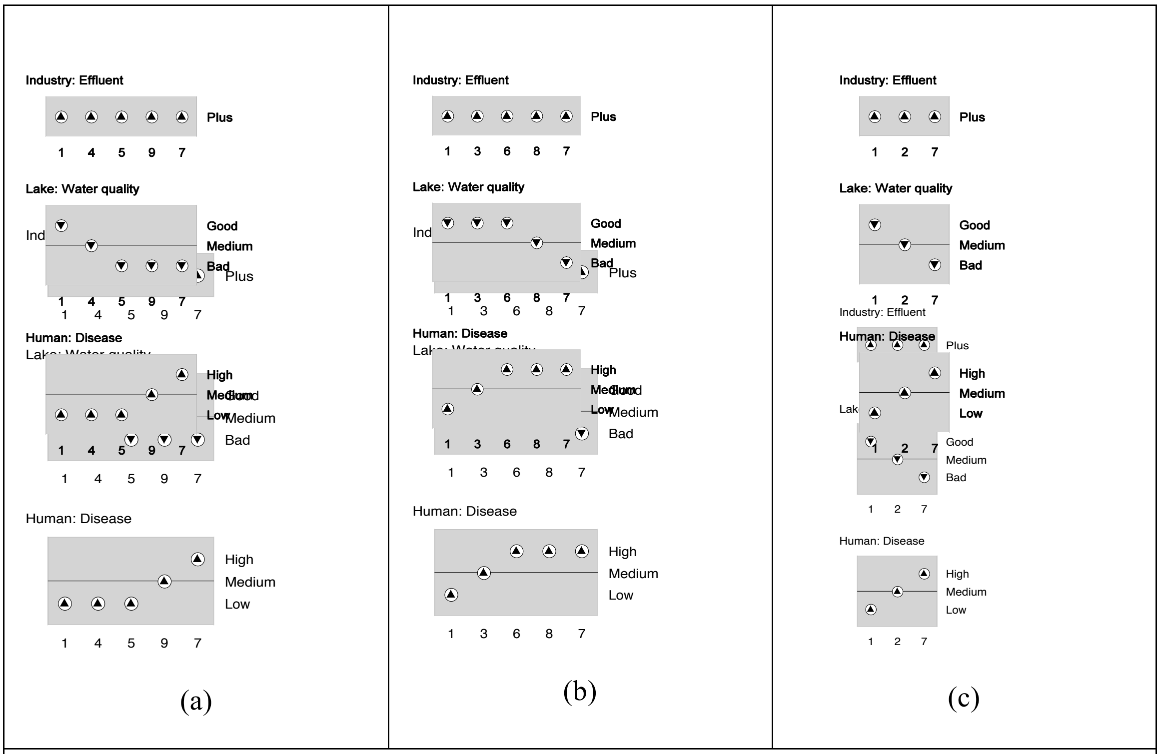


Figure 9. Values of the three quantities (*Effluent*, *Water quality* and *Disease*), in three behaviour paths.

Analyses of the three possible behaviours show possible reactions of the people towards the water quality, so that in Figure 9a the population is more resistant to the decrease in the quality of water; in Figure 9b the population is more sensitive to changes in water quality and in Figure 9c, the relation between quality and disease is in between the first two cases. The learner may find out from the literature collected in the project which is the most adequate way to describe the behaviour of these two quantities, *Water quality* and *Disease*. Suppose the student recognize Figure 9b as being the behaviour observed in nature. The population needs to be protected quickly.

The learner is now facing the problem of select ways to solve the pollution problem. At least three solutions may be possible: (a) use some substance that work as a sort of water cleaner and remove the pollution; (b) provide medical care to the people and heal the disease; (b) control the effluents produced by the industry.

In order to solve the problem, the learner shall develop the skill '(S7) interpreting models, formulating hypotheses and predicting results'. In order to develop this skill, the learner may develop alternative versions of the model.

- *Learning goal 13*: Create a hypothesis about the influence of a water cleaner substance and predict its effect on the disease.
  [*the learner should create a hypothesis such as: IF the substance cleans the water, THEN the number of people with disease should decrease even if the industry keeps producing the effluents*].
- *Learning goal 14*: Create a representation for the water cleaner as a means to control the disease.
  [*the learner should create the quantity* Water cleaner *and make it an influence on water quality; the representation of the causal dependencies is shown in Fig. 10*].

The resultant model in represented in Figure 10.

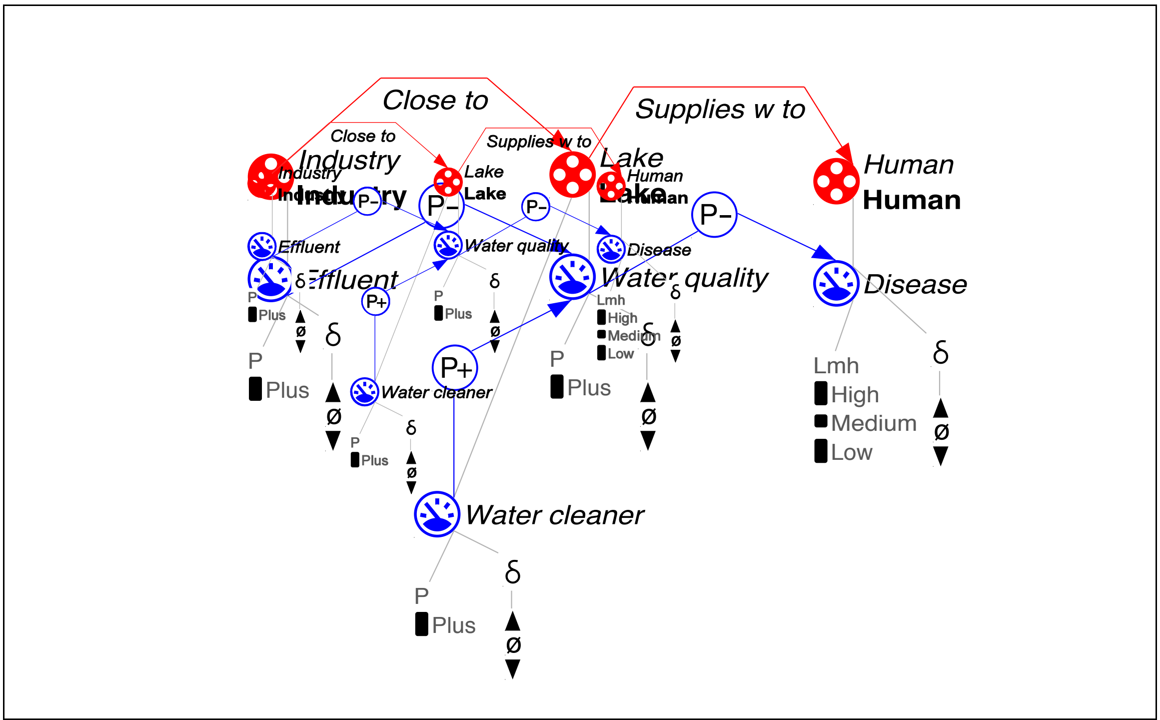


Figure 10. Model in DynaLearn use-level 3 introducing the quantity *Water cleaner*.

A simulation with this model produces the results shown in Figure 11.

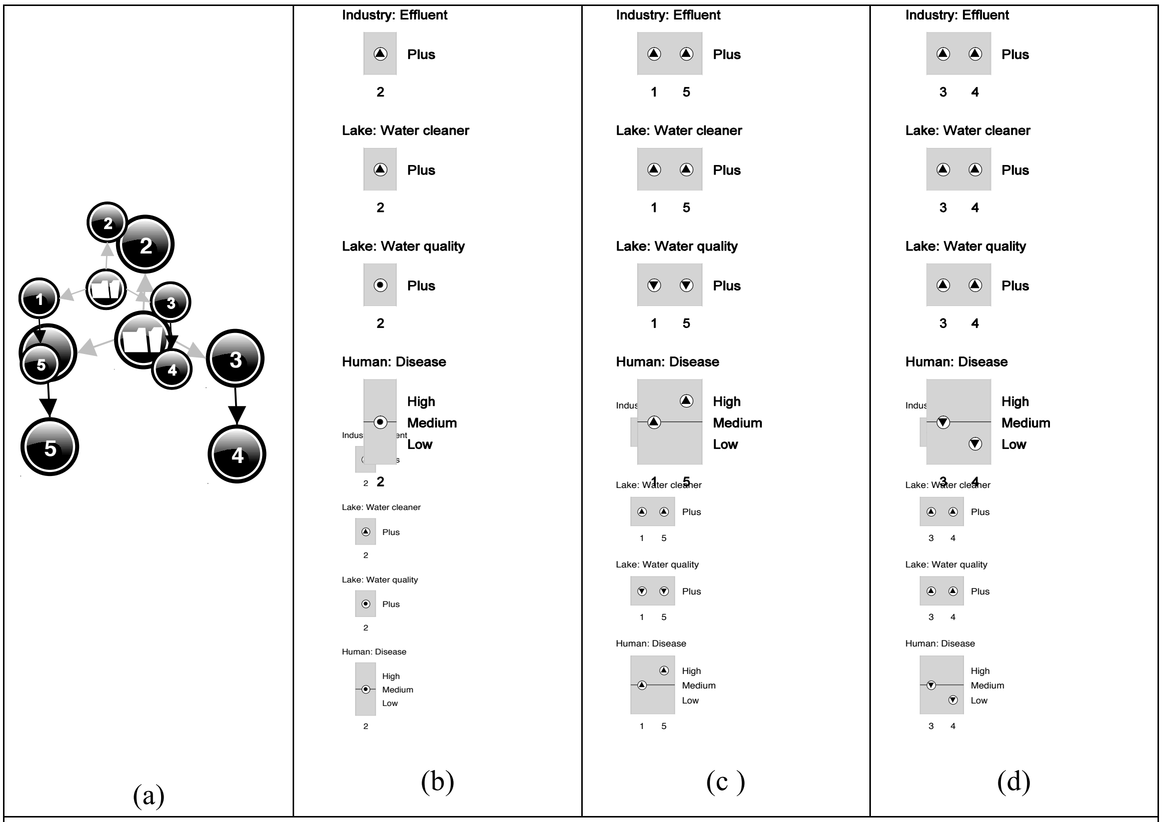


Figure 11. Simulation with the model with the *Water cleaner* quantity; (a) behaviour graph; (b, c, d) values of the quantities in three possible behaviour paths.

- *Learning goal 15*: Analyse the results of the simulation with the model that represents the effect of water cleaner on to the control the disease.
  [*the learner should be able to produce a text such as the following:*

  The analysis of the simulation shows that Water cleaner *may produce the expected behaviour (decrease the incidence of the disease) as shown in Figure 11d. However, given the influence of the effluent emission, the* Water cleaner *effect may just remove the pollution at the same rate it is introduced in the water (Figure 11b) or work at a lower rate (Figure 11c). In both cases, the prediction will fail.*] This activity is also related to the skill '(S6) Critically analysing solutions found for problems'.

Next the learner would go for the second possibility.

- *Learning goal 16*: Create a hypothesis about the influence of the medical care and predict its effect on the disease.
  [*the learner should create a hypothesis such as: IF the people receives adequate medical care, THEN the number of people with the disease should decrease, even if the industry keeps producing the effluents*].

- *Learning goal 17*: Create a representation for the medical care as a means to control the disease.
  [*the learner should create the quantity* Medical care *and make it an influence on the disease; the representation of the causal dependencies is shown in Fig. 12*].

The resultant model in represented in Figure 12.

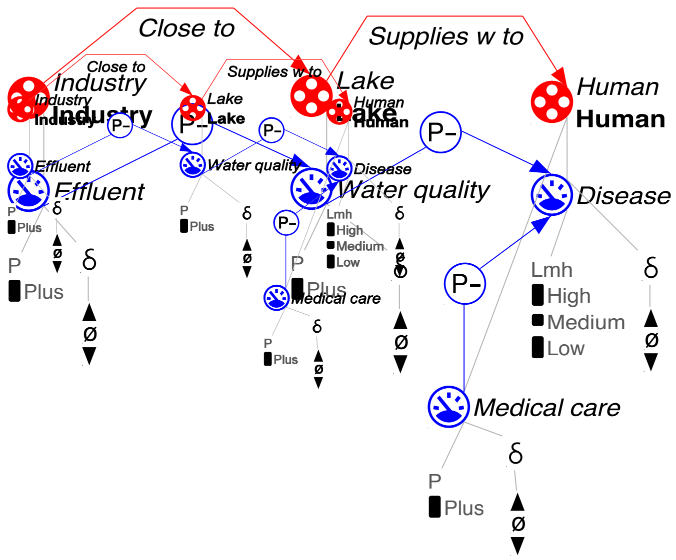


Figure 12. Model in DynaLearn use-level 3 introducing the quantity *Medical care*.

The results of a simulation with this model are shown in Figure 13.

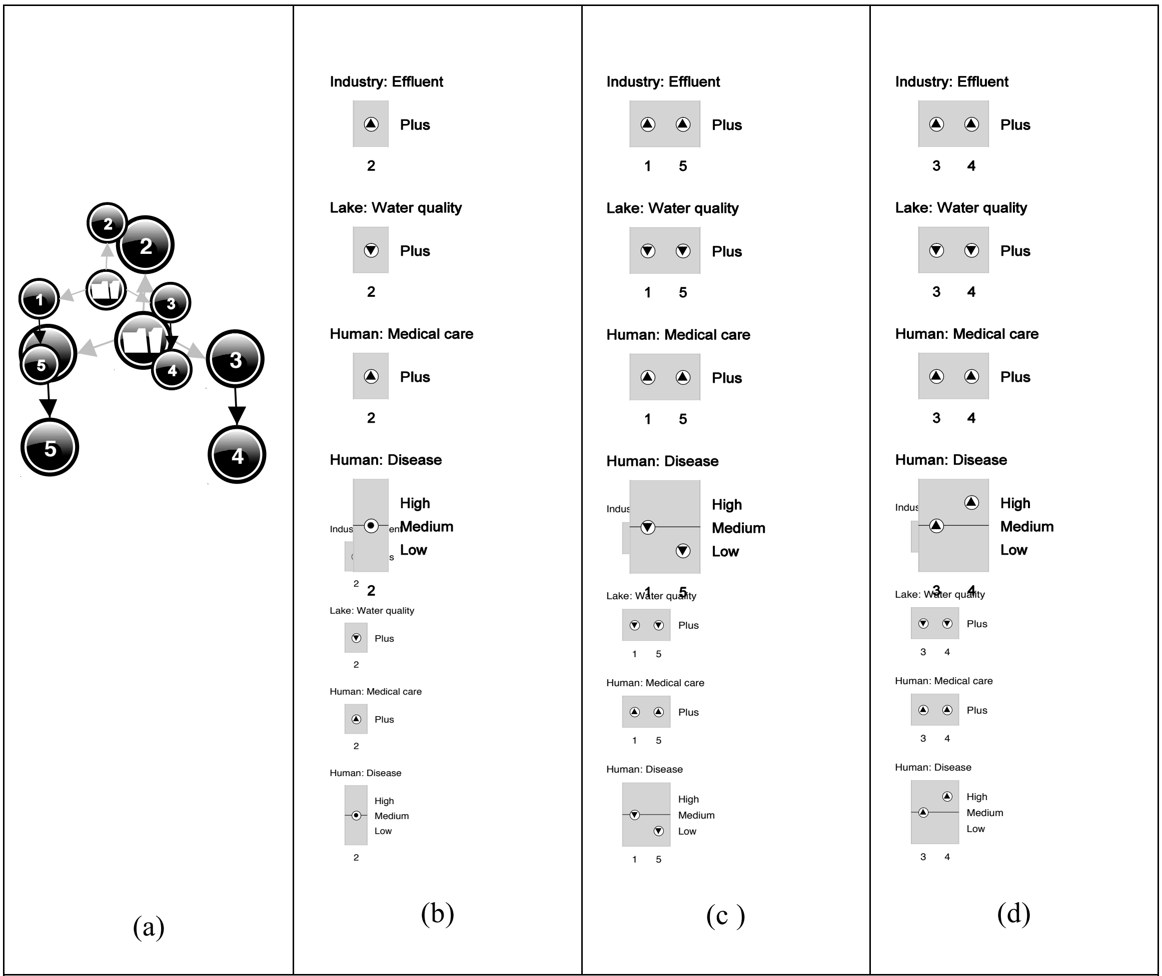


Figure 13. Simulation with the model with the *Water cleaner* quantity; (a) behaviour graph; (b, c, d) values of the quantities in three possible behaviour paths.

- *Learning goal 18*: Analyse the results of the simulation with the model that represents the effect of medical care on to the control the disease.
  [*the learner should be able to produce a text such as the following:*

  Very much as in the case mentioned above, the simulation shows that Medical care may produce the expected behaviour (decrease the incidence of the disease) as shown in Figure 13c despite the quality of the water. However, given the continuous influence of the effluent emission, the Medical care may just heal the people at the same rate as other people get the disease (Figure 13b) or work at a lower rate (Figure 11d). In both cases, the prediction will fail.] This activity is also related to the skill '(S9) Critically analysing solutions found for problems'.

Finally the learner would go for the third possibility.

- *Learning goal 19*: Create a hypothesis about reducing the emission of effluents and predict its effect on the disease.
  [*the learner should create a hypothesis such as: IF the industry reduces its emissions of the effluent, THEN the number of people with the disease should decrease, even if the industry keeps producing effluents*].

- *Learning goal 20*: Create a representation for reducing the effluent emissions as a means to control the disease.
  [*the learner should create the quantity* Effluent *and make it an influence on the disease*].

In fact, that model was already discussed above (see *Learning goals* 6-8, and Figures 3-5). The simulation mentioned here was already run (see *Learning goal* 9, and Figure 6).

- *Learning goal 20*: Analyse the results of the simulation with the model that represents the effect of medical care on to the control the disease.
  [*the learner should be able to produce a text such as the following:*

  The simulation shows that if Effluent *is decreasing, it produces the expected behaviour (decrease the incidence of the disease) as shown in Figure 6. The quality of the water also improves, and this is the closest influence on the incidence of diseases.*] This activity is also related to the skill '(S6) Critically analysing solutions found for problems'.

After these analyses, the learner should be able to compare the results of the three models (S6).

- *Learning goal 21*: Compare the outcomes of the simulations based on the three models, introducing a cleaner substance to the water and providing medical care to people ill and their effects on to the control the disease.
  [*the learner should be able to produce a text such as the following:*

  The simulations with the models involving a cleaner water substance and introducing medical care show that, it is, in principle, possible to get the desired result using the proposed solutions. However, both solutions may fail. In fact, there is a fundamental problem: pollution is continuously decreasing the quality of the water, and this may hamper the efforts to protect public health. The solution is the one expressed in the third model: it is really necessary to reduce the effluent emissions, in order to be sure that the incidence of the disease would decrease.]

Now a better representation of the industry-lake-human system is required to make explicit the solution proposed in the model, that is the reduction in the level of effluent emission, in order to create a really explicative model, as required for the development of skill (S7). A more complex model has to be developed, in which differentiated causal relations are used. The mechanism that causes change to the system, the process, has to be modeled. This is done by introducing a new quantity, the *rate*, that will cause a direct influence (I+ or I-) to the *state variable*. The effects of the process will then propagate to the other quantities in the system via qualitative proportionalities (P+ or P-). Causal differentiation is introduced in DynaLearn use-level 4.

- *Learning goal 22*: Create a representation for the effluent emission process and show how this process eventually causes change in the incidence of disease in the human population.
  [*the learner should create the quantity* Emission rate*, give it the quantity space that captures the qualitative states active / inactive and make it a direct influence on* Effluent. *Next, create negative qualitative proportionalities to better represent causal relations involving the quantities* Water *quality* and Disease*; the representation of these causal dependencies is shown in Fiure 14*].

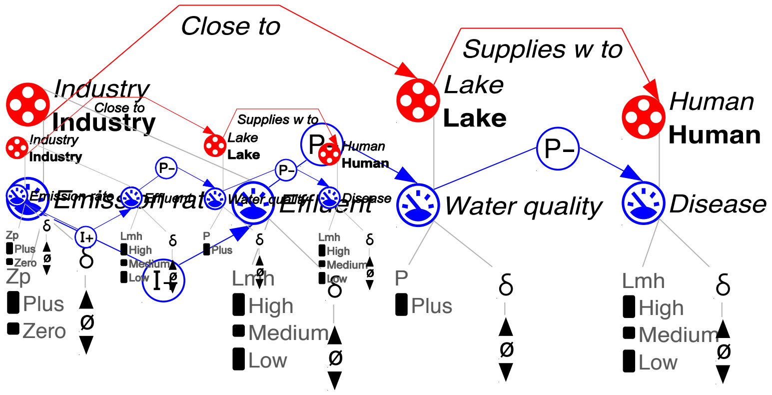


Figure 14: Model of DynaLearn use-level 4 showing the process Emission of effluents, captured by the quantity *Emission rate*.

A simulation with this model produces the same result as the less complex model shown above: the incidence of diseases increase when the Emission process is active. In order to make the amount of effluent to decrease, the model should include a competing process, the Removal of Effluents process.

- *Learning goal 23*: Create a representation for the effluent removal process and show how this process competes with the emission process.
  [*the learner should create the quantity* Removal rate*, give it the quantity space that captures the qualitative states active / inactive and make it a negative direct influence on* Effluent; *these causal dependencies are shown in Figure 15*].

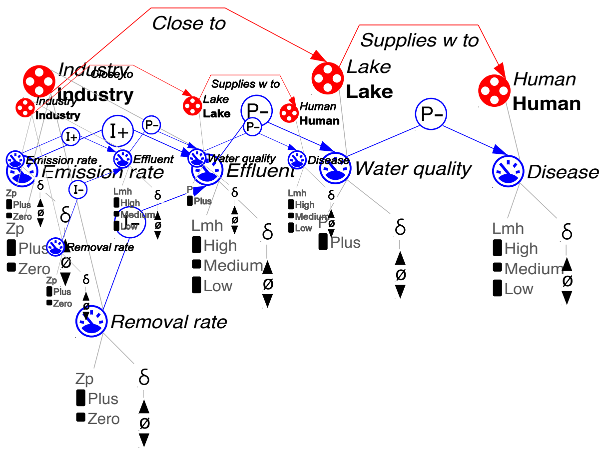


Figure 15: Model of DynaLearn use-level 4 showing the competing processes Emission of effluents and Removal of effluents, captured by the quantities *Emission rate* and *Removal rate* respectively.

Now the learner can run a simulation in order to explain how the control of effluent emissions can contribute to reduce the incidence of diseases caused by pollution.

- *Learning goal 24*: Create a scenario for a simulation in which the removal process is greater than the emission process, so that this situation causes the incidence of diseases to decrease.
  [*the learner should create an inequality showing the quantity* Removal rate *is greater than* Emission rate*; the representation of these inequality relation is shown in Fig. 16*].

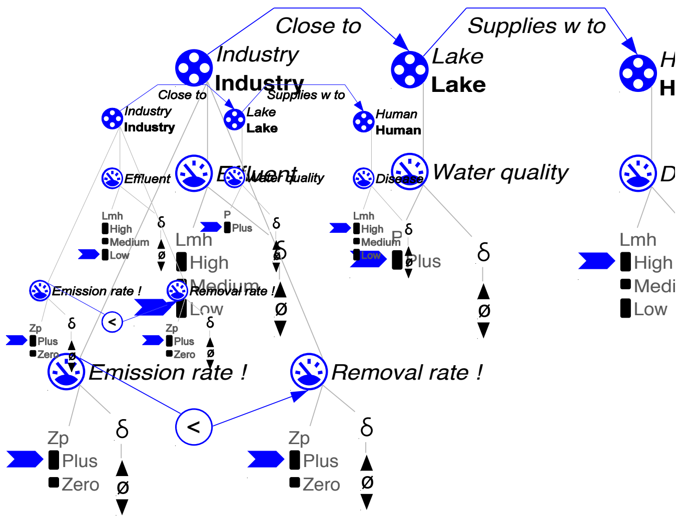


Figure 16: Scenario of a model of DynaLearn use-level 4 showing *Removal rate* greater *Emission rate*.

- *Learning goal 25*: Demonstrate how a greater rate of effluent removal may result in a decrease in the incidence of diseases to decrease.
  [*the learner should run the simulation and get the results and the causal model in order to create an explanation for the results; the representation of both is shown in Fig. 17*].

The learner then could create the following explanation: in state 7 the incidence of disease decreased to the lowest level because the quality of the water was continuously increasing in previous states 2 and 1. And this has happened because the rate of effluent removal was greater than the rate of effluent emission. These changes and the causal relations can be pointed out in the causal model shown in Figure 17.

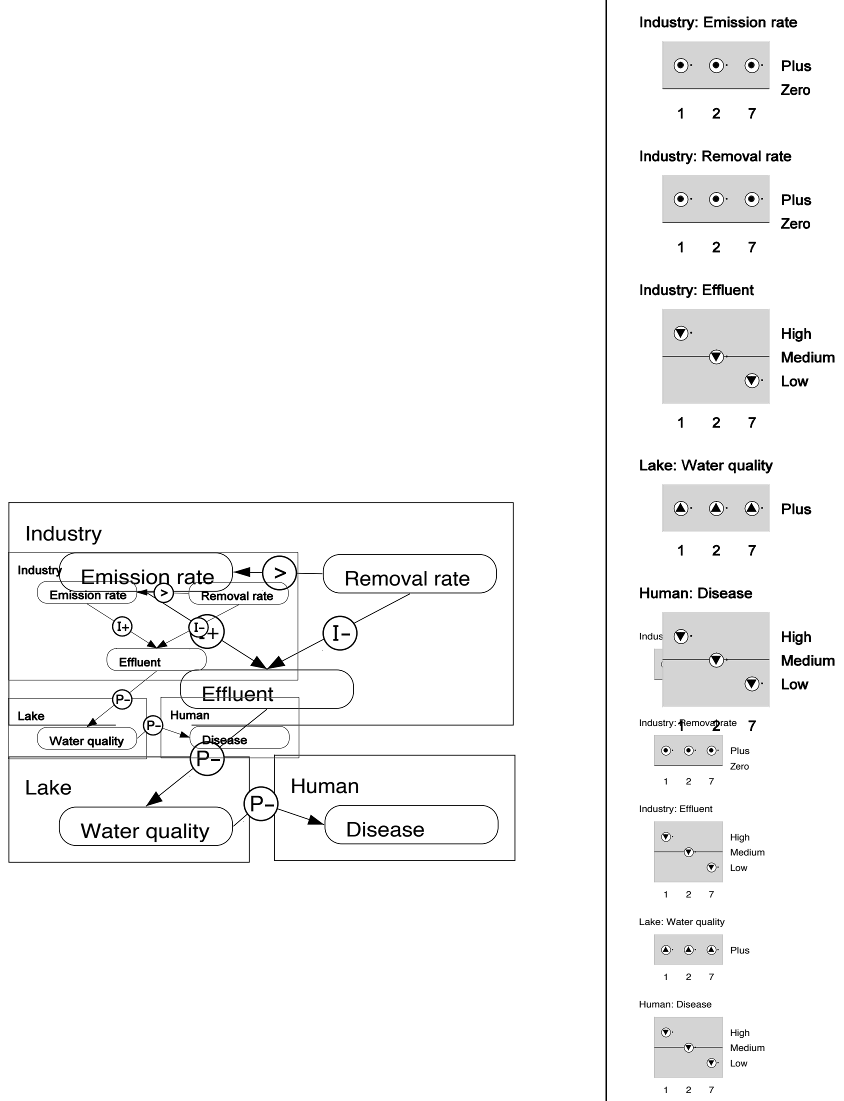


Figure 17: Causal model and value diagrams obtained in a simulation starting with the inequality *Removal rate* greater *Emission rate*.

The other skills not mentioned in this exercise can be developed exploring the communication capability of the learner in the interdisciplinary process. ‘(S9) Elaborating well structured written texts (essays, reports) in which there is thematic progression’ would be achieved with the support of documents found during the project, maybe reporting the sequence of activities developed in the present document. An important skill to be developed is ‘(S8) Formulating and articulating adequate argumentation’, which may be done with the support of models and simulations as discussed above. Details about industrial activities, water quality and diseases could be included to show why the removal of the effluents, before they affect the quality of water, would be a better solution than just treating the water or people ill. Finally, other aspects such as costs and benefits of all the solutions discussed in this effort, and the importance of keeping public health as priority should be included in the texts, in order to show that the learner was (S1 and S10) Judging the adequacy of technical, social, ethical and political options while making decisions.

Appendix II – Pilot study at the Tel-Aviv University

During the 2009/2010 academic semester, a pilot course was administered at the Faculty of Life Sciences in Tel Aviv University. Within the context of an ongoing a Marine Biology course, a 1 point academic credit exercise was designed to elaborate on Marine Biology issues using QR modelling. A group of 10 undergraduate students (third year) attended a 7 lesson (2 hours each) exercise using the Garp3 modelling environment with the purpose of constructing models related to the course syllabus. Two lecturers conducted the exercise by integrating lectures and hands-on practice in the computer lab. The students were also given individual tutoring sessions in addition to the class exercise. The students worked in pairs from the beginning of the exercise. They were asked to choose a scientific paper related to the course syllabus (from an approved list published on the exercise's website). Each pair also spent time building models of their chosen scientific papers as homework during the 7 weeks exercise.

The students attended 6 lessons in which they: (1) built an intuitive concept map representing entities and types of relationships in a given system; (2) learned and used the qualitative modelling language and terminology in its particular instantiation in DynaLearn; (3) defined quantities, their values sets, interrelationships and their character population dynamics; (4) addressed processes, conditions, consequences in dynamic systems (processes such as predation, competition, symbiosis, diving pressure etc.); (5) ran scenarios and analysed the state graphs (identifying problematic cases and conditions); (6) dealt with external agents (such as over-fishing and pollution) and their influence on the system; (7) developed complex models/tailor together existing model fragments into more complex scenarios in the marine environment.

During the 7th meeting each pair presented their scientific paper, QR model and the results of the simulation. Each pair was given 20 minutes to present the background, research hypotheses and assumptions, the model, the scenario and the results. At the end of the course, the students presented their work in a special 2 hours session in front of the Marine Biology class (comprising also students who did not attend the exercise).

A formative evaluation (pilot research) was conducted during the exercise. Each meeting was accompanied by an evaluation task, observational notes, unstructured open-ended interviews, participants' journal and thinking-aloud process. These were conducted to follow and analyse the students' active construction of their models, their ability to interpret given states of a model, their abilities to adapt a model to given data and scenarios or assessing their ability to tailor a model from already existing fragments in accordance with a given environmental phenomena or text. The students also filled in a questionnaire at the end of the exercise.

A preliminary account and key insights from observations on students' learning process and students' questioners and interviews indicate that the students found the "Learning by Modelling" approach engaging and motivating (even if more time consuming than regular classes). Several insights were obtained during the pilot study concerning the students' conceptual understanding, their acquisition of the qualitative modelling language and skills, their ability to move among representations (text, models, report and presentation) while working on a scientific problem. A substantial insight, expressed at the end of the learning cycle by the students, indicated that the modelling experience and the systemic perspective on the scientific topic they were working on, generated the need to integrate several pieces of knowledge from different domains, including knowledge from previous courses that until its use here remained separately "classed" with the corresponding course.

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