Deliverable number:	D6.3
Deliverable title:	DynaLearn curriculum reflection and advancement

Delivery date:	2011/01/31
Submission date:	2011/03/02
Leading beneficiary:	University of Brasilia (UNB)
Status:	Version 06 (Final)
Dissemination level:	PU (public)
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Project number:	231526
Project acronym:	DynaLearn
Project title:	DynaLearn - Engaging and informed tools for learning conceptual system knowledge
Starting date:	February 1st, 2009
Duration:	36 Months
Call identifier:	FP7-ICT-2007-3
Funding scheme:	Collaborative project (STREP)

Abstract

This deliverable presents a reflection and analysis of the material presented in deliverables D6.1 and D6.2-(1-5) in order to refine the curriculum on DynaLearn Environmental sciences and make plans for the refinement of advanced models and for a refined DynaLearn curriculum. This deliverable deals with the following issues: reflection on what has been achieved so far; the refinement of the DynaLearn curriculum in terms of defining goals for structuring domain knowledge in advanced models; defining and planning advanced models in the context of refined curricula; and setting a proposal for the future work being delivered in D6.4 and D6.5.

Internal Review

- Bert Bredeweg, University of Amsterdam (UVA).
- Moshe Leiba, Tel Aviv University (TAU).

Acknowledgements

The main authors would like to thank all the people involved in producing material for this deliverable and the people who contributed to D6.1, D6.2-(1-5) and those who worked on Deliverables from WP7.

Document History

Version	Modification(s)	Date	Author(s)
01	Basic layout and structure	2011-01-5	Richard Noble
02	Collation of first contributions	2011-01-24	R. Noble, A. Zitek, D. Mioduser, R Zuzovsky, P. Borisova, P Salles
03	Zitek comments, Chapter 6 added	2011-01-31	R. Noble, A. Zitek, D. Mioduser, R Zuzovsky, P. Borisova, P Salles
04	Completion of Chapter 7 and edits – sent for internal review	1/2/2011	R. Noble, A. Zitek, D. Mioduser, R Zuzovsky, P. Borisova, P Salles
05	Re-draft and re-structure following review Section 2 and 3 merged, elements of LS section moved to Modelling practice section	18/02/2011	R. Noble, A. Zitek, D. Mioduser, R Zuzovsky, P. Borisova, P Salles
06	Final draft	2/3/2011	R. Noble, A. Zitek, D. Mioduser, R Zuzovsky, P. Borisova, P Salles

Contents

1. Introduction and Objectives

1.1. Objectives

Following the results of the first round of model building and evaluation activities, ongoing studies about relevant issues of environmental systems and further development of conceptual models, the aim of Task 6.4 of the DynaLearn project is to develop more advanced content and models for the repository and the curriculum in Environmental Science. A careful analysis of the material presented in deliverables D6.1 (Salles *et al.*, 2009) and D6.2-(1-5) (Salles *et al.*, 2010; Noble 2010; Borisova *et al.*, 2010; Zurel *et al.*, 2010; Zitek *et al.*, 2010) was required in order to refine best practice of model building in the different Learning Spaces to convey key principles of Environmental Science. The results of this work are the reviews and plans presented here to facilitate the development of advanced topics and models, and further develop the curriculum.

Following the requirement of developing advanced topics and models this deliverable has the following objectives:

- Reflect on what has been done so far – modelling outputs; coverage of environmental science curricula; Learning Space (LS) issues and opportunities; commonalities in modelling approach.
- Refine the terms of reference for advanced topics and models in the context of the refined curricula.
- Setting a proposal for the future work being delivered in D6.4 and D6.5.

The key aim of D6.3 was a structured reflection on the DynaLearn curricula, the basic models delivered to the repository and the outputs of the evaluation activities to provide context for the development of plans for development of advanced topics and models. In this context the focus of the review and plans are on the following issues:

1. Approaches to re-defining content or setting models within existing curricula to make best use of the qualitative systems modelling approach.
2. Reviewing the coverage of basic and advanced topics from the curriculum (D6.1, Salles *et al.* 2009) in the repository of models.
3. How were the different Learning Spaces used for the basic topics and models?
4. What are the opportunities and limitations for modelling (and learning activities) in the different Learning Spaces?
5. What is required to develop good modelling practice in each of these Learning Spaces and harmonise model building approaches with any functional requirements of the semantic and virtual character technologies?
6. Given the outcome of this review what is required to re-frame the DynaLearn approach to Environmental Science curricula in Task 6.5?

1.2. Methodology

As part of the internal quality assurance process and the defined activities for D6.3 the models delivered in D6.2-(1-5) were reviewed using a common framework (Appendix A). The models were assigned between WP6 and WP7 partners for review and reports compiled for each model (Appendix B). The internal review of the model was used to primarily to identify any issues in the submitted models that could be improved but also acted to provide important information on the approaches and modelling patterns the different partners used. Information on the different modelling approaches, patterns and modelling issues serve as important input for the development of more advanced contents and model that will be produced in Task 6.4 (T6.4). A careful analysis of the content and model material was undertaken to help refine the curriculum on DynaLearn Environmental sciences. The review presented here is mainly used to clarify the extent to which the basic models were fulfilling the requirements of being:

- scientifically valid;
- insightful in representation;
- based on clear decisions;
- justified in the choice and use of the features of different Learning Spaces.

The review of modelling patterns and opportunities in the different Learning Spaces is also used to focus good modelling practice towards defining and delivering advanced topics and models.

From this review partners were allocated subjects related to the six main aims of D6.3 (Section 1.1). Meta-analyses of D6.1 and D6.2-(1-5) were undertaken using the following approaches:

1. **Re-defining content or setting models with existing curricula.** The deliverables were analysed for the clarity of modelling decisions and situated perspectives in terms of grounding models within local curricula requirements. In addition the approach to framing individual models (or suites of models) was analysed in the context of explaining individual phenomena, presenting different perspectives on a single curricula topic or exploring a progression of the concepts involved.
2. **Reviewing the coverage of basic and advanced topics from the curriculum.** A meta-analysis of the models was undertaken to identify the extent to which basic concepts were well described and which topics should be considered as advanced and will require further development in T6.4.
3. **Use of different Learning Spaces.** A meta-analysis of models in each Learning Space was undertaken to identify how modellers had utilised the different levels of functionality in their models. This was especially important for the lower Learning Spaces which constituted a new approach even for expert qualitative modellers. Each partner was assigned a Learning Space to review.
4. **Opportunities and limitations in the different Learning Spaces**. Following the meta-analysis for (3) a review of the appropriate use of each Learning Space was made, identify good modelling practice for further model development and for improvement/refinement of existing models.
5. **Development of good modelling practice.** Following (4) guidelines were prepared through discussion for good modelling practice across all Learning Spaces. In particular consideration

was given to the influence of modelling approaches to the utilisation of expert model information by the semantic and virtual character technologies.

6. **Refinement of the DynaLearn approach to Environmental Science curricula.** Outcomes of the model review and meta-analysis were evaluated in context with the outcomes of the WF7 evaluation activities to identify issues for development in the DynaLearn curricula (T6.5) and future evaluation requirements (T7.3).

1.3. D6.3 contents and structure

The following sections of this deliverable comprise reviews of the progress made so far in the development of basic topics and models (Section 2.1), their internal evaluation (Section 1.2 for methods and Section 3 for outcomes) and the approaches that were used to re-frame the topics or set the topics and models within existing curricula (Section 2.2). Section 3 focuses on the outcomes of the internal model review in the context of the different Learning Spaces of the DynaLearn software and their application to explaining different domain phenomena. For each Learning Space a review of current modelling patterns and opportunities is given along with suggestions for future modelling practice towards the definition of advanced models.

Section 4 considers the importance of model structure and good modelling practice in the context of the requirement to optimise the interaction between content models and the virtual characters and support the semantic feedback technology. Suggestions are made for the development of good modelling practice to optimise these technologies.

Section 5 re-focuses on the DynaLearn curricula and serves to re-define plans for modelling activities in T6.4 in terms of structuring domain knowledge and defining modelling goals for models to represent advanced topics. These plans are presented in Section 6.

2. Review of models developed for Deliverables 6.2-(1-5)

2.1. Summary of models and curriculum

In total 173 models were delivered as part of T6.2 basic topics and models (Table 1). These models covered 61 of the main topics defined in D6.1 (Salles *et al.*, 2009) across the seven DynaLearn themes in Environmental Science. For some of these main topics models were created to explore different concepts or sub-topics. In general the majority of the modelling effort focused on models built in LS2 (basic causal models) and LS4 (causal differentiation models). The low number of models developed in LS5 (conditional knowledge models) was due to technological problems of implementing this Learning Space within the software.

Table 1 Summary of the topics and models delivered in D6.2-(1-5) per theme in the DynaLearn curriculum (D6.1) and per Learning Space in the DynaLearn software.

D6.1 Theme	**Topics**	**Sub-topics / concepts**	**Number of models**					
			LS1	**LS2**	**LS3**	**LS4**	**LS5**	**LS6**
Earth Systems & Resources	9	15	4	5	3	7	1	7
The Living World	10	16	7	13	6	8	1	6
Human Population	10	15	9	3	2	5	1	5
Land and Water Use	11	15	4	6	4	6	2	4
Energy Resources & Consumption	5	7	2	4	3	3	0	0
Pollution	7	8	4	7	5	4	0	3
Global changes	9	11	2	6	2	6	0	3
Total	**61**	**87**	**32**	**44**	**25**	**39**	**5**	**28**

2.2. Setting of models within domain topics and curricula

Implementation of topics as basic conceptual models followed three main approaches in Deliverables D6.2.-(1-5) (see table in Appendix B):

1) Individual model expressions (LS2-4) or models (LS5-6) capturing a **single phenomena** in the Learning Space most appropriate for conveying the systems concept contained in the topic.

2) A suite of model expressions that represent a range of **perspectives** or concepts contained within a topic. For example, the suite of expressions/models may express fundamental

knowledge together with expressions that then implement the fundamental knowledge within specific contexts.

3) A suite of model expressions that form a **progression** of implementation of a single topic through each Learning Space, making progressive use of the new primitives that become available to build up detail of particular phenomena. For example, LS2 expressions are used to represent structure, LS3 to represent qualitative states and LS4 to implement processes.

The selection of the first set of basic models for the curriculum in general followed different approaches mainly related to the local settings and integration of the modelling activity into current curricula. From an educational perspective the models served three main goals:

(1) expressing clear explanations of domain knowledge (there was a clear focus on integrating the most relevant entities and processes of a specific topic into the model; generally **single phenomena**).

(2) serving as examples to introduce specific software features to represent the world (simple example models showing increasingly the new features of each Learning Space - **progression**).

(3) building up transferable modelling skills (it was tried to identify generic modelling patterns, that could be transferred between domains – **progression and perspectives**).

For example, FUB's models (D6.2.1; Salles *et al.*, 2010) in many cases are built in different Learning Spaces showing a clear progression of ideas in different Learning Spaces. This makes it easy to understand which features are added for which reason to the model along the increasing capabilities of DynaLearn. However, clearly identifiable re-usable patterns are rare.

UH model building activity (D6.2.2; Noble, 2010) was guided by A-level curricula for Biology, Geography and Environmental Science in the UK. These were considered as the appropriate level to focus the topics and model content and goals for the models were mostly defined using literature and texts associated with A-level guides and text books aimed at this level. The models greatly differ in complexity, some serving clear and insightful representations of the systems, some being complex expert models. UH modelling activity was closely associated with local environmental science curricula.

IBER (D6.2.3; Borisova *et al.*, 2010) also built their models based on literature review serving as the basis for developing model concepts and goals. However, the focus was also towards the comprehensive representation of the topic, and models serving as examples for introducing principles were rare. In many cases there was no clear decision identifiable, why certain Learning Spaces were chosen to represent a model. Model topics were treated at different Learning Spaces, with a focus on LS6, with the clear aim of running simulations following "what if" questions.

At TAU (D6.2.4; Zurel *et al.*, 2010) models were mainly based on single scientific papers, which gave a complete framework for selecting the relevant entities and processes, but also supporting the development of different scenarios that were beyond the scope of the paper. Clear re-usable modelling patterns are not easy to identify, as the focus was on the reflection of the content of the paper in the model.

At BOKU, (D6.2.5; Zitek *et al.*, 2010) a comprehensive review of the existing University curriculum on Applied River Management and additional relevant literature was conducted, and the main scientific issues to be modelled were selected. Then the most relevant processes and entities were identified to be represented in the models. The models served mainly two aims:

(1) the introduction of an important domain specific principle or viewpoint;

(2) the introduction of generic, re-usable patterns of model building, and hence structuring the world following a systems dynamics perspective.

Goals of the models were clearly distinguished in content related issues, and also in modelling issues; many models intentionally tried to introduce specific features of each Learning Space hence trying to align the content delivered with the specific capabilities of each Learning Space to represent environmental issues. However, some models need further re-thinking and re-structuring following the internal reviews, mainly from a content point of view. So far LS6 models have not been created for these topics, although advanced models for these topics will utilise this Learning Space.

The meta-analysis of topics and models highlighted that both basic and advanced topics have been addressed in T6.2. These cover both fundamental concepts in biology/ecology as well as topics that can be seen as foundations of environmental sciences.

Table 2 Example topics and models that can be seen as basic (fundamental topics), advanced fundamentals (in environmental science) or advanced integrative (treating complex or integrated systems).

Category	**Topics/models**
Basic fundamentals (Key Processes and Concepts)	Evolution Photosynthesis Cellular respiration Diffusion and Osmosis Reproductive strategies Biodiversity Aerobic and Anaerobic respiration Populations
Advanced fundamentals (Integrated processes and environmental systems)	Biomagnification Eutrophication Nutrient cycles Adaption to environmental stress Climate change Natural processes forming riverine habitats The River Continuum concept Food webs and energy flows
Advanced integrative (Human environment interactions)	Ecosystem services Fishery Consumerism Reduce, re-use, recycle Land use and conflicts Diving pressure Integrated plans for management of catchments

The topics delivered in D6.2-(1-5) can be characterised according to their position within a curriculum for Environmental Science. The basic topic examples in Table 2 are those that can be seen as fundamental concepts/processes in biology/ecology that need to be understood as they are the foundations upon which explanations of more complex phenomena are formed. Typically these topics are taught within Biology curricula. The advanced fundamental examples shown in Table 2 are those that form the fundamentals of ecology and environmental sciences, integrating the basic concepts to explain how natural systems work. The advance integrative topic examples are those that generally deal with social, environmental and economic aspects of human-environment relationships including resource use and environmental management. These advanced integrative topics merge fundamental concepts from a range of different perspectives. This is one of the strengths of qualitative conceptual modelling, that models can be constructed across different domains (e.g. social, economic and ecological).

Meta-analysis of D6.2-(1-5) identified examples of the fundamental themes/patterns covered by the models at different hierarchical levels and domains in environmental systems so far.

- Equilibrium – competing influences, balancing feedback loops
- Environmental cycling
- Non-linear dynamics
  - positive/re-enforcing feedback loops
  - conditional knowledge
- Population dynamics and interactions
- Human environment interactions – resource use and management

Examples of models that fit these fundamental themes/patterns are shown in Table 3. Models and topics can and often do sit across multiple themes and make re-use of fundamental patterns. For, example Fishery (Noble 2010, D6.2.2) represents logistic population growth, a fundamental concept of population growth, but also applies this pattern to themes related to human resource use and the concept of maximum sustainable yield. This is one of the strengths of qualitative modelling, especially in LS6 where generic knowledge can be re-used and applied to specific scenarios. This is a feature that needs to be exploited in advanced topics and models.

From this review it can be concluded that conceptual models can be situated and grounded with topic-based curricula using different approaches. However, irrespective of the approach used the strength of the conceptual approach requires that the model contains concise explanations of scientifically proven core knowledge accompanied by transparent modelling decisions. This requires that expert models, especially advanced models, need to be situated in this re-framed approach to delivering model content and domain concepts. Whilst conceptual models can be applied to support existing curricula and perspectives the re-framing of whole curricula from a systems-based approach should have the greatest impact. This approach should be applied to the development of all advanced models.

Table 3 Example topics and models that can be seen to be based on fundamental themes/patterns in environmental systems.

Concept	**Topics/models**
Equilibrium or System (in)balances Competing influences and/or balancing feedbacks	Diffusion and osmosis Meta-populations Sediment balance Homeostasis (Adaption to environmental stress) Climate change Control circuit (Catchment management)
Environmental cycling	Nutrient cycles Decomposition Water cycle
Non-linear dynamics a) Positive/re-enforcing feedbacks b) Conditional knowledge	Exponential Population growth Flooding Fishery
Population dynamics and interactions	Introduction of non-native species Meta-populations Biomagnifications Decomposition Biodiversity Competition for space Symbiosis Populations Food webs and energy flows
Human environment interactions Resource use and management	Ecosystem services Nutrient cycles Reduce, re-use, recycle Fishery Fossil fuel Hydropower generation

3. Learning Spaces: modelling results and opportunities

3.1. Learning Spaces – summary of opportunities

The purpose of the first phase of modelling (T6.2) was to deliver a set of basic topics and models. These basic topics and models explore important concepts in environmental science in the form of simple models that utilise the different opportunities available in the new Learning Spaces of the prototype DynaLearn workbench. These Learning Spaces are designed to handle different levels of complexity and focus on different types of modelling. Each of these Learning Spaces provides different opportunities for exploring and representing conceptual knowledge. The basic topics and models delivered in D6.2-(1-5) served three purposes:

- explore and test the capabilities of the new modelling software and the Learning Spaces;
- provide a resource of models to for use by (and testing of) the semantic and virtual character technologies;
- provide a resource on which evaluation activities could be developed.

The following sections review the use of each Learning Space in T6.2, the opportunities and limitations of each Learning Space and presents ideas for optimising good modelling practice within each Learning Space. Links are also made with the outcomes of some of the evaluation activities that utilised the different Learning Spaces.

3.2. Learning Spaces – Progression of concepts in model expressions

DynaLearn can be seen either as a suite of independent modelling environments of different complexity suited for modelling different phenomena, or as a sequence of Learning Spaces where the modeller can develop representations of a concept with increasing complexity and detail, using a step by step approach. The second, progressive, option is considered in this section. For the sake of clarity each Learning Space is seen as an environment where an increasing number of modelling elements is available, so model expressions built in the previous Learning Space can be further improved and become more complex.

LS1 - Concept map is seen as a starter for the modelling process: the modeller organises initial ideas and defines the limits of the systems limits, a condition for specification of what should be included in the model. To move from the expression of initial concepts in LS1 into a better description of the system structure, LS2 requires the formal definition of system structure using entities, quantities and configurations. Having defined the system structure, the modeller then formalises the causal relations between quantities, the initial steps for building the chain of dependencies that will result/ explain/ generate/ simulate the system behaviour.

Advancing from LS1, modelling in LS2 requires:

- Refining the knowledge representation to an explicit and consistent model of the physical system using a formal vocabulary.
- The addition of dynamics to the system represented (expression of basic causal relations)

LS2 provides a basis on which to define the causality flow that determines the basic system behaviour. The result of modelling in LS2 is, in fact, the description of one state of behaviour of the system. Paradoxically, the behaviour obtained in a simulation in LS2 describes a state of transformation – potentially all the quantities are changing, as their qualitative values are derivative values = {decreasing, stable, increasing} or, technically speaking, {negative, zero, positive}. In this context models in Learning Space do not represent information about processes.

Advancing from LS2 to LS3 allows integration of knowledge and concepts pertaining to:

- Changes in the magnitude value of quantities in a simulated behaviour.
- Distinctions of qualitative states that are important in the system (and therefore landmarks/thresholds between them) and which states co-occur for individual quantities.
- Expression of sequences of behaviour (representing time passing) during qualitative simulation.

Although LS2 creates the notion of a state and behaviours and LS3 materialises the notion of state change and state transition, creating a representation for time, there are three main concepts that would necessitate the transition to representations at LS4:

- Representation of processes as the cause of the behaviour (competing processes/rates etc.)
- Representation of changes from unbalanced to balanced situations in the system behaviour.
- Description of situations in which the consequences of changes motivated by the initial cause of change feed back into the same initial causes, controlling the system.

In Learning Space (LS4) models the system structure is well defined (with relevant entities and configurations), the basis for the system behaviour is also implemented and with influences and proportionalities are defined to represent processes, causes and effects of change. The wealth of modelling at LS4 and the broad set of possibilities for representing knowledge that is at the basis of the systems thinking may be sufficient to represent specific ideas or general behavioural concepts. However, LS5 models allow addressing the following concepts:

- Phenomena that require specific conditions to happen / situations in which specific conditions of the system enable specific changes to happen.
- Representation of alternative outcomes for specific situations the system can be found in. The basic definition of scenarios and simulations in which specific knowledge could be replaced by alternative features that may determine different system behaviour (including modelling assumptions, conditional knowledge and deductive reasoning).

In representations of complex phenomena the modeller may face the situation where specific quantities, processes or sub-systems reappear in the system, so that the same knowledge has to be repeated in the model (for example a model about three populations would the processes of natality and mortality to be represented three times). The hierarchy and inheritance features in LS6 together with the use of the compositional approach of model fragments mean that in this Learning Space generic knowledge can be reused and the combined with the pieces of knowledge to address specific scenarios and situations. Advancing models in LS6 address three main questions:

- How to optimise the modelling / representational apparatus so that specific sub-systems or model elements can be reused in the same (or new) model?

- How to create a mechanism so that pieces of different models could be combined into a single model (how to compose models and create simulations that put together fragments/ elements)?

- How to control the level of details to be included in different views of the same system, by creating different simulations of the same model or alternative models using the same basic knowledge?

Therefore LS6 follows a different modelling approach – the so called 'compositional modelling' forming a solution of combining components of generic knowledge and applying them to specific situations (Falkenhainer & Forbus, 1991). In this context it is important to make a distinction between knowledge about generic facts and case specific instantiations of such knowledge (Bredeweg and Salles, 2009). Each model fragment shall represent fundamental knowledge ('first principles'), independent of any context created by the use, so that this fragment can be used across different systems within the domain knowledge. In this way, the set of fragments in a model "library" captures generic facts for a certain domain, which in principle applies to a wide range of systems within that domain.

Whilst in LS5 models, conditions for behaviour are usually defined by the use of inequalities, in LS6 all the components (entities, configurations, correspondences, quantities, quantity values, inequalities) can be used to define conditions and to specify consequences. Finally, LS6 introduces a powerful way to represent knowledge: the possibility to create hierarchies of entities and agents, model fragments and assumptions, further exploring the compositional modelling approach. In this approach, knowledge that is defined for entities represented above in the hierarchy tree ("parent" entities) are inherited by entities that are represented below. For example, if the modeller defines an entity 'Tree' and specifies (in a model fragment) that trees have chlorophyll, and further defines that mahogany is a type of tree (introducing 'Mahogany' as a type of 'Tree' in the entity hierarchy), then DynaLearn assumes that Mahogany also has chlorophyll. Similarly, hierarchically related assumptions may be used to introduce specification or generalization of conditional knowledge; and model fragments may have 'children', and inherit the knowledge represented in the parent fragment.

In LS6 a scenario captures information about the structure a specific system and thus may be used to start a simulation and instantiate generic knowledge. The DynaLearn reasoning engine searches the library of model fragments that apply to the conditions described in the scenario, applies them, and, in doing so, composes a full simulation of possible behaviour(s). In an iterative process, the reasoning engine creates a sequence of qualitative states that will describe the behaviour of the system under the initial conditions established in the scenario until no more changes are possible. Each state is thus an instantiation of (a subset of) the generic knowledge as far as that knowledge turned out relevant for the system specified in the scenario, and the system behaviour.

Compositional modelling brings flexibility to model building. Model fragments can be instantiated within the same library and reused (simultaneously) in different models. This approach makes it possible for different views on the same phenomenon, sometimes even contradictory views, to coexist in the same library. It is also possible to create models that explore parts of the system, and this way progressively increases the complexity of models and simulations.

3.3. LS1 – Concept mapping

3.3.1. Domain concepts and modelling patterns

Ecological systems are characterized by diversity, heterogeneity and complexity. Complexity often results from nonlinear interactions among a large number of system components which frequently lead to emergent properties, unexpected dynamics and characteristics of self-organization. Understanding complex environmental systems requires modellers to identify and see the connections between multiple components. In that sense the use of concept maps has been suggested as powerful technique for representing the structure of a complex phenomenon or system (Novak, 1991). Concept maps are two-dimensional, node-link, diagrams that depict the most important entities and processes within a system domain. The procedure of concept mapping starts with the generation of a list of concepts. Connecting lines are drawn between these concepts to indicate interrelationships. Labels along the connecting lines further explain the interrelationships between concepts completing the knowledge structure. This tool could then be used as the first step towards the modelling of more complex aspects of the system.

In DynaLearn, the task of concept map drawing is the very first stage of modelling, i.e., representing the static configuration and elements in the system. In D6.2-(1-5) expert modellers used concept maps in LS1 to collate and represent all the concepts that could be important within each specific topic listed in D6.1 (for example Figure 1, Noble 2010). This activity also served to collate the concepts that were deemed to be important in relation to existing curricula in different settings. Therefore, LS1 maps should be used to frame the curricula context for all basic and advanced models.

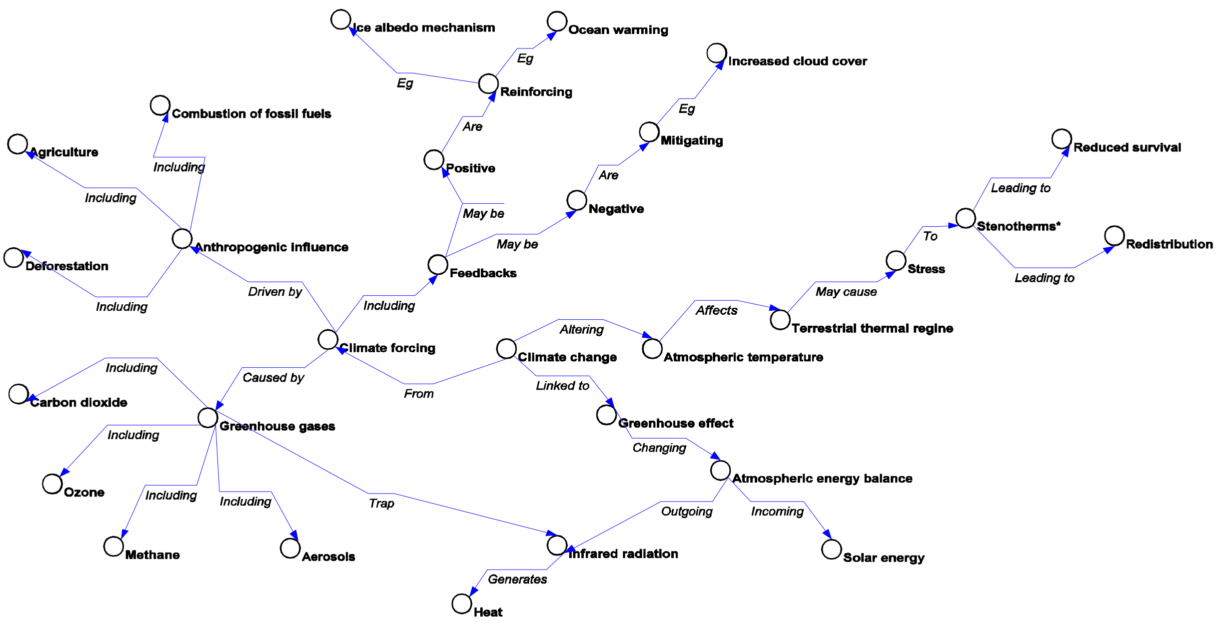


Figure 1 Concept map for Climate Change LS1.hgp built in the concept Learning Space of the DynaLearn platform (D6.2.2; Noble, 2010).

3.3.2. Issues identified for resolution in T6.4

Whilst concept mapping is not a dynamic form of conceptual modelling it serves a very useful purpose of collating and formulating ideas and identification of system concepts. As such this is a Learning Space which can potentially contribute towards focusing modelling in all other Learning Spaces. Therefore, LS1 concept maps should be produced for all advanced topics and models as a way of representing the context and setting of the model expression or concept within a topic. Despite the strength of LS1 maps for formulating ideas and their inclusion within the deliverables and repository, their status and use as repository models remains unclear. During T6.4 the importance and potential use of LS1 concept maps in the repository (for generating feedback or directing navigation through the curricula) should be explored and defined.

3.4. LS2 – Basic causal models

3.4.1. Domain concepts and modelling patterns

Learning Space 2 (LS2) was one of the most widely used Learning Spaces for creating basic models for most of the curricula topics. Learning Space 2 allows modellers to create basic causal models and to represent an overall picture of the cause-effect relationships governing the behaviour of a system. The main focus of this level is the representation of causal knowledge through causal relationships that can be placed between quantities. Furthermore, LS2 shows how the quantities change and how those changes cause other quantities to change. There are two types of causal dependencies in this Learning Space: [+] and [–], that propagate changes between quantities (Bredeweg *et al*., 2010). The direction of change that is calculated for each quantity can be either decreasing, steady, increasing, ambiguous (due to opposing influences), or unknown (when missing information).

The use of the basic causal modelling provides an opportunity for the formalization of the model expressions, moving beyond concept maps. This formalized expression forms a structured diagram of concepts which can potentially be more elaborate than models in other Learning Spaces. This Learning Space enables representations of structural configurations and relationships. As such there is potential for a modeller to move from models with only a few entities and quantities to an elaborate diagram with numerous concept involved. The review of LS2 models produced in D6.2-(1-5) indicated that modellers exhibited a range of approaches to using LS2:

- simple linear causal expressions (Erosion, Deforestation D6.2.1; Community diversity basic, D6.2.2);
- concise diagrams with a small number of integrated causal paths (Wind power, D6.2.1);
- elaborate diagrammatic representations of causal webs (Decomposition basic, Carbon cycle D6.2.2).

Since LS2 models contain no notion of processes causing change in systems, they are best used to represent the effects of processes on systems behaviour without representing a causal argument as to why it is changing. That is, LS2 models capture the propagation of defined changes through a system. Given that most environmental systems are based around interacting processes the development of good LS2 models requires careful planning and nomenclature such that the description of behaviour is correct. One example of this requirement can be seen in the LS2 basic models for Photosynthesis and Respiration (D6.2.2, Noble 2010) where despite the focus being on process based phenomena the model expressions capture an explanation of the effects of increasing or decreasing rates of the phenomena without requiring causal differentiation (as is usually required when modelling with rate quantities). This was achieved by careful selection of the quantities, referring to the “production” and “consumption” of oxygen and carbon dioxide rather than the “amount” (Figure 2). In this way the semantics of the effects of increasing, decreasing or steady rates of photosynthesis are correct (increasing, decreasing or steady “production” of oxygen respectively rather than the incorrect statement of a “steady” rate of photosynthesis resulting in a steady amount of oxygen). This pattern of modelling (careful use of quantity names to reflect amounts of change rather than absolute amounts and clear focus on the effects of change rather than the initial cause of change) also translated well into some of the larger LS2 models that represented large systems (Decomposition basic LS2 and Climate change LS2, D6.2.2; River continuum concept models D6.2.5).

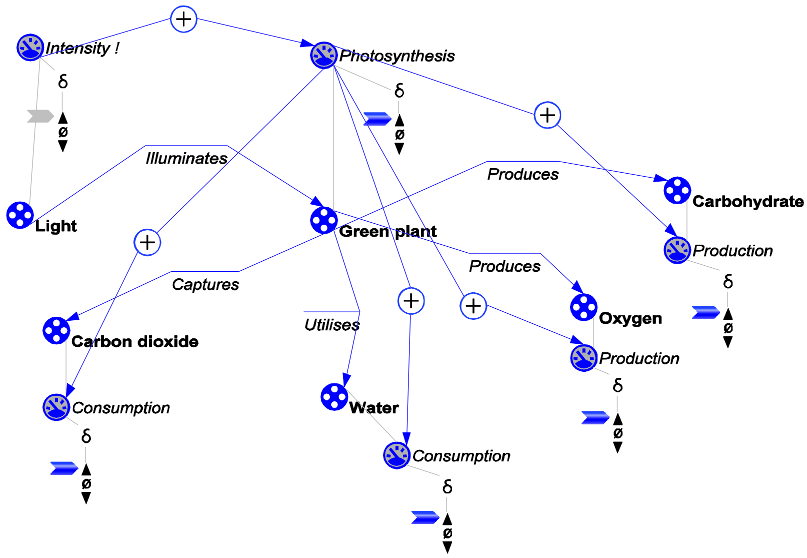


Figure 2 The Photosynthesis basic LS2 model expression (Noble 2010) highlighting how LS2 models can be concise and present consistent information about behaviour relating to processes in the absence of causal differentiation for expressing causality of processes. In this example this is achieved using careful nomenclature to describe the effects of processes.

3.4.2. Issues identified for resolution in T6.4

The development of good models using the basic notions of causality in LS2 is not straightforward, as the specific representation of the positive and negative relations as proportionalities means that only specific causal ideas can actually be correctly represented and simulated in this Learning Space. This has implications for the expert models created in this Learning Space. Indeed development of domain ideas within this Learning Space proved difficult for all partners. The models submitted in D6.2-(1-5) highlight three key issues faced when building model expressions in LS2:

1) LS2 models are not designed to express notions of processes (quantities equivalent to rates requiring the use of influences in LS4 and above), however many LS2 models contained notions of processes.

2) LS2 models are not designed to simulate notions of systems containing feedback loops (for which the notions of processes, rates and influences are require), however many LS2 models contained feedback loop structure.

3) LS2 models were often used as extensive diagrams representing the structure of large complex systems

These three issues identify that domain ideas for LS2 expressions are still under-developed. Generally, the first two issues result in model expressions that would not simulate correctly, either as a result of ambiguity from representations of negative feedback loops or from expressions related to processes that would require causality using direct influences to express. The first issue can be overcome with careful use of nomenclature and selection of quantities such that the effects of processes can be described without presenting their causality. However, the second issue cannot be resolved at LS2. Furthermore, it was apparent that models, acting as extensive representations of large systems, with numerous entities and quantities, rapidly become difficult to simulate in this Learning Space. This is especially the case where the model is not purely linear in its reasoning (D6.2.2; Noble, 2010).

Feedback mechanisms are common occurrence in natural processes. Such processes have a non-linear form of causality. For example, the natality rate of a population does not uniformly increase the size of the population. Instead, the process may become more or less powerful when the size of the population increases depending on the type of population growth being represented. A loop of the simple causal relationships ([+] and [-]) is the only vocabulary available to represent such a pattern in LS2 and LS3. However, whilst these positive and negative relations can be viewed in a general sense, without specific indication of the nature of these relationships, the [+] and [-] are reasoned specifically as proportionalities. If there is a loop of proportionalities (A – P+→ B and B – P+→ A), by default it not possible to calculate the derivative of either quantity. The reason is that to calculate the derivative of a quantity that is affected by proportionalities, the derivatives of the quantities from which those proportionalities originate have to be known. In the simple example above, the derivative of A is needed to calculate B, and to calculate the derivative of B we need A. Additionally a loop which had a basic form of (A – [+]→ B and B – [-] → A) (negative feedback) would result in inconsistency in the causal reasoning (A cannot both be simultaneously increasing and decreasing). In QR models the concept of feedbacks needs to be represented through a positive influence (I+) from *Natality* to the *Size of the population*, and a proportionality (P+ or P-) from the *Size of the population* to the *Natality*. A feedback mechanism occurs when a process has an effect that propagates back to itself. There are many examples of feedback loops in environmental science topics. As feedback mechanisms require both influences and proportionalities, they can, and should, only be expressed in LS4 and above. LS2 should only be used by experts to express appropriate behavioural phenomena.

3.5. LS3 – Basic causal models with quantity spaces

3.5.1. Domain concepts and modelling patterns

Learning Space 3 (LS3) introduces the concepts of qualitative states to simulations. In this context it requires the modeller to identify important states or situations in a concept. The modelling toolbox introduces two new ingredients, the quantity space (magnitude information in addition to derivative information) and correspondences. These ingredients represent notions of qualitative states and the relationship/co-occurrence of these states. The evaluation of LS3 models here thus focuses on the definition of quantity spaces and use of correspondences in modelling.

In this context LS3 allows for models to focus on developing qualitative state information for only the key quantities (retaining only derivative information for the other quantities). Again, following the objectives of LS2 and LS3, models represent the effects of change, rather than the causes, on the state of the system being modelled. Perhaps the best examples of this in LS3 models are in *Photosynthesis biochemistry LS3* and *Fitness LS3* (D6.2.2, Noble 2010). In *Photosynthesis biochemistry LS3* minimum quantity space variation is used to consider the concept of a "zero" point, which is what happens when the rate of the light-dependent photosynthesis process is zero? This then translates into zero production and consumptions of the biochemical metabolites. In *Fitness LS3* the frequency of occurrence of positive and negative traits in a population is considered using an expanded quantity space (zero, low, medium, high, all) and an inverse correspondence denotes that when the frequency of one trait is high then the other trait must have a low frequency (Figure 3).

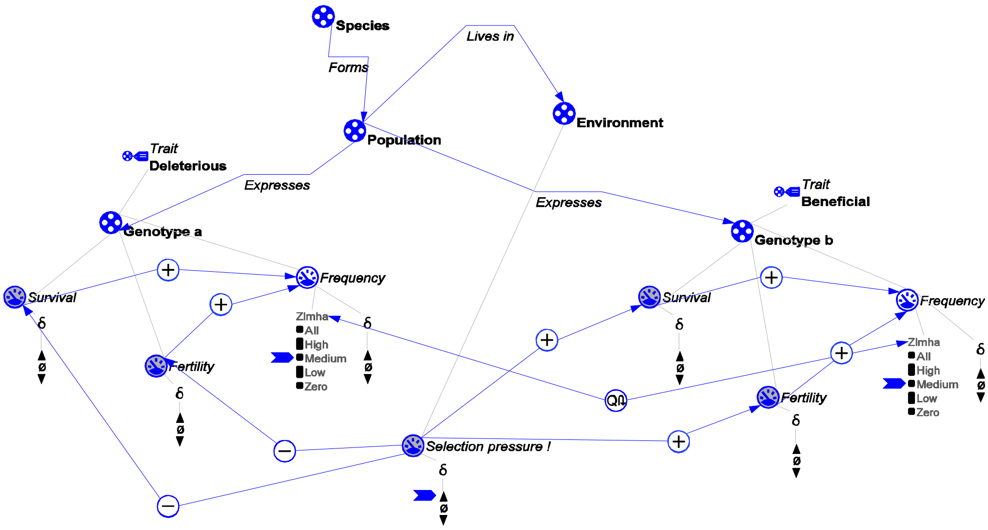


Figure 3 The Fitness LS3 model expression (Noble 2010) highlighting how LS3 models can be concise and present consistent information about quantity spaces and qualitative states for a restricted subset of quantities. In this example an inverse correspondence is also used to define the relationship between the states.

Examples of models introducing important qualitative states to models in LS3 are rare, most models where this information was used were found in LS4 or LS5, using the important landmark values in relation to triggering processes or defining conditional knowledge. LS3 was mostly used to introduce semi-quantitative information about the relative size of quantities and the concept of state graphs within simulation results to visually represent behaviours relating to changes in magnitude (e.g. *Biomagnification* (Figure 4), *Lake Pollution*, Salles *et al.* 2010; D6.2.1).

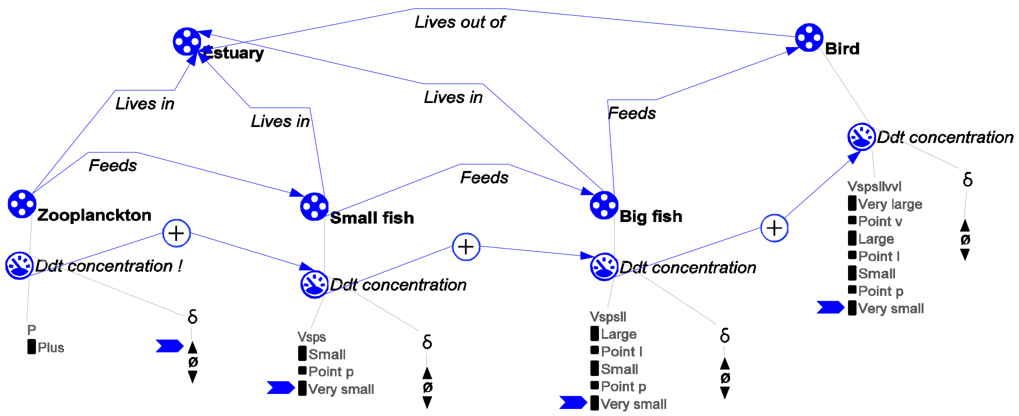


Figure 4 The Biomagnification LS3 model expression (Salles *et al.* 2010) highlighting how LS3 models can be used to develop concepts of a semi-quantitative nature and to generate visual representations of magnitude changes in state graphs.

3.5.2. Issues identified for resolution in T6.4

The summary of the evaluation of models in all applicable Learning Spaces from Deliverables D6.2-(1-5) indicates that in general quantity spaces and qualitative states are loosely chosen (e.g. Low, Medium, High etc.), such as they are not focused on representing qualitatively unique states but are aimed to visualise behaviours in the state graph view of a simulation. Furthermore, correspondences are often not implemented alongside them (Table 4). In addition to under development of quantity spaces there were occasional errors in the specification of point or interval values. Development of insightful quantity spaces, qualitative states and correspondences should be the focus of all models in LS3 and thus good modelling practice needs to be developed.

Table 4 Summary of the use of quantity spaces and correspondences used in D6.2-(1-5) models in LS3 to LS6. Quantity spaces are categorised in terms of the development of specific qualitative states in the model.

Number of models	LS3	LS4	LS5	LS6
Vague or non-specific QS	18	31	2	24
Specific QS (Distinct qualitative states)	4	10	3	4
Point/interval errors	3	5	1	0
Use correspondences on vague or non-specific QS	4	22	2	19
Use correspondences on specific QS	3	8	3	3

3.6. LS4 – Causal differentiation models

3.6.1. Domain concepts and modelling patterns

LS4 is the first Learning Space in which processes can be modelled. As such, LS4 models should be used to make concise expressions of the process that are most important to a topic/concept. Such LS4 expressions, when understood deeply, would form a central basis for other processes that could be added in same 'modelling pattern' to build up a bigger systems view (such as in LS6). Therefore, Learning Space 4 (LS4) was mainly used to make use of the differentiation between rates and state variables in more complex and realistic system representations.

One other main element in LS4 is the possibility to create feedback loops allowing for the implementation of the idea of re-enforcing or balancing feedback behaviours e.g. exponential growth and equilibrium. Furthermore, (in)-equality statements are available for the first time. In this context the minus calculus is also a very important feature of LS4 allowing modellers to calculate the difference between two quantities allowing for the calculation of positive and negative rates which are triggering the changes in state variables. Rates are the reasons for change, whereas the change propagates through the system by proportionalities. These elements can be seen as equivalent to 'stocks' and 'flows' of typical system dynamics models.

Given this, the strength in representations using LS4 probably lies in representing concepts that relate to systems characterised by competing processes, equilibrium and simple feedbacks. These characteristic patterns can be seen in a range of models covering a host of domain topics. Good examples of basic LS4 models include:

- Meta-population source and sink (D6.2.1)
- Osmosis and diffusion (D6.2.2)
- Homeostasis (D6.2.2)
- Population (D6.2.5, Figure 5)
- Control circuit management (D6.2.5)

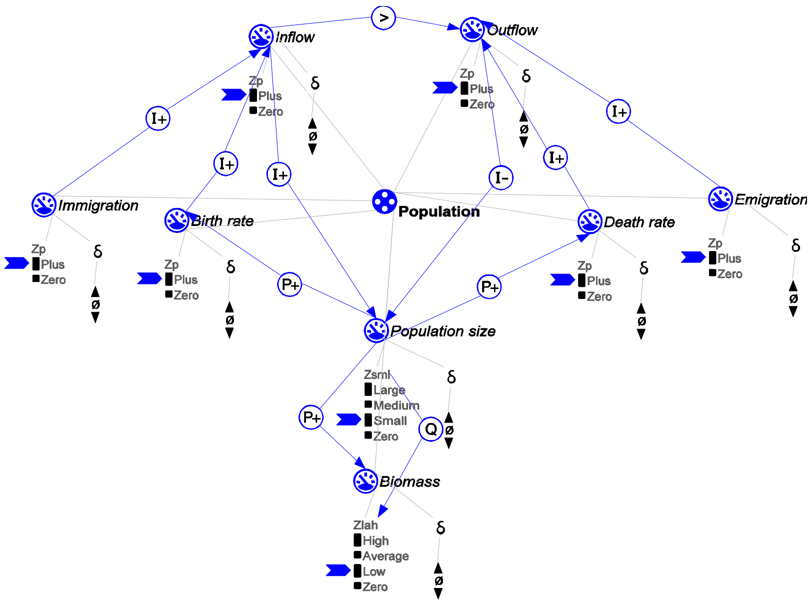


Figure 5 The Population LS4 model expression (Zitek *et al.* 2010) highlighting how LS4 models can be used to provide concise and consistent explanations of basic concepts such as factors affecting population dynamics.

Models such as these capture the key concepts and effects of systems causality as the effect of single or multiple competing processes. Such basic models can then be re-used and refined in LS6 models to explore more complex systems relating to the interaction of more processes.

3.6.2. Issues identified for resolution in T6.4

Learning Space 4 was one of the most used Learning Spaces for developing basic models, mostly due to the requirement in explaining most environmental systems/phenomena to consider processes and feedback mechanisms. The review of LS4 models produced in D6.2-(1-5) indicated that modellers exhibited a range of approaches to using LS4, similar to those approaches used in LS2:

- simple causal expressions considering one or two processes;
- concise diagrams with a small number of integrated causal paths, including feedbacks;
- elaborate diagrammatic representations of causal webs (for example Decomposition basic, Carbon cycle D6.2.2).

Whilst all of these approaches can produce valid models with accurate explanations of the phenomena being considered, models that form elaborate diagrammatic representations of complex causal webs rapidly become unwieldy and difficult to explore visually. This can be seen even in LS4 models of some of the fundamental topics e.g. Osmosis and diffusion (Figure 6), where the number of entities, quantities, causal relations and correspondences rapidly make the diagram cluttered and complex. This is even more of an issue at LS4 than at LS2 because of the increase in the number of primitives that can be used to describe the model. Given this, advanced models/topics should make use of model expressions in LS4 following the first two modelling patterns to explain key processes or phenomena However, full models considering complex system should make more use of the compositional approach to model building in LS6.

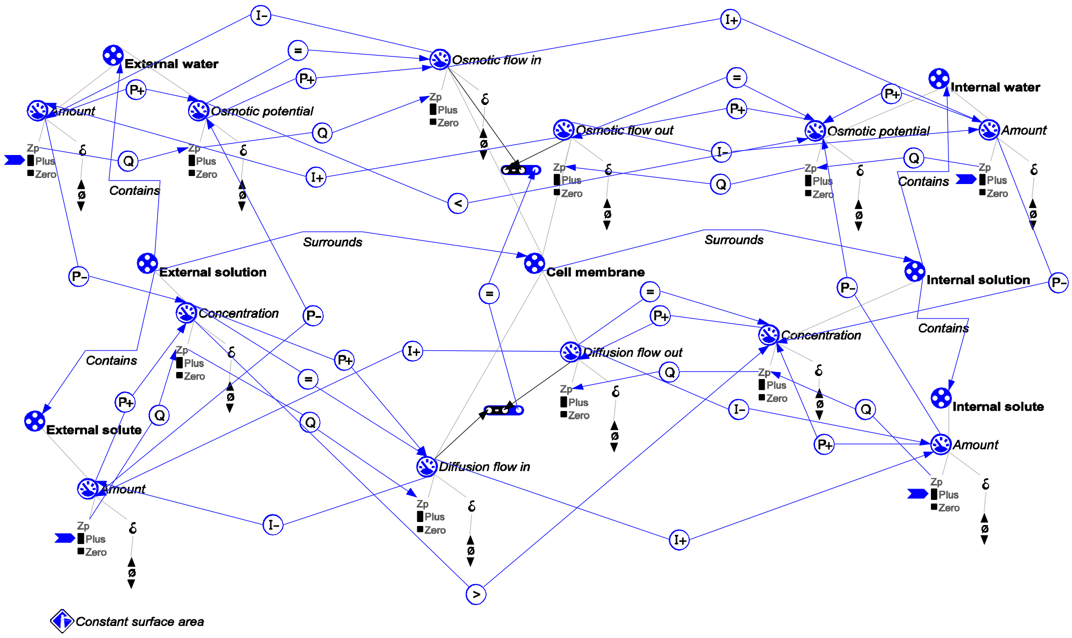


Figure 6 The Cellular Osmosis and Diffusion LS4 model expression (Noble 2010) highlighting how LS4 models can easily become complex and cluttered even when addressing basic phenomena.

3.7. LS5 – Conditional knowledge models

3.7.1. Domain concepts and modelling patterns

The LS5 models so far were used to represent the effects of critical states on the behaviour of a system and the activity of processes (for example *Bank-full discharge*, where flooding only can occur when this level is exceeded, Figure 7; Zitek *et al.,* 2010). LS5 therefore allows the implementation of non-linear dynamics, where behaviour of the system can change during a simulation depending upon the conditions. LS5 models therefore require the definition of conditions, under which a certain part of the system becomes active or certain behaviour of the system occurs. LS5 offers the possibility to build multiple conditional fragments based around a single basic model expression allowing the definition of complex cascading system structures in a very insightful manner.

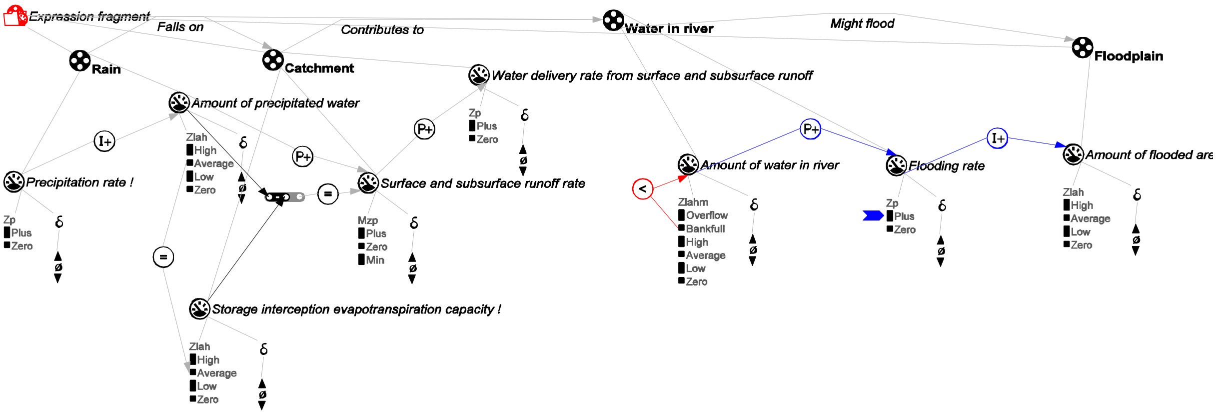


Figure 7 The Precipitation and flooding LS5 model expression (Zitek *et al.* 2010) highlighting how LS5 can be used to address conditional knowledge in simulations. Furthermore, this model exhibits the relationship between explicit qualitative states, well defined quantity spaces and the links to conditional behaviour.

3.7.2. Issues identified for resolution in T6.4

Only five LS5 models were delivered in D6.2-(1-5) due to the technological difficulties encountered in implementing this Learning Space. However, these difficulties have now been overcome and the creation of advanced topics and models should make full use of this Learning Space. LS5 will become a critical tool for the representation of conditional knowledge concerning some of the fundamental topics as an extension of those defined in LS4. Therefore, full use of LS5 should be made when refining basic models and developing advanced models in T6.4.

3.8. LS6 – Compositional and hierarchical models

3.8.1. Domain concepts and modelling patterns

Learning space 6 (LS6) deals with generic and reusable knowledge. LS6 has three main features: (a) it introduces the compositional modelling approach; (b) it expands the concept of conditional knowledge; and (c) it explores hierarchical representations of modelling components and inheritance of features present in "parent" by "children" components. Compositional modelling (Falkenhainer & Forbus, 1991) is a modelling approach in which, instead of developing a dedicated model for a specific system, the modeller develops libraries of reusable fragments of models from which multiple models can be generated automatically during a simulation.

Although T6.2 was aimed at developing basic topics and models some LS6 models have been developed addressing many of the curricula topics from D6.1 (Salles *et al.* 2009) that fall into the advanced fundamentals or advanced integrated categories. In particular the LS6 was used for those topics that required consideration of multiple interacting processes. Furthermore, many of the topics addressed in LS6 were those that fit the advanced integrated category that considered the social, economic and ecological perspectives of environmental systems, particularly those related to resource use and environmental management. The compositional approach (allied to the general qualitative approach) used in LS6 allows models and concepts from different sub-domains or perspectives in environmental sciences to be linked together (e.g. Figure 8). This is something that is virtually impossible in quantitative models (even more so in the context of education). This enables advanced scenarios to be developed for the complex phenomena and environmental problems that define the DynaLearn curricula themes (Section 5).

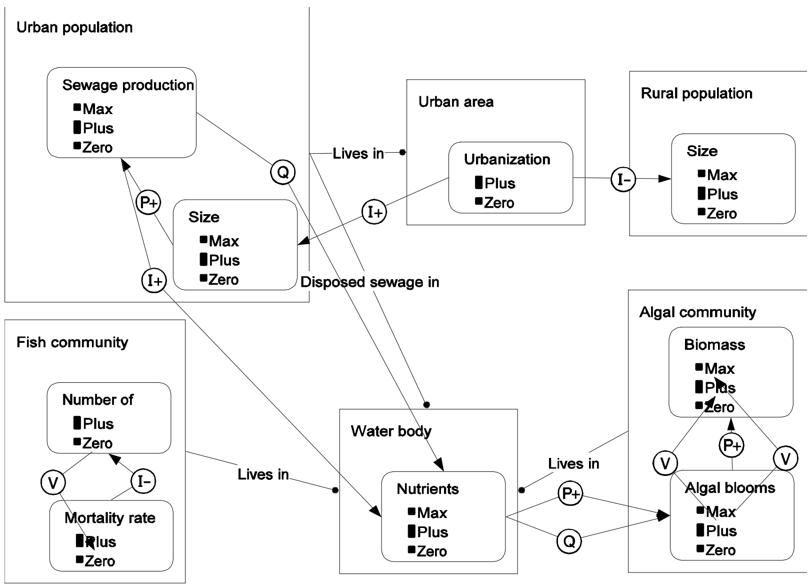


Figure 8 The causal model of the Urbanization LS6 model (Borisova *et al.*, 2010) highlighting how LS6 models can be used to integrate concepts across different social and ecological viewpoints.

The LS6 models developed as part of T6.2 can be refined to form the basis of the approaches used to develop more advanced topics and models in T6.4.

3.8.2. Issues identified for resolution in T6.4

In the LS6 models submitted in D6.2-(1-5) two modelling strategies can be identified:

1) Specification of multiple model fragments (similar to LS4 expressions) of generic, re-useable, knowledge that can be combined in specific scenarios. The additional value of LS6 lies here in the possibility to set assumptions, under which a certain model fragment applies.

2) De-composition of large systems into model fragments containing small chunks of specific knowledge expressed in static and process model fragments. These fragments of specific knowledge are then re-combined for simulations in a scenario.

However, most of the LS6 models submitted in D6.2-(1-5) followed the second of these strategies, that is that they generally modelled specific knowledge and did not make use of entity hierarchies or inheritance. In some cases where the topic was framed as a progression of model development through the Learning Spaces the LS6 model was a decomposition of the overall model expression developed in LS4. Given that modelling advanced topics will require the advanced representations and functionality available in LS6 to express complex phenomena more use should be made of the first of these strategies. Developing the first strategy, making much more use of generic re-useable knowledge and the hierarchies available in LS6, will also mean that the knowledge captured in basic models can be refined and re-used in advanced models.

3.9. Summary of modelling

The review of the models produced in D6.2-(1-5) indicated that the models could be characterised into a number of different types based on complexity, focus and simulation capabilities. This gave the following categories of model:

- ***Complexity***
  - Simple linear reasoning
  - Concise expressions of single small (non-linear) concepts
  - Extensive representations of complete topics/concepts (e.g. nutrient cycle models)
- ***Focus***
  - Structure and relationships (both physical and general causality)
  - Behaviour
- ***Simulation capabilities***
  - Models with complete and consistent simulation
  - Models with incomplete/inconsistent simulations

It should be noted that incomplete/inconsistent simulations are generally the result sub-optimal modelling for a given Learning Space. Often this was because the focus of the model was on the general structure (entities, quantities and configurations) and which quantities were related rather than on the system behaviour. Sometimes it was apparent that the key concept addressed in the model would require more appropriate Learning Space (e.g. models representing processes in LS2). In general those models that aimed to be extensive representations of complete topics and concepts (equivalent to formalised concept maps or structured diagrams) were also those that had issues with incomplete or inconsistent simulations. This gives rise to the requirements of advanced models to:

(1) Be optimised to the opportunities of the Learning Space.

(2) Address issues of complexity by focussing on individual concepts in single model expressions.

(3) Be developed using good modelling practice (considering advances in the software to make best use of the technology).

This is particularly apparent for LS2 and LS3 which represented new challenges for the partners in T6.2. For example, whilst extensive representations of complex systems in LS2 may result in model expressions which form useful static diagrams their simulations are incomplete or inconsistent and would be unsuitable for explaining behaviour. Whilst such a model could be optimised for use in a learning activity exploring system structure, or for aiding model-based feedback on structural concepts through the repository, they are not suitable as clear explanations for behaviour. Therefore, T6.4 should include a refinement of basic models in LS2 and LS3 to optimise good modelling practice (Section 4) such that the basic models focus much more clearly on explanations for systems behaviour appropriate to those Learning Spaces.

Review of the models also indicate that the use of and development of qualitative states and quantity spaces are still problematic in all Learning Spaces from LS3 to LS6. Therefore, advanced models should take much more care to develop insightful quantity spaces.

4. Good modelling practice

4.1. Development of good modelling practice

The main purpose of the environmental science expert models developed in the DynaLearn project is to capture clear and insightful explanations of domain phenomena which can then be applied to ontology-based-feedback from the repository. As such, the models need to be clear, be consistent in the use of modelling vocabulary. The coherence in modelling approaches between the expert models is therefore of great importance, especially in terms of the ability of the semantic technology to make linkages between models in terms of the concepts they convey. For this reason, it is important that the expert models use a uniform vocabulary and approaches to representations to express concepts about the domain. Consistent modelling approaches in advanced models becomes more important given the requirement to optimise the relationship between the model content and the implementation of the model in the repository and the feedback technologies that will utilise them. The following sections summarise the requirements to optimise the modelling practice in general terms and for working alongside the virtual character interactions and the semantic technology.

4.2. General model building

4.2.1. Definition of system structure – entities and quantities

In all qualitative models it is important to make a clear distinction between the structural and the behavioural aspects of a system. As such, it becomes important to make a clear distinction between entities and quantities. Doing this correctly will make a model more understandable. There should be a balance between the number of entities and the number of quantities. That is, between the structural aspects of the system and the behavioural aspects, as an imbalance, such as having many more quantities than entities, makes a model visually more difficult to understand.

However, from the review of D6.2-(1-5) models it was clear that modellers did not always make a clear distinction between quantities and entities. There are trade-offs in choosing whether to represent a particular concept specifically separated into entities and quantities (such that the quantity name is purely “Abundance”, “Mass”, “Height” etc.). The use of separate entities should depend on the importance of these entities in the system (although from an educational viewpoint it should be important to have a consistent definition and separation between entities and quantities). If a specific entity is not the focus of the model, they are often represented together with a particular quantity. For example, the concept of “abundance of fish in a river” can be modelled with *Fish* as an entity in the system (living in the *River*), but can be also presented as quantity of the *River* (*Number of Fish*). The choice of implementation often depends on the importance of the *Fish* for the system or the requirement to minimise the complexity of the model expression in terms of the number of ingredients used. If for example the *Mortality* of the fish or their *Number* is important, then *Fish* should become an entity with these features as quantities, since these quantities are features of the fish and not of the river. In addition to a question of consistency in the use of modelling vocabulary, the introduction of entity concepts in quantities with compound names will have significant implications for the performance of virtual character dialog (Section 4.3) and the semantic grounding technology (Section 4.4).

The important thing, when modelling is the clarity of the ideas represented. A model should have a clear modelling goal in the sense that it should explain a particular mechanism that is aimed to be conveyed to the student. The words, which are used to name ingredients and the phrases used to describe model relations, are therefore an important part of creating a model. Ultimately, the name of the quantities should be in line with the vocabulary required within the domain.

4.2.2. Use of configurations

The configurations are a part of the structure of a model, and as such taking care of configurations is an important step to take for all models from LS2 onward. Furthermore, choice of configuration names will influence the verbalization of models through the virtual characters (such as in the TA use-case) (see Section 4.3 for discussion). However, only a small number of configurations are generally used. One common issue with configurations found in models in D6.2-(1-5) was that modellers do not always distinguish precisely between structure and causality. This often results in configurations being named after causal relationships. For example, *Phytoplankton → affects → Water body* instead of *Phytoplankton → lives in → Water body*. Or, *Farm → influences → River* instead of *Farm → is next to → Lake*. In general, structural relationships should never be named after causal relationships. They are used to indicate spatial relationships or other conceptually informative relationships between entities. As a guideline, advanced models should be checked for configurations named after causal relationships (such as 'influence' and 'affect'), and those configurations should be replaced by better structural configuration names.

4.2.3. Qualitative states, Quantity Spaces and use of Correspondences

The review of models in LS2 to LS6 indicated that in many cases quantity spaces were not well developed beyond {Zero, Plus}; {Zero, Low, Medium, High} or {Zero, Plus, Max} and rarely did these qualitative states have consequences to the model or the behaviour (lack of correspondences). Ideally, good quantity spaces will be insightful in describing truly important qualitative states for the system/quantity and be shown to have some consequence for the behaviour. In this way qualitative states and correspondences can be seen as important precursors to the conditional knowledge information used in LS5 and LS6. Ideally quantity spaces should be more descriptive than {Low, Medium, High} as often there is no information as to what these values really mean and what is important about the qualitative state {High}. Therefore, a parsimonious approach should be applied to the definition of quantity spaces, where the spaces are only expanded where there is a need to show explicitly distinct qualitative states or there is a clear need to visualise behaviour within a simulation value history.

4.3. Virtual Character interaction and dialogue

The generation of natural language dialogue by the VC as it "reads" the teacher/student model will be greatly affected by the modelling approach and nomenclature used. In particular this relates to the definition of entities and quantities and the approach used for naming quantities. The creation of the natural language interaction requires that the dialogue is built from a standard framework where the model ingredient names are slotted in as place holders within a predefined sentence structure. For example:

What happens to** <u>Quantity</u> **of** <u>Entity</u> **if** <u>Quantity</u> **of** <u>Entity</u> **increases?

With this sentence structure the underlined aspects are directly "read" from the names of the model ingredients. So the way in which modelling ingredients are named in terms of handling quantity/entity relationships will greatly influence the quality of the dialogue produced. Following the different approaches found in modelling seen in Figure 9 the standard framework for creating text could result in the following dialogs:

Example 1) *What happens to Concentration of dissolved oxygen of Water.....?*

Example 2) *What happens to Amount of dissolved oxygen of Dissolved oxygen.....?*

Example 3A) *What happens to Concentration of Oxygen.....?*

Example 3B) *What happens to Concentration of Dissolved oxygen.....?*

Example 4) *What happens to Concentration of Oxygen......?*

Of these, Example (2) is obviously totally undesirable in dialogue terms (repetition of entity information) and Example (1) is undesirable in terms of natural language ("of" rather than "in"). However, the solution to these rests in both the modelling approach (Example 2) and the dialogue construction (Example 1).

It should be note that in LS2 to LS5 whilst entities are created, the super-type information is hidden, such that it is the instance name that is viewed. Hence, there cannot be a model with a "*Dissolved oxygen*" entity created twice. Currently, where it has been required compound names e.g. "*Dissolved oxygen in water*" and "*Dissolved oxygen in blood*" have been used. In this context to make a clear distinction between an entity and multiple instances or occurrences of the entity the super-type information would need to be utilised such that the entity names were changed to "Dissolved oxygen" whilst retaining the different instance names. However, this functionality has not been exploited in LS2 to LS5 basic models. This use of super-type information again introduces issues for grounding of terms and concepts. Work in T6.4 should address this functionality to explore its use in LS2 to LS5 both in terms of increasing the strength of model expressions in these Learning Spaces but also as a preparatory step for learners to identify the concepts of entities and instances of entities as a precursor for working with entity hierarchies and inheritance in LS6.

The use and direction of configurations between entities has implications for verbalisation of models, especially if explicit representations of quantities and entities are used, such as in Examples (3) and Example (4). In most basic models the sequence of model building (first adding entities, then configurations, then quantities and finally causal relations) means that models can be seen as having a "top-down" configuration such as in Example (3B). This configuration is easily verbalised when the context of the dialog is based around an entity perspective e.g. "The Entity *Water* Contains *Dissolved oxygen*". The problem for natural language generation occurs when the behaviour of the system is the focus (such as in the TA mode). For instance, Example 3B might generate a dialogue of "If the *Concentration* of *Dissolved Oxygen* Contains *Water* increases...." as opposed to "If the *Concentration* of *Oxygen* Dissolved in *Water* increases" as would be generated in Example 3A. This issue is not easily resolved such that all ways of exploring/verbalising the model are optimised. Development of good modelling practice to optimise the functionality should be an early focus of T6.4 and software development.

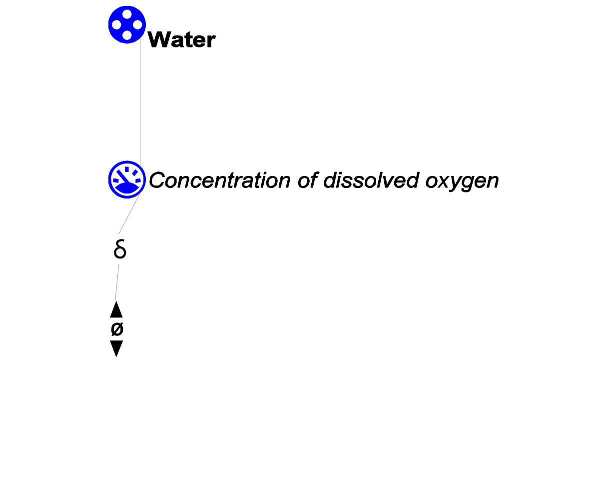
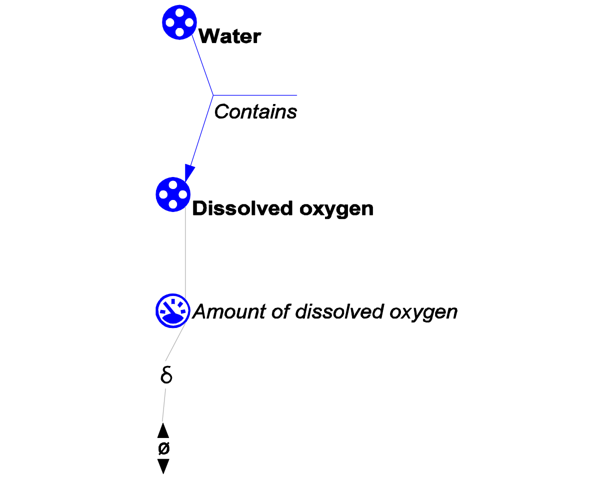
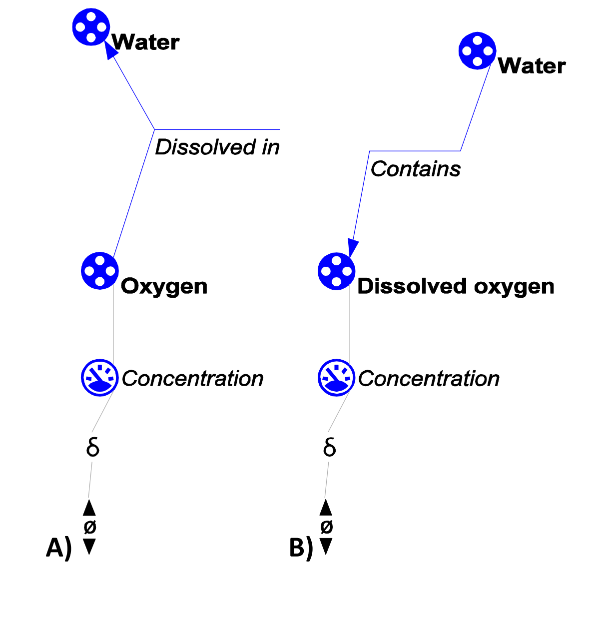
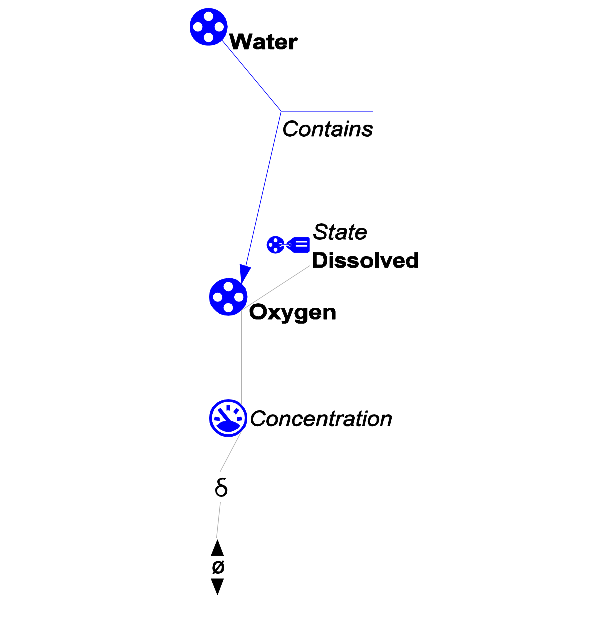
	
Example 1 – compound quantity name containing quantity, newly introduced entity and attribute/instance of the entity	**Example 2** – compound entity name containing a repeat of the entity and the attribute/instance
	
Example 3 (A) and (B) – configuration contains instance/attribute information. Note the direction of the configuration makes statements where the entity (A) or the quantity (B) is the main focus.	**Example 4** – use of attribute label, something that has never been really used in either Garp3 or DynaLearn.

Figure 9 Examples of ways to model the concept of the "*concentration of dissolved oxygen in water*".

4.4. Grounding and model-based feedback

The grounding functionality developed in DynaLearn (Gracia, 2010) allows the vocabulary used by export modellers to be linked to terms in DBpedia. By establishing such relationships, potentially sub-optimally named model ingredients can be improved by using the terminology as it is used in DBpedia. By grounding all the expert models, we assure that the vocabulary used in all the expert models will be uniform. Making the vocabulary uniform, becomes important at LS2, since there the proper conceptual decomposition of ideas into the correct model ingredients becomes important. In LS1, having concepts that mix multiple concepts (in terms of model ingredients and vocabulary) is less important, since it is only meant as an initial orientation on the topic.

An additional benefit of grounding is that it allows the automatic structuring of the expert models into a curriculum (in terms of selecting expert models as reference and generating feedback). The Semantic Technology (ST) provides feedback based on the set of grounded expert models (Gracia, 2010), which includes which extensions to a student's model is appropriate. Due to the use of consistent vocabulary (in terms of grounding), the ST functionality can guide a learner through the knowledge contained in the set of expert models.

The review of models highlighted that concepts could be modelled in different ways, a few of which are represented in the examples in Figure 9. Essentially each structural "concept" could be viewed as a combination of one quantity and one or more entities and aspects of the instance of the entities. For example the concept in this example is "*The concentration of dissolved oxygen in water*" where *Concentration* is the quantity, *Oxygen* and *Water* are entities and *Dissolved* is the particular occurrence (in this case often defined using the instance name) of the *Oxygen*. The range of representations possible has great implications for groundings, in particular the use of anchor terms or DBpedia terms. For example the representations above could have the following groundings (as available in the repository in January 2011):

- Example 1 – "*Concentration of dissolved oxygen*" (Anchor term); "*Water*" (DBpedia).
- Example 2 - "*Water*" (DBpedia); "*Contains*", "*Dissolved oxygen*", "*Amount of dissolved oxygen*" (Anchor terms)
- Example 3A – "*Water*", "*Oxygen*", "*Concentration*" (DBpedia); "*Dissolved in*" (Anchor term)
- Example 3B - "*Water*", "*Concentration*" (DBpedia); "*Contains*", "*Dissolved oxygen*" (Anchor terms)
- Example 4 - "*Water*", "*Oxygen*", "*Concentration*" (DBpedia); "*Contains*", "*Dissolved*" (Anchor terms)

The main difficulty is grounding multiple compound terms such as "*Dissolved oxygen*" or "*Oxygen concentration*". In general the current grounding capability requires that these are grounded using a single anchor term (as opposed to grounding against two entries in DBpedia "*Oxygen*" and "*Concentration*"). The main issue here is whether concepts grounded using different approaches can still easily be related and identified within the model-based feedback technology. Ideally an approach needs to be defined for both model building and for the semantic technology that optimises the educational benefits of the approach with defined learning activities. One option is that entity, quantity and occurrence/instance information are represented as separate ingredients in all models and grounding makes as much use of general definitions as possible (e.g. "*Water*", "*Oxygen*", "*Concentration*", "*Dissolved*") which together would define the overall concept. However, this approach does have significant implications for model complexity and clarity in terms of the total number of ingredients that need to be added into a model expression (Section 4.2.1).

5. Refining and advancing the DynaLearn Curriculum

5.1. Introduction - DynaLearn Curriculum Rationale

Environmental Science as scientific discipline has many unique aspects that affect the development of appropriate curricula: (a) its interdisciplinary nature, implying that its body of knowledge comprises concepts originated in the Life, Earth, Matter and Social sciences as well as new concepts from the emerging discipline; (b) its holistic perspective on environmental phenomena, marked by a systems approach for coping with Complexity; (c) its evolving methodological means and procedures, of which modelling and simulation, in their role as both methods and products in the inquiry process, are substantial representatives.

Despite the growing educational awareness, the status of environmental education in formal educational system is not clear. This stems, to a large extent, from its interdisciplinary nature, but not less from an ideological controversy between those who perceive environmental education as a branch of science education that provides factual knowledge, yet it is value- and judgment-free, and those who perceive it as education for sustainability which is not free of social, cultural and ethical considerations (Cairns, 2002; Flader & Callicott, 1991).

This controversy is now addressed by those who call for a merger between the two opposing approaches (Berkowitz, Ford & Brewer, 2005; Orr, 1994), claiming that environmental education must include both ecological literacy and civic literacy leading to environmentally responsible behaviour and political action. The DynaLearn environmental sciences curriculum as defined in D6.1 (Salles *et al.* 2009) acknowledges both types of literacy. Thus, the DynaLearn curricular goals are:

1. To promote learners' environmental literacy, and increase their awareness towards the need to learn, understand and act in relation to environmental issues.
2. To promote the learners' understanding of key concepts in Environmental Science and in related scientific disciplines knowledge and skills.
3. To support learners' development of system thinking and skills required to cope with complexity.
4. To support learners' acquisition of QM approach and skills, as powerful intellectual tools for inquiring systemic phenomena.
5. To contribute to learners' motivation to address Environmental Science learning.
6. To contribute to the learners' gradual consolidation of self-directed and independent learning practice.

To reflect these goals in the development of a refined curriculum the advanced models representing the more complex topics must address issues (1) and (2). That is that they must present in a systematic and detailed way key concepts in Environmental Science and promote environmental literacy. The DynaLearn curriculum, since it first formulation in D6.1, was not meant to be a linear sequence of environmental contents, but rather a web of topics that represents seven main themes in environmental science, some of which are more focused on scientific concepts and some more targeted to the interface of human-environment relationships.

In addition to the delivery of domain knowledge the refinement of an advanced curricula as a way of framing knowledge within and between topics/models can be used to address issues (3) and (4) relating to developing an understanding of the systems dynamics approach and the qualitative modelling approach. That is, appropriately framed models and sequences of models can be used to highlight more generic patterns and concepts. In order to address the formulation of modelling goals, and the framing and sequencing of models within topics, a range of principles or perspectives on curricula organisation need to be considered.

5.2. Curricular approach and organising principles

The organisation of domain knowledge within the DynaLearn curriculum can be seen to have three aspects:

1) The viewpoint taken on a particular topic (ecological, social, economic etc.).

2) Organisation of knowledge within individual, sequences or suites of models addressing particular topic.

3) Organisation of sequences or suites of models and/or sequences of topics as a way of exploring the wider curricula or delivering wider concepts across the seven domain themes.

To create advanced models and address more complicated topics the DynaLearn curricula needs to include a transition from basic concepts through to detailed explanations of complex systems built on a refinement and integration of these first principles. The DynaLearn curricula, as presented in D6.1 (Salles *et al.* 2009), was organised around seven main themes. These themes treated environmental science not only from a pure ecological or scientific perspective, but also from human, social and ethical perspective. The themes, and the vast array of topics included under each theme, adopted an integrated approach, amalgamating between scientific disciplinary knowledge and a systemic ecological perspective. These topics and models comprised basic fundamentals, advanced fundamentals and integrated topics (Section 2). As such the integrated approach is based around the concept refining basic knowledge to explain complex systems, including those concerning human-environment relationships. The refinement of the DynaLearn curriculum, enhancing and refining the treatment of domain knowledge to develop understanding of the behaviour of complex systems, can therefore allow higher concepts to be modelled and considered in T6.4.

Given the focus on refining and integrating basic knowledge in advanced models for T6.4, consideration needs to be given to what knowledge is required and how this should be organised within a model or a suite of models addressing a topic. This leads to the requirement for refining the modelling goals for advanced topics and models. Given that this relates to a specific systems viewpoint of representing environmental science concepts, these different goals could move the focus of the curricula from specific domain phenomena to more generic systems concepts amongst them: non-linear effects, decentralized control, probabilistic causes, dynamic self-organization and emergence. To explore this, organising principles, other than the seven main themes described in D6.1, need to be considered.

The definition of modelling goals needs to be framed against a number of principles or perspectives for which information is to be structured and conveyed in the models. Such perspectives can also be used to support structuring of the overall curriculum. The organising principles on which goals for advanced models can be defined are:

The Ecological/social principle

This guiding principle relates to specifying the domain knowledge to be conveyed and the domain perspectives applied. In advanced models emphasis is put on topic stressing human/environment interactions and environmental dilemmas stemming from this interaction. Examples of relevant topics include: populations and meta-populations; education; green architecture; legislation; land-use conflicts; agro-ecology; deforestation; river rehabilitation; low carbon society; sustainable use of energy; conservation and recycling pollutants.

System thinking/complexity principle

Here the focus is defining the goals of topics and models in terms of higher scientific and thinking skills related to coping with complex systems, including the Pattern Oriented Modelling (POM) approach. The principles of POM and system dynamics, as well as well accepted first order principles of ecosystems like hierarchy and thermodynamics, are practically applicable to all types of models. Examples of relevant curricular topics are: climate change; water cycle; food webs and energy flow; evolution; biodiversity; urbanization, and management of catchment areas. This principle would focuses on how specific domain topics and phenomena highlight the more generic systems concepts that underlie them.

QM and the inquiry skills' principle

Qualitative modelling allows ecologists to understand and predict the behaviour of complex ecological systems. It allows a transition beyond static structural depictions of cause/effect relationships among variables to show the net effects of all of these relationships interacting simultaneously. Qualitative Modelling (QM) with DynaLearn enables to investigate the dynamic interplay between the system' components and acquire inquiry skills (Hogan & Thomas, 2001). A critical example of a target skill relates to the understanding of- and ability to model causal relationships within a system and between it and its environment. Several dimensions are relevant here in relation to the selection of topics. One is the **level** addressed in the "systemic hierarchy" (from the molecular level -e.g., as in diffusion and osmosis processes, up to the multiple-systems level -e.g., health and environment issues). Another dimension is the complexity of the **causal configuration** (from single unidirectional relationships to complex feedback-loops configurations). A third example of a dimension relates to the **behaviour-level** at which causal configurations are considered (from the level of system-components behaviour to the system's overall-behaviour emerging from causal configurations at the lower levels).

In similar ways, the gradual construction of other aspects of QM skills as powerful intellectual tools should be afforded by the selection of the best fitting contents and topics. In this context advanced models regarding specific domain phenomena should be used to situate and ground higher level concepts.

Learning Spaces characteristics principle

This principle is unique to DynaLearn and emanates directly from a substantial feature of DynaLearn as learning environment: it's Learning Spaces. By this principle, topical items and clusters can be created to best fit the type and level of understandings and learning expected to be achieved in each Learning Space. Although potentially each Learning Space offers a particular perspective of any phenomenon under study, seeking the best correspondence between a Learning Spaces features and a topic's features is what this principle is about. Hence, advanced models need to be justified in the use of individual or sequences of Learning Spaces.

Authenticity/relevance principle

Focusing on authentic themes and tasks which are relevant to the learners' interest is critical for increasing their motivation and readiness to approach complex issues and concepts in Environmental

Science. Hence advanced models must be justified in their choice of domain settings to relate to local perspectives. By this criterion topical configurations may address issues such as: Human population (e.g., population growth; Health and the environment; reduce/reuse/recycle, tourism and recreation); Human-environment relationships (e.g., land and water use, sustainable use of energy, greenhouse gases); Earth systems and resources (e.g., the Water cycle, ecological services, climate change); the living world (e.g., biodiversity, populations, conservation biology). Also at this level, **localisation** and **contextualisation** are of significant value for selecting topics and devising modelling activities to be perceived by the learners as relevant and important to deal with. By this, curricular topics contextualized within environmental scenarios and data connected with the learners' real-life experiences have better prospect to draw their curiosity and increase their awareness to the need to study, understand and solve them.

All of these principles need to be considered and formalised in the goals for advanced topics both in terms of structuring knowledge within single models and structuring knowledge in a suite of models to represent complete topics.

5.3. Implications for models and modelling activities

In addition to the different organising and selection principles for defining topics and models there are several dimensions affecting the development of models to support learning/modelling activities to be undertaken during the evaluation activities. These dimensions include:

1. Content sequences configurations: This dimension refers to the configurations in which topics are concatenated while developing lessons and even courses. Examples of these are linear, spiral or web-like sequences. An example of a **linear** sequence might include the topics: photosynthesis, aerobic respiration, anaerobic respiration, primary production, secondary production. A **spiral** sequence is built upon the recurrent treatment of topics in phases of increasing complexity: Phase 1- basic topics such as land use conflicts, or air/water/soil pollution; Phase 2 – agro-ecology systems, or pollution mitigation correspondingly; Phase 3 - deforestation or climate change correspondingly, etc. **Web-like** configurations might include clusters of interlinked topics allowing multiple paths by different learners according to their interests and learning goals.

2. Progression of modelling skills and abilities: By this dimension lesson plans are developed as to foster the acquisition and use of QM skills and abilities. Tasks and lesson components are developed to facilitate the construction of a skill, and sequences of lessons are defined accompanying the gradual construction of ability.

3. Modelling modality and sequencing: this dimension relates to the extent to which modelling activities are planned as sequences of focused and independent models (e.g., one model-building activity focused on one topic in one Learning Space), or as an "evolving model" series of tasks (e.g., progression of tasks among Learning Spaces or of increasing complexity focusing on one main theme).

4. Integration of modelling with DynaLearn with other resources: This dimension relates to the pedagogical context for the implementation of DynaLearn modelling tasks. Decisions at this level range from devising a lesson plan based exclusively on a modelling activity, to a lessons sequence in which modelling tasks are threaded with other pedagogical resources, e.g., lab activities, lectures, field trips.

Whilst the advanced models developed as part of T6.4 do not need to address all these dimensions *per se*, they do form an important background for the development of the final curricula document (T6.5) and also relate closely to the activities in WP7. Whilst the advanced models do not need to address modelling modality or mode of involvement of modelling (as advanced models act as references in the repository) some consideration should be given to the content sequences (1), progression of models (2) and integration of modelling with other resources and learning activities (5). Consideration and refinement of advanced models following these dimensions will advance the focus from individual models to suites of models that could form course related activities where modelling is used alongside other learning activities to foster both learning of domain knowledge and development of higher skills and concepts.

Many of these dimensions and guiding principles relate to how knowledge is structured in models and the knowledge base in repository needs to support sequences of modelling activities. In this context it is the formulation of feedback from the model repository that can act to structure sequences of modelling activities. To support this, the knowledge base must support generation of different types of feedback and also different principles/perspectives on the topics. So in addition to the guiding principles and dimensions list above sequences of models to address advanced topics need to take account of the type of feedback that could be generated or the types of model progression that could be used to structure sequence. In this context Salles & Bredeweg (2001) identified a classification system for knowledge representation, model progression and sequencing. These include:

1) **Order.** This relates to the types of behaviour or changes captured in the models. In the DynaLearn context this can be seen as the different aspects of causality in the different Learning Spaces.

2) **Analogy.** Development of concepts or comparison of models with similar patterns but in different situations or systems. Identification or explanation of patterns through analogous structure/behaviour.

3) **Inverse.** Identification or comparison of models/systems with inverse behaviours or processes that are seen as inverse e.g. photosynthesis vs. respiration; birth vs. death; emigration vs. immigration.

4) **Generalisation/Specification.** Including notions of hierarchy and inheritance within models and the concept of re-useable generic knowledge or refinement and integration of basic concepts into complex systems. This also relates to representation of generic patterns using specific systems.

5) **Structural change.** Progression of models using structural change e.g. moving from models considering single population to those that considers population interactions etc. In the context of qualitative models this relates to expanding models through the addition of new entities.

These five classes of model progression, in addition to the organising principles and curricula dimensions can be used to frame advanced model content, model progressions for advanced topics and options for delivering feedback during modelling activities within WP7 evaluations.

6. Conclusions and Future plans

6.1. Goals for advanced topics and models

Task 6.4 (T6.4), Advanced topics and models (M22 - 30), is defined in the Description of Work as follows:

A refined set of curriculum topics and related models will be timely provided by FUB, TAU, UH, CLGE, and BOKU for the evaluation study in WP7, so that WP7 beneficiaries have material to prepare the second lessons and evaluation activities. Topics and models will be customized in accordance to each beneficiary's expertise and interest.

To develop a refined set of curriculum topics and related models so that they will be timely provided by the partners for the evaluation study in WP7 some requirements need to be fulfilled: early planning for the development of advanced models and topics; cooperation among partners on building models to support specific evaluation activities; and, finally, cooperation on refining basic models to produce integrated advanced topics and models. Following the internal review and the results of this deliverable, advanced topics and models should fulfil the requirement of being independent units of system oriented knowledge that could be re-used in different curricula on environmental science. Here it is important to identify the most important patterns and processes. Furthermore, the advanced models should be insightful and situated at an appropriate level of complexity to capture insightful explanations of phenomena, taking best advantage of the available features of each Learning Space in DynaLearn.

The features identified for "advanced models" by WP6 and 7 partners include:

- "advanced" means more complex models, that provide insightful explanation for more complex domain phenomena;
- "advanced" model "complexity" comes from two sources;
  - by representing more complex phenomena = integration of basic laws and first principles to address a more complex problem;
  - including more elements on the model, refining concepts = requires complex LS 2-4 models, and LS5 and LS6 models;
- describe mechanisms that explain how things work and integrate;
- develop formal explanations for the system behaviour of advanced topics;
- advanced models should better explore the software capabilities.

In T6.2 each partner followed a different paradigm of model building, with each approach fitting best in the local settings (Section 2). For a more generic and coherent approach models need to be developed based on modelling goals following clear and traceable decisions, defining why a specific modelling approach was chosen. Models have to be developed following clear goals and should consider content knowledge, generic system patterns and the available features of each Learning Space of DynaLearn simultaneously. Section 5 highlighted that the domain content needs to be structured following modelling goals relating to various organising principles. From that perspective in some situations, depending on the domain concepts to be conveyed, it might make sense to build more than one model on the same topic exploring different aspects of the curriculum topic. Whereas in other situations it might be very insightful to treat a single aspect on different Learning Spaces with a clear progression showing a development of ideas with an insightful application of the available modelling features at each Learning Space of DynaLearn.

Identifying generic and recurring patterns in ecology should provide an important basis for developing generic modelling patterns in DynaLearn that could be transferred between different topics. In this context basic models of fundamental knowledge can be refined and integrated to explore more complex phenomena. Here advanced DynaLearn topics and models could also explore, and take advantage of, existing ideas like the ‘Pattern Oriented Modelling’ (POM) approach (Grimm et al. 2005). Whereas traditional ecosystem models, and some models produced for the DynaLearn curriculum so far, try to picture the real system as closely as possible in all its details, POM tries to focus on relevant patterns in the system guided by the question posed. Different questions produce different models based on the patterns identified. For example some models might follow: the population-community paradigm in ecology whereas others might follow the energy-flux (process-function) paradigm. Currently models belonging to both categories have been built; however, the approaches used were not explicitly defined in the modelling goals. Furthermore, modern first principles of ecology like thermodynamics or hierarchy theory could serve as additional backbones of a modern environmental education. Some advanced topics and models could be framed to explore the potential links of DynaLearn to these approaches.

Furthermore, advanced models need to have the right level of complexity to gain the maximum learning effect in terms of their ability to explain phenomena. Grimm & Railsback (2005) describe the so called ‘Medawar zone’ of medium model complexity as zone of the optimum payoff (Figure 10).

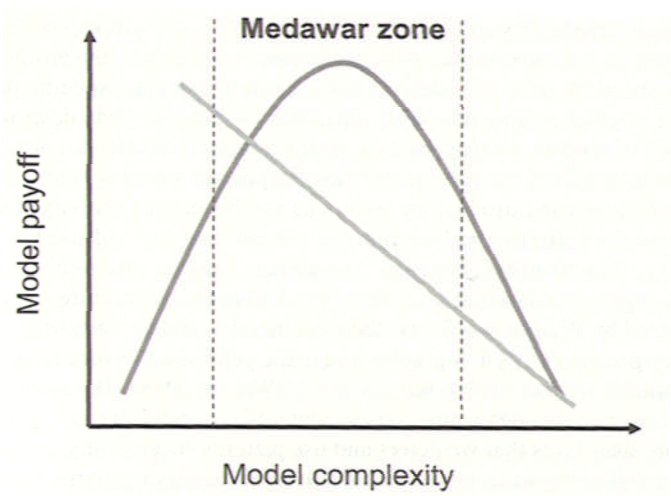


Figure 10. Medawar zone of model complexity to maximise the benefit that is gained from a model (Grimm & Railsback 2005).

Therefore, advanced models, in the context of refined DynaLearn curricula, are not just models that cover more complicated concepts but can also be seen as a refinement of models, using the best modelling practice identified here such that they make best use of the qualitative systems approach for conveying conceptual knowledge. In this context the models must work together with the software to support learning of a key concept within the overall topic of a broader environmental curriculum. The models delivered as part of T6.4 should therefore:

- Be clearly and suitable framed within a domain topic and an appropriate curricula context.

- Make appropriate use of different Learning Spaces to convey explanations for conceptual ideas.

- Be optimised for their use by the technological components of DynaLearn (in conjunction with using advanced modelling ideas to define how the technology should function).

- Have consistency in their design and the approach to nomenclature from an expert, technological and educational perspective.

- Act as a resource base of knowledge for the DynaLearn curriculum in the repository to support evaluation activities of feedback technologies.

- Showcase the opportunities and technologies created by the DynaLearn environment.

6.2. Learning Spaces and implementation of good modelling practice

Whilst T6.4 should aim to make best and appropriate use of all Learning Spaces, the review of the basic models indicates that focus should also be put on refining basic models or developing advanced models for:

- **LS3** – making more appropriate use of quantity spaces, qualitative states and correspondences. Ideally quantity spaces will be advanced beyond the {low, medium, high} approach that currently dominates in qualitative modelling. In LS3 the defined quantity spaces should be insightful and also have some consequences for the model (through the use of correspondences).

- **LS5** – this Learning Space was under-used for the basic models due to technological issues. However, the use of conditional knowledge will be vital to produce models of certain conceptual patterns and behaviours. This Learning Space also links closely to refining the approach to LS3 models as the definition of quantity spaces in terms of qualitative states links to qualitative states having specific consequences for system behaviour.

- **LS6** – use of the compositional approach to modelling should be developed for advanced topics and models. In particular the educational aspects of this Learning Space need to be developed. Additionally, the modelling patterns of hierarchy and inheritance should be utilised more to move use of this Learning Space beyond the model fragment approach to conceptual models offered by the compositional approach. That is, models in this Learning Space should integrate generic patterns and fundamental knowledge and integrate/re-use the knowledge to explore more complex phenomena.

To achieve this, and to optimise the relationship between the software and the domain content, two components of good modelling practice will be resolved at an early stage in T6.4:

(1) Definition, between education and technology partners, of the optimal approach to be used for nomenclature with dialogue creation for use in advanced models and future software releases.

(2) Definition, between education and technology partners, of the optimal approach to be used for nomenclature with semantic technology for use in advanced models and future software development.

6.3. Work plan for T6.4

The models produced by DynaLearn partners during the first phase of the project (T6.2), and described in deliverables D6.2-(1-5), include both “basic” and “advanced” topics. Most topics/ models are represented, but some are not developed to an advanced level. These existing models will be improved to become models that fit the criteria discussed above for T6.4. Each partner will select models to be further developed, or topics that need real advanced models, and will present detailed plans for the development of T6.4. Models in LS1-3 may be useful, but could hardly capture the complexity of the phenomena and of possible solutions. For representing such advanced topics, models should be built, respectively, in LS4, LS5 and LS6. Such models would explore DynaLearn capabilities and really develop formal explanations for concepts and phenomena.

Overall, the aim of T6.4 should not be one of completeness in the context of “a model per Learning Space per topic from D6.1” but should be one where there is an appropriate balance between coverage of domain topics, maximising opportunities in Learning Spaces and exploring individual topics in appropriate detail and from a range of different perspectives. This aim requires the following work plan:

1. Flash meeting and development of good modelling practice with software development.
2. Partners review the list of 14 topics assigned to them and identify:
    a. Topics to be developed into “advanced” models in LS5 and LS6
    b. Topics that will be treated as a “progression” of modelling ideas through a single concept – filling in gaps in Learning Spaces where appropriate.
    c. Topics that will be treated using “Perspectives” (multiple models explaining different concepts with a topic) to support research into ontology-based-feedback.
3. All partners amend/refine basic models where required, following the results of the internal review of models.
4. Partners will collaborate at an early stage to identify topics to be used during evaluation activities (especially ontology-based-feedback) to identify where existing topics can be integrated and refined. Priority should be given to modelling topics required within evaluations.
5. Early development of a framework for delivery of advanced models and supporting materials. These should include: greater use of model meta-data within the model file (early discussion with software developers to identify any technical solutions required); definition of the deliverable report format; formation of separate support materials?
6. The internal model review pro-forma will be reviewed in a Flash meeting and the refined approach will be used for internal evaluation of advanced model quality prior to model delivery in D6.4. This requires:
    a. Each partner clearly identifies which topics will be delivered (as in point 2).
    b. A partner is assigned to review each topic.
    c. Individual time-tables are defined to allow for timely review and delivery.

The advanced models shall become the basis for T6.5. These will create new curricula, to be explored in learning by modelling activities supported by conceptual models, virtual characters and semantic technology. The goals given above highlight the importance of appropriate definition of modelling goals, setting models within appropriate curricula and the consistent use of good modelling practice.

6.4. Plans for the DynaLearn curriculum (T6.5)

Given the curricula issues discussed in Section 5 in relation to model building and structuring domain content, it should be noted that DynaLearn curriculum is not implemented in a vacuum. High Schools and Universities run their own curricula related to Environmental Science topics in different formats and configurations. Policy directives in different countries define the way the subject is taught at the different levels. In countries where there is no explicit subject in the High School defined as Environmental Science, many of its topics are included in the Life, Earth and Matter sciences curricula and even in the social sciences. At the Higher Education level Environmental Science can be found either as separate program or integrated within a wide range of academic programs.

Thus, the DynaLearn curriculum should be formulated as to afford varied configurations, to be implemented not only as coherent unit, but also in modular form integrated within existing curricula and programs. Organizing the curriculum as a web of themes and topics, and indicating the various possible organizing principles and implementation modalities, allow teachers and course planners to devise the best-fitting configuration of topics and modelling activities according to their educational goals.

The final DynaLearn curriculum, to be presented in D6.5, should consider aspects of:

(1) The overall set of topics to be covered for Environmental Science

(2) Where the qualitative systems approach fits best in the domain topics and how it fits with different use cases and educational activities.

(3) Learning about qualitative systems dynamics – application of situated domain concepts to highlight higher concepts

(4) Learner autonomy, self-directed learning and options for navigating through the topics.

(5) Didactic materials accompanying the models/topics to support students/teachers in specific settings.

These topics will be considered whilst creating advanced models for T6.4 and for the ongoing evaluation activities. In turn these activities will feedback into the definition of the final curricula in T6.5.

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Appendix A

CHECK LIST FOR THE QUALITY OF DYNALEARN TOPICS AND MODELS

I) TOPIC IDENTIFICATION

Topic: ____

Author(s): ____

Partner: ________________________ Version/date:____________________

If the author did not give the model a name, please use sequential letters (LS 3a, LS3b ...) to clearly identify each model and the Learning Space.

II) IMPLEMENTATION ISSUES

Is the topic implemented in a single model?

Yes/No?__________ If Yes, how does the author justify the choice of Learning Space? ____

Implemented Learning Space(s)

Learning Spaces	Model(s)?	Model files
LS1 Concept map		
LS2 Basic causal model		
LS3 Basic causal model with state-graph		
LS4 Causal differentiation		
LS5 Conditional knowledge		
LS6 Re-usable knowledge		

If the author did not give the model a name, please use sequential letters (LS 3a, LS3b ...) to clearly identify each model and the Learning Space.

If there is more than one model on the same topic, do the models explore different aspects of the curriculum topic?

Yes/No? ___________ Why? ____

Is there a clear progression showing the development of ideas in different Learning Space?

Yes/No? ___________ Why? ____

Is the Environmental Science topic expressed at an adequate level of complexity?

Yes/No?___________ Why? ____

IN THE QUESTIONS BELOW:

If there is more than one model implemented, either in the same Learning Space or in different Learning Spaces, please complete section (III) for each model individually.

III) MODEL EVALUATION

i) Model name: ______________________________________ Learning Space: ___________

ii) Model Objectives

Model objectives (defined by the author)____

Intended users of the model: ____

Are the model goals expressed by the modeller clearly recognizable in the model?

Yes/No_____________Why?____

iii) Conceptual aspects

	Yes/No
Is the knowledge represented in the model relevant for the intended users of the model?	
Is the representation of the system structure acceptable for the intended purpose of the model?	
Is the representation of the causal relationships acceptable for the intended purpose of the model?	

Are the concepts represented in the model

	All of them	Some of them
justified in the literature?		
based on common- sense?		
not justified at all?		

Comments:

____

iv) Model ingredients

Entities and quantities - In any Learning Space between LS 2 – 6:

Modelling ingredients	Yes/No
Are the entities and configurations enough to represent the system?	
Are there agents in the model? Do they really represent “entities” outside the system, influencing but not being influenced?	
Is there a clear difference between entities and quantities?	
Are the quantities meaningful? Are they enough considering the modelling goals?	
Are the causal relations between the quantities correctly implemented?	

Quantity spaces and Correspondences - In any Learning Space between L3 – L6:

	Yes/No
Is it easy to recognize the units to measure the quantities? Do these units make sense?	
Are the values selected to compose the quantity space enough to produce the minimum required variation?	
Is it possible to indentify landmark Are the values in the quantity space truly different qualitative states of the quantity?	
Are the (Q, V) correspondences justifiable?	

Direct Influences and Qualitative Proportionalities - In any Learning Space between L4 - L6:

	Yes/No
Are the rates really representations of the amount of change in “time”?	
Would the rates be measured using the same units as the state variable they influence?	
Are the direct influences (I+ or I-) correctly implemented? Is there always a rate coupled with a state variable associated to an I+ or I-?	
Are the qualitative proportionalities (P+ or P-) correctly implemented?	
Is there any quantity being simultaneously influenced by Is and Ps?	
Are there feedback loops with only Ps? Does every loop have at least one direct influence (process) on it?	
Are the points in the quantity spaces of relevant variables landmark values, that is, values where the system behaviour does change?	

Assumptions - In any Learning Spaces between L5 - L6:

	Yes/No
Are the assumptions correctly implemented?	
Are the assumptions justifiable?	

Model fragments and other elements - Only in Learning Space LS6

	Yes/No
Is the entity hierarchy correctly used? Is the inheritance mechanism being used?	
Are the model fragments clear? Complete? Correct?	
Is the differentiation between Static, Process and Agent model fragments used correctly?	
Are the conditions correctly set for the consequences to happen?	

v) Scenarios and simulations

Scenarios and causal model - In any Learning Space between LS2 – 6:

	Yes/No
Are the scenarios clearly implemented?	
Are the scenarios clear representations of situations the system can be found?	
Are the causes of change (internal or exogenous) clearly identifiable in the scenarios?	

Simulation behaviour

	Yes/No
Are the simulation results meaningful and insightful considering the modelling goals?	
Are there dead ends in the simulation (the quantity value should change – go to zero or to maximum – but it doesn't change and the end state is missing)?	
Are all the quantities involved in the simulations?	
Are there quantities with no magnitude value calculated?	
Are there quantities with no derivative value calculated?	
Do the values of the quantities in the behaviour paths make sense?	

Testing alternative scenarios - Learning Space L6

Is the simulation correct when it starts with a quantity that has exogenous behaviour…

	Yes/No
generate all values?	
constant?	
increasing?	
decreasing?	
positive parabola?	
negative parabola?	
sinusoidal?	

IV) OVERALL EVALUATION

Given your understanding of the model, are the overall modelling decisions clear, justifiable and correct? Yes/ No? _________________

If no, why not?____

Additional comments

Appendix B

DISTRIBUTION OF TOPICS FROM D6.2-(1-5) FOR REVIEW

PARTNER	TOPICS	REVIEWERS	N Models (LS or approach)
D6.2.1 FUB Salles et al. 2010	1 Mining	UH	5 (Progression)
	2 Pollination	BOKU	4 (Progression)
	3 Services Nitrogen cycle	UH	1 (LS6)
	4 Farming Cerrado	TAU	5 (Progression)
	5 Main drivers of biodiversity loss	TAU	5 (Progression)
	6 Introduction of non-native species	BOKU	5 (Progression)
	7 Meta-population	UH	3 (Perspectives)
	8 Social aspects of human population growth	TAU	5 (Progression)
	9 Dengue fever	TAU	1 (LS6)
	10 Deforestation	IBER	4 (Progression)
	11 Erosion	UH	4 (Progression)
	12 Wind power	BOKU	4 (Progression)
	13 Bio-fuel	IBER	3 (Progression)
	14 Soil contamination	BOKU	1 (LS6)
	15 Lake pollution	BOKU	4 (Progression)
	16 Eichornia	BOKU	4 (Progression)
	17 Biomagnification	UH	1 (LS3)
	18 Eutrophication	BOKU	5 (Progression)
	19 Consumerism	TAU	2 (Perspectives)
	20 Carbon market	UH	2 (Perspectives)
D6.2.2 UH Noble 2010	1 Carbon cycle	FUB	1 (LS2)
	2 Nitrogen cycle	FUB	1 (LS4)
	3 Phosphorus cycle	FUB	2 (Perspectives)
	4 Nutrient cycles	FUB	1 (LS1)
	5 Adaptation to environmental stress	IBER	1 (LS4) + 1 (LS1)
	6 Evolution	BOKU	5 (Perspectives)
	7 Decomposition	IBER	5 (Perspectives)
	8 Reduce, re-use, recycle	TAU	1 (LS4) + 1 (LS1)
	9 Human development index	TAU	1 (LS2) + 1 (LS1)
	10 Agro-ecology systems	FUB	1 (LS2) + 1 (LS1)
	11 Fishery	BOKU	3 (Perspectives)
	12 Photosynthesis	BOKU	4 (Perspectives)
	13 Cellular respiration	IBER	3 (Perspectives)
	14 Diffusion and osmosis	TAU	4 (Perspectives)
	15 River rehabilitation	IBER	1 (LS2) + 1 (LS1)
	16 Greenhouse gases and climate change	FUB	5 (Perspectives)
D6.2.3 IBER Borisova et al. 2010	1 Urbanization	BOKU	5 (Progression)
	2 Legislation	TAU	5 (Progression)
	3 Fossil fuel	FUB	5 (Progression)
	4 Land use and conflict	TAU	5 (Progression)
	5 Atmospheric oxygen and ozone	TAU	5 (Progression)
	6 Reproductive strategies	UH	4 (Perspectives)
	7 Biodiversity	UH	3 (Perspectives)
D6.2.4 TAU Zurel et al. 2010	1 Adaptation to invasion	FUB	1 (LS6)
	2 Shrimp and Goby symbiosis	UH	3 (Progression)
	3 Competition for space	FUB	2 (Progression)
	4 Metabolism and acidity	FUB	2 (Progression)
	5 TBT and imposex	BOKU	4 (Progression)
	6 Diving pressure	IBER	1 (LS3)

PARTNER	TOPICS	REVIEWERS	N Models (LS or approach)
	7 Over fishing	UH	4 (Progression)
	8 Reversed osmosis for sweet water desalination	BOKU	1 (LS3)
	9 Aerobic and anaerobic respiration	FUB	1 (LS3)
D6.2.5 BOKU Zitek et al. 2010	1 Natural processes forming riverine landscapes and habitats	UH	3 (Perspectives)
	2 Populations	IBER	2 (Perspectives)
	3 The river continuum concept	UH	4 (Perspectives)
	4 Education	TAU	5 (Perspectives)
	5 Tourism and recreation	TAU	2 (Progression)
	6 Flood protection	IBER	3 (Perspectives)
	7 Integrated plans for management of catchment areas	IBER	2 (Perspectives)
	8 Food webs and energy flow	FUB	3 (Perspectives)
	9 Hydropower generation	IBER	1 (LS2)
	10 Indicator species	FUB	1 (LS3)
	11 Organic water pollution	IBER	1 (LS2)
	12 Climate change effects on river catchments	UH	3 (Perspectives)
	13 Dynamic restoration versus conservation	IBER	1 (LS4)

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