Deliverable number:	D6.2.2
Deliverable title:	University of Hull – Basic Topics and Models

Delivery date:	2010/07/31
Submission date:	2010/08/31
Leading beneficiary:	University of Hull (UH)
Status:	Version 03 (Final)
Dissemination level:	PU (public)
Authors:	Richard Noble

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 (D6.2.2) documents the models and topics developed by The University of Hull (UN) for Task 6.2. The models are developed in the different learning spaces of the prototype DynaLearn software. D6.2.2 covers basic topics and models that address the seven core themes identified in the DynaLearn curriculum for Environmental Science. In all 30 models and 13 learning space 1 concept maps are presented for the topics: Nutrient cycles; Human Development Index; Evolution; Decomposition; Photosynthesis; River Rehabilitation; Fishery; Adaption to environmental stress; Reduce, re-use, recycle; Aerobic respiration; Diffusion and Osmosis; Greenhouse gases and Climate change.

Internal review

- Wouter Beek (UVA)
- Andreas Zitek (BOKU)

Acknowledgements

The authors would like to that Paulo Salles and all other partners in WP6 for their work in developing the approach to modelling in the new DynaLearn software. The authors would also like to thank partners from UVA and BOKU for undertaking the internal review of this deliverable.

Document History

Version	Modification(s)	Date	Author(s)
01	First draft	2010-06-23	Richard Noble
02	Re-draft following review & new models added	2010-08-22	Richard Noble
03	Future plans added and layout optimisation	2010-08-26	Richard Noble

Contents

Document History 3

Contents 4

1. Introduction 11

2. Topics and models addressed in this deliverable 12

2.1. Links to DynaLearn Curricula (D6.1) 12

2.2. Educational context of modelling content and goals 13

2.3. Model presentation and documentation 13

3. Nutrient Cycles 14

3.1. Topic and model metadata 14

3.2. Topic rationale 14

3.2.1. Background 14

3.2.2. Key themes 15

3.3. Carbon cycle LS2 16

3.3.1. Concepts and goals 16

3.3.2. Model expression 16

3.3.3. Scenarios and simulations 17

3.4. Nitrogen cycle LS4 17

3.4.1. Concepts and goals 17

3.4.2. Model expression 18

3.4.3. Scenarios and simulations 18

3.5. Phosphorus cycle LS4 19

3.5.1. Concepts and goals 19

3.5.2. Model expression 20

3.5.3. Scenarios and simulations 21

3.6. Plant growth phosphorus LS4 21

3.6.1. Concepts and goals 21

3.6.2. Model expression 21

3.6.3. Scenarios and simulations 22

3.7. Conclusions and future development 23

4. Adaptation to Environmental stress 24

4.1. Topic and model metadata 24
4.2. Topic rationale 24
4.2.1. Background 24
4.2.2. Key themes 25
4.2.3. General contents and ingredients 25
4.3. Homeostasis LS4 26
4.3.1. Concepts and goals 26
4.3.2. Model expression 26
4.3.3. Scenarios and simulations 26
4.4. Conclusions and future development 28
5. Evolution 29
5.1. Topic and model metadata 29
5.2. Topic rationale 29
5.2.1. Background 29
5.2.2. Key themes 30
5.2.3. General contents and ingredients 30
5.3. Micro-evolution LS2 31
5.3.1. Concepts and goals 31
5.3.2. Model expression 32
5.3.3. Scenarios and simulations 32
5.4. Trait frequency LS2 32
5.4.1. Concepts and goals 32
5.4.2. Model expression 33
5.4.3. Scenarios and simulations 33
5.5. Fitness LS3 33
5.5.1. Concepts and goals 33
5.5.2. Model expression 34
5.5.3. Scenarios and simulations 34
5.6. Community diversity basic LS2 35
5.6.1. Concepts and goals 35
5.6.2. Model expression 35
5.6.3. Scenarios and simulations 36

5.7. Conclusions and future development 36
6. Decomposition 37
6.1. Topic and model metadata 37
6.2. Topic rationale 37
6.2.1. Background 37
6.2.2. Key concepts 38
6.2.3. General contents and ingredients 38
6.3. Model – Decomposition basic LS2 39
6.3.1. Concepts and goals 39
6.3.2. Model expression 40
6.3.3. Scenarios and simulations 40
6.4. Decomposition basic LS4 40
6.4.1. Concepts and goals 40
6.4.2. Model expression 41
6.4.3. Scenarios and simulations 41
6.5. Decomposition available nutrients LS3 42
6.5.1. Concepts and goals 42
6.5.2. Model expression 42
6.5.3. Scenarios and simulations 43
6.6. Decomposition available nutrients LS4 43
6.6.1. Concepts and goals 43
6.6.2. Model expression 44
6.6.3. Scenarios and simulations 44
6.7. Conclusions and future development 45
7. Reduce, Re-use, Recycle 46
7.1. Topic and model metadata 46
7.2. Topic rationale 46
7.2.1. Background 46
7.2.2. Key themes 47
7.2.3. General contents and ingredients 47
7.3. Reduce reuse recycle LS4 48
7.3.1. Concepts and goals 48

7.3.2. Model expression 48
7.3.3. Scenarios and simulations 48
7.4. Conclusions and future development 49
8. Human Development Index 50
8.1. Topic and model metadata 50
8.2. Topic rationale 50
8.2.1. Background 50
8.2.2. Key themes 51
8.2.3. General contents and ingredients 51
8.3. Human Development Index LS2 52
8.3.1. Concepts and goals 52
8.3.2. Model expression 52
8.3.3. Scenarios and simulations 52
8.4. Conclusions and future development 52
9. Agro-ecology systems 53
9.1. Topic and model metadata 53
9.2. Topic rationale 53
9.2.1. Background 53
9.2.2. Key themes 54
9.2.3. General contents and ingredients 54
9.3. Soil erosion LS2 55
9.3.1. Concepts and goals 55
9.3.2. Model expression 55
9.3.3. Scenarios and simulations 55
9.4. Conclusions and future development 55
10. Fishery 56
10.1. Topic and model metadata 56
10.2. Topic rationale 56
10.2.1. Background 56
10.2.2. Key themes 57
10.2.3. General contents and ingredients 57
10.3. Fishery LS4 58

10.3.1. Concepts and goals 58
10.3.2. Model expression 58
10.3.3. Scenarios and simulations 58
10.4. Fishery LS6 59
10.4.1. Concepts and goals 59
10.4.2. Model expression 59
10.4.3. Scenarios and simulations 60
10.5. Conclusions and future development 61
11. Photosynthesis 62
11.1. Topic and model metadata 62
11.2. Topic rationale 62
11.2.1. Background 62
11.2.2. Key themes 63
11.2.3. General contents and ingredients 63
11.3. Photosynthesis basic LS2 64
11.3.1. Concepts and goals 64
11.3.2. Model expression 64
11.3.3. Scenarios and simulations 64
11.4. Photosynthesis biochemistry LS3 65
11.4.1. Concepts and goals 65
11.4.2. Model expression 65
11.4.3. Scenarios and simulations 65
11.5. Photosynthesis and respiration LS4 66
11.5.1. Concepts and goals 66
11.5.2. Model expression 66
11.5.3. Scenarios and simulations 66
11.6. Conclusions and future development 67
12. Aerobic respiration 68
12.1. Topic and model metadata 68
12.2. Topic rationale 68
12.2.1. Background 68
12.2.2. Key themes 69

12.2.3. General contents and ingredients 69
12.3. Respiration basic LS2 69
12.3.1. Concepts and goals 69
12.3.2. Model expression 70
12.3.3. Scenarios and simulations 70
12.4. Conclusions and future development 70
13. Diffusion and Osmosis 71
13.1. Topic and model metadata 71
13.2. Topic rationale 71
13.2.1. Background 71
13.2.2. Key themes 72
13.2.3. General contents and ingredients 72
13.3. Diffusion one sided LS2 73
13.3.1. Concepts and goals 73
13.3.2. Model expression 73
13.3.3. Scenarios and simulations 73
13.4. Osmosis one sided LS2 74
13.4.1. Concepts and goals 74
13.4.2. Model expression 74
13.4.3. Scenarios and simulations 74
13.5. Cellular diffusion and osmosis LS4 75
13.5.1. Concepts and goals 75
13.5.2. Model expression 75
13.5.3. Scenarios and simulations 76
13.6. Conclusions and future development 77
14. River rehabilitation 78
14.1. Topic and model metadata 78
14.2. Topic rationale 78
14.2.1. Background 78
14.2.2. Key themes 79
14.2.3. General contents and ingredients 80
14.3. River rehabilitation LS2 80

14.3.1. Concepts and goals 80
14.3.2. Model expression 80
14.3.3. Scenarios and simulations 80
14.4. Conclusions and future development 81
15. Greenhouse gases and Climate change 82
15.1. Topic and model metadata 82
15.2. Topic rationale 82
15.2.1. Background 82
15.2.2. Key themes 83
15.2.3. General contents and ingredients 83
15.3. Greenhouse gases sources LS2 85
15.3.1. Concepts and goals 85
15.3.2. Model expression 85
15.3.3. Scenarios and simulations 85
15.4. Climate change basic LS3 86
15.4.1. Concepts and goals 86
15.4.2. Model expression 86
15.4.3. Scenarios and simulations 86
15.5. Climate change LS2 87
15.5.1. Concepts and goals 87
15.5.2. Model expression 88
15.5.3. Scenarios and simulations 88
15.6. Climate change LS4 89
15.6.1. Concepts and goals 89
15.6.2. Model expression 89
15.6.3. Scenarios and simulations 89
15.7. Conclusions and future development 91
16. Discussion 92
17. Conclusion 94
References 95

1. Introduction

The DynaLearn project is developing a software learning environment that integrates three well established, but as yet independent, technologies to create an individualised and engaging cognitive tool for acquiring conceptual knowledge in environmental science. The software integrates a diagrammatic approach to constructing qualitative conceptual models, ontology mapping and semantic technology to ground model building terms and compare models, and virtual character technology to provide individualised feedback and enhance motivation of learners. In addition to the software development the project is also developing a curriculum in environmental science based around the learning by modelling approach which is the cornerstone concept for the DynaLearn pedagogical approach.

Development of the learning by modelling curriculum requires the creation of a resource base of models that cover important concepts identified in the themes and topics relevant to environment science education. The relevant themes and topics were identified in project deliverable D6.1 (Salles *et al.* 2009). In addition to providing a resource base for an environmental science curriculum the topics and models (and modelling activity) presented here serve three purposes:

- Explore and test the capabilities of the new modelling software and the new learning spaces (LS);
- Provide a resource of models to help develop and test the semantic and virtual character technologies;
- Provide a resource on which lesson plans and evaluation activities can be developed.

The purpose of the first phase of modelling (Task 6.2) 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 targeted 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 knowledge. The six learning spaces in the software are as follows:

LS1 – Concept maps

LS2 – Basic causal models with emphasis on model structure, definition of entities, quantities and configurations and the sign of the relationships (positive or negative) between quantities.

LS3 – Basic causal models with state graphs focussing on the qualitative states and values of quantities that are important to the concept (including correspondences between values for different quantities).

LS4 – Causal differentiation models where the emphasis is differentiating between direct influence relationships and proportionality relationships denoting aspects of causality within the system.

LS5 – Conditional knowledge models where the emphasis is on representing consequences that may only occur under certain conditions.

LS6 – Generic and re-useable models that utilise the full qualitative modelling approach within Garp3 (Bredeweg *et al.* 2009), includes the compositional modelling approach and the use of hierarchy and inheritance of properties.

Models were developed in each learning space that was appropriate to convey key concepts in each topic in the curriculum (Section 2).

2. Topics and models addressed in this deliverable

2.1. Links to DynaLearn Curricula (D6.1)

The DynaLearn deliverable D6.1 (Salles *et al.* 2009) identified and described a series of topics in Environmental Science that cover the seven main themes identified in the project description of work (Table 2.1). These topics and themes are considered to be a comprehensive curriculum for concepts in environmental science. Table 2.1 summarises the themes and topics allocated to UH for development in work package 6. Of these topics some were initially allocated to D6.2.2 as being those that may represent basic topics and models within the curricula. Within these basic topics models were developed in all suitable learning spaces available in the prototype DynaLearn software. The appropriate learning space(s) for each topic were determined by the nature of the concepts that needed to be conveyed at the chosen educational level (Section 2.2). Some topics within themes, such as respiration/photosynthesis and greenhouse gases/climate change, were grouped and modelled together as they shared a considerable amount of concepts.

Table 2.1 Summary of themes and topics assigned to UH from the D6.1 curricula in Environmental Sciences and the topics and models covered in UH D6.2.2.

Theme	Topic	Sub-topic	LS01	LS02	LS03	LS04	LS05	LS06
ESR	Nutrient availability and cycling	Carbon cycle		✓				
		Nitrogen cycle				✓		
		Phosphorous cycle				✓		
		Nutrient cycles	✓					
	Adaptation to environmental stress[#]		✓			✓		
TLW	Evolution	Evolution	✓	✓	✓			
	Decomposition	Decomposition	✓	✓	✓	✓		
HP	Reduce, reuse, recycle[#]		✓			✓		
	Human Development Index (HDI)		✓	✓				
LWU	Agro-ecology systems[#]		✓	✓				
	Fishery[#]		✓	✓				
	Photosynthesis	Photosynthesis	✓	✓	✓	✓		
	Aerobic respiration	Cellular Respiration	✓	✓		✓		
P	Diffusion and osmosis	Diffusion and Osmosis	✓	✓	✓	✓		
	River rehabilitation[#]		✓	✓				
GC	Greenhouse gases	Green house gasses and climate change	✓	✓	✓	✓		
	Climate change[#]							

Earth Systems and Resources (ESR), The Living World (TLW), Human Population (HP), Land and Water Use (LWU), Pollution (P), and Global Changes (GC)

[#] Topics considered as advanced topics in an educational context

Many of the topics allocated within this first group are basic concepts, the understanding of which could be considered as a pre-requisite for many of the advanced topics covered by the curriculum as a whole. The topics identified as advanced topics for detailed development in later work-package tasks

are explored in this deliverable using concept maps and basic model expressions in one or more learning spaces to provide materials for the evaluation of the software and to develop the basis for future refinement and advancement of the topics and their associated models.

2.2. Educational context of modelling content and goals

Whilst the purpose of work package 6 was to develop a repository of models for use in testing the DynaLearn software, the requirement to use at least some of the models in the evaluation activities in the project means that the educational context of the topics and models must also be considered. Although construction of the models has not considered the actual use of the model in an educational setting (in terms of whether students would be learning by building or exploring the model), the modelling process has taken account of the potential education settings as a requirement to determine the content and concepts to be included within each topic.

To frame the models within an education setting the current curricula requirements of the selected topics were considered. By defining the educational level at which the models would be used, the appropriate level of content and concepts was identified. For the purposes of the basic topics considered in D6.2.2 the current A level curricula for Biology, Geography and Environmental Science in the UK were considered as the appropriate level to focus the topics and models delivered here (AQA 2007a, b; CCEA 2008; Edexcel 2008). Therefore, the content and goals for the models were mostly defined using literature and texts associated with A level guides (Pickering 2009) and text books aimed at this level. In addition to these guides, general text books aimed at under-graduate level were also used to generate the background material required to frame the models.

2.3. Model presentation and documentation

The models presented here are grouped by topic. Within each section the background knowledge relevant for the topic at the appropriate educational level is presented and a concept map (LS1) is used to represent the key concepts to be delivered. For each topic a suite of models are presented. In many cases the general model contents and ingredients are shared between the different models (model ingredients for all models are generally summarised in a single table). For each model the rationale assumption and goals are briefly summarised and the model structure is presented. For each model an example scenario and simulation or the range of possible scenarios/simulations is described. For each specific scenario the causes and conditions for the resulting behaviour are given in terms of exogenous controls, (in)equalities and ambiguity.

Models are presented for the following topics: Nutrient cycles (Section 3), Adaption to environmental stress (Section 3), Evolution (Section 4), Decomposition (Section 5), Reduce Re-use Recycle (Section 6), Human Development Index (HDI) (Section 7), Agro-ecology systems (Section 8), Fishery (Section 9), Photosynthesis (Section 10), Aerobic respiration (Section 11), Diffusion and osmosis (Section 12) River rehabilitation (Section 13)and Greenhouse gases and climate change (Section 14).

3. Nutrient Cycles

3.1. Topic and model metadata

Topic	Nutrient Cycles (Carbon, Phosphorus and Nitrogen)		
Author	R Noble	**Version(s)**	DL v0.6.12
Models	Carbon cycle LS2.hgp Nitrogen cycle LS4.hgp Phosphorus cycle LS4.hgp Plant growth phosphorus LS4.hgp		
Target users	A Level		

3.2. Topic rationale

3.2.1. Background

Nutrient cycles are the biogeochemical cycles and processes that transport and store nutrients vital to life on earth. The nutrients most often considered within this topic at A level are Nitrogen, Phosphorus and Carbon. However, water in the form of the hydrological cycle is often also considered a nutrient cycle in its own right in addition to the fundamental role it plays in the cycling of many other nutrients. One of the fundamental concepts involved in the nutrient cycle topic is the movement of the nutrients in different forms through gaseous (atmospheric), hydrological, sedimentary and biological "reservoirs". A number of physical processes (e.g. hydrological cycle) and biological processes (decomposition, photosynthesis and respiration) are involved in transporting nutrients between these stores (Figure 3.1). A general model for a nutrient cycle would consider that the nutrients move between four general modes depending on whether the nutrient was in an organic or inorganic form and whether it was available or unavailable to be utilised by plants or animals (Campbell 1993; Gregory *et al.* 2009; Pickering 2009).

The carbon cycle is a fundamental concept in environmental science and is pre-requisite knowledge for considering the impacts of green house gas emissions (e.g. carbon dioxide and methane) on global climate change. Many of the feedback mechanisms for climate change are directly linked to carbon cycle processes. In general the carbon cycle is the reciprocal process of photosynthesis and respiration.

The key concept for the nitrogen cycle is the exchange of various nitrogenous compounds in the soil by bacteria. Whilst all nutrient cycles pass through the soil community, directly linked to the decomposition process, the cycles within the soil are particularly important for the nitrogen cycle, as there is only a limited contribution of nitrogen fixation (direct capture from atmospheric nitrogen).

The phosphorus cycle differs from most other nutrient cycles in that there is no atmospheric form of phosphorus. Two cycles occur within the phosphorus cycles that act on very different time scales. The

first occurs on a biological timescale and involves the local cycling of phosphorus through plants (producers), animals (consumers) and the soil community (decomposition). The second cycle occurs on a geological timescale and is the process of weathering and sedimentation of rock and inorganic forms of phosphorous.

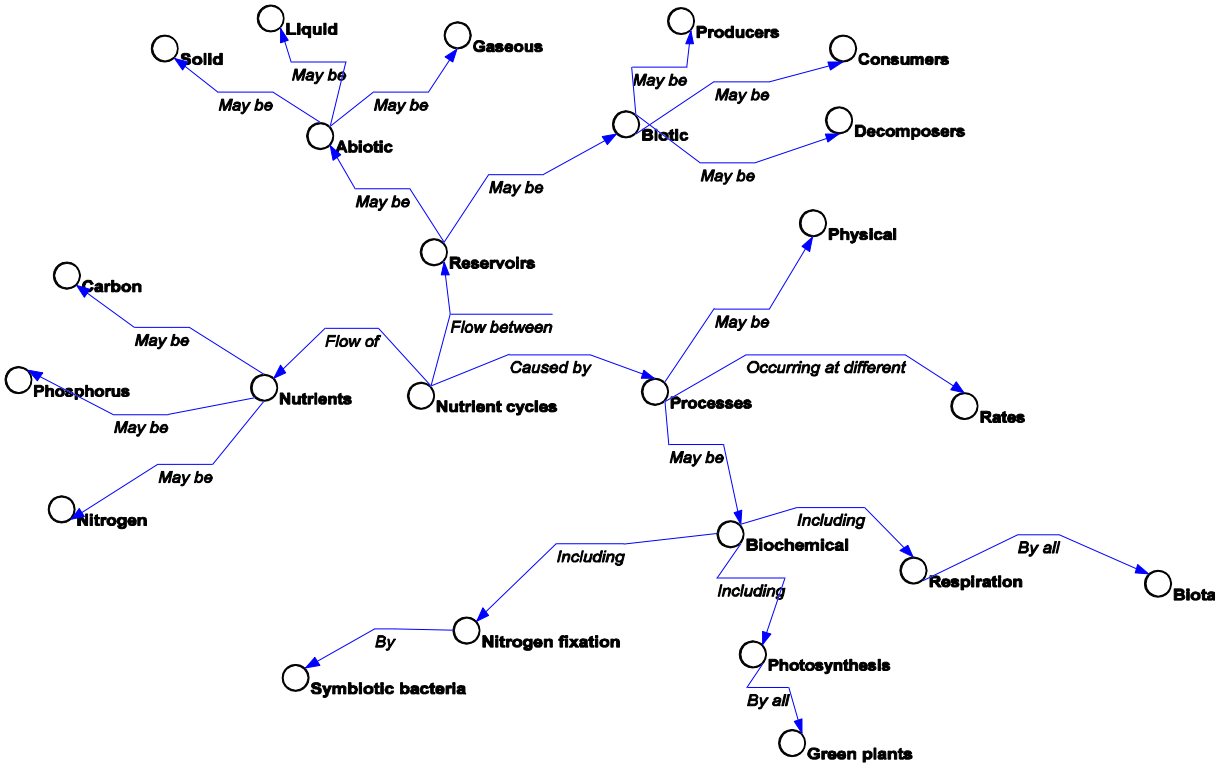

Figure 3.1 Concept map of the nutrient cycles topic prepared in the concept map learning space of the DynaLearn software.

3.2.2. Key themes

- Nutrients exist in a number of “reservoirs”, in solid, liquid, gaseous and both organic and inorganic forms.
- A number of biotic and abiotic (physical and chemical) processes control the movement of nutrients between theses reservoirs.
- Nitrogen availability to plants is greatly aided by the activity of mutualistic and soil living bacteria.
- Phosphorus availability can limit plant growth – hence the need for agricultural fertilisation.
- Photosynthesis and respiration are the key processes in biotic side the carbon cycle.

3.3. Carbon cycle LS2

3.3.1. Concepts and goals

This basic causal model represents the main “reservoirs” of organic and inorganic carbon in the environment and the main processes (photosynthesis, respiration and decomposition) involved in the movement of carbon between these different forms and reservoirs. The model considers both the terrestrial and aquatic environments. The entities and quantities used in the model are summarised in Table 3.1.

Table 3.1 Entities, quantities and quantity spaces (QS) used in the model Carbon cycle LS2.

Entity	***Quantities***	***QS***	***Remarks***
Biotic reservoir	Amount of stored carbon	*na*	Total amount of carbon in all biota
Terrestrial life	Respiration	*na*	
	Photosynthesis	*na*	
	Aerobic decay	*na*	Release of CO_2 from dead organic matter
	Anaerobic decay	*na*	Primary mechanism forming coal/peat/oil
Aquatic Life	Respiration	*na*	
	Photosynthesis	*na*	
	Aerobic decay	*na*	Release of CO_2 from dead organic matter
	Anaerobic decay	*na*	Primary mechanism forming oil/gas
Atmospheric reservoir	Amount of stored carbon	*na*	Mainly as CO_2
Earth reservoir	Amount of stored carbon	*na*	Fossil fuels such as coal/oil/gas/minerals
Ocean reservoir	Amount of stored carbon	*na*	Dissolved CO_2
	Absorption	*na*	
Humans	Combustion of fossil fuels	*na*	

3.3.2. Model expression

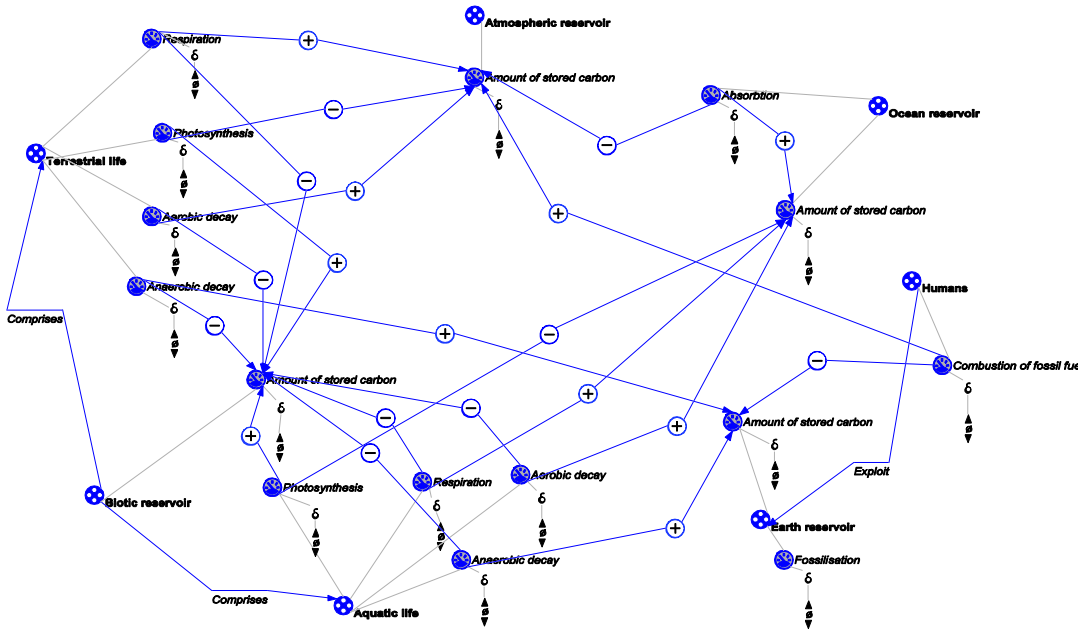

Figure 3.2 Model expression for Carbon cycle LS2 built in the basic causal model learning space of the DynaLearn software.

3.3.3. Scenarios and simulations

This model acts more as a diagrammatic representation of the system structure and main dynamic relationships in the Carbon cycle. For this model to be simulated students will have to consider the behaviour of many of the processes, as such it may be of use to discuss enabling conditions in scenarios and/or aspects of the system that could be expanded into a more detailed model.

3.4. Nitrogen cycle LS4

3.4.1. Concepts and goals

This causal differentiation model represents the key components and processes of the nitrogen cycle in the context of nutrients in a food chain and the importance of mutualistic bacteria for the assimilation of nitrogen in plants in the form of ammonium and its conversion into amino acids and other organic forms. The key elements in the system are the different types of bacteria that undertake the decay, nitrification and fixation processes releasing stored nitrogen from dead organic matter and making it available. The entities and quantities used in this model, together with their quantity spaces are summarised in Table 3.2.

Table 3.2 Entities, quantities and quantity spaces (QS) used in the model Nitrogen cycle LS4.

Entity	***Quantities***	***QS***	***Remarks***
Soil			
Rhizophere	Amount of nitrogen	P	Soil atmosphere
Soil solution	Amount of ammonium	Zp	
	Amount of nitrite	Zp	
	Amount of nitrate	Zsml	
Dead organic matter	Amount of organic nitrogen	Zp	
Animals	Amount of organic nitrogen	P	Consumers
	Death	Zp	
	Consumption	Zp	
Plants	Amount of organic nitrogen	P	Primary producers
	Reduction rate	Zp	
	Amount of ammonium	Zp	
	Growth	Zp	
Mutualistic bacteria	Fixation rate	Zp	
Saprobiotic bacteria	Decomposition rate	Zp	
Nitrosomonas bacteria	Nitrification rate	Zp	
Nitrobacter bacteria	Nitrification rate	Zp	

Zsml {Zero, Small, Medium, Large}

3.4.2. Model expression

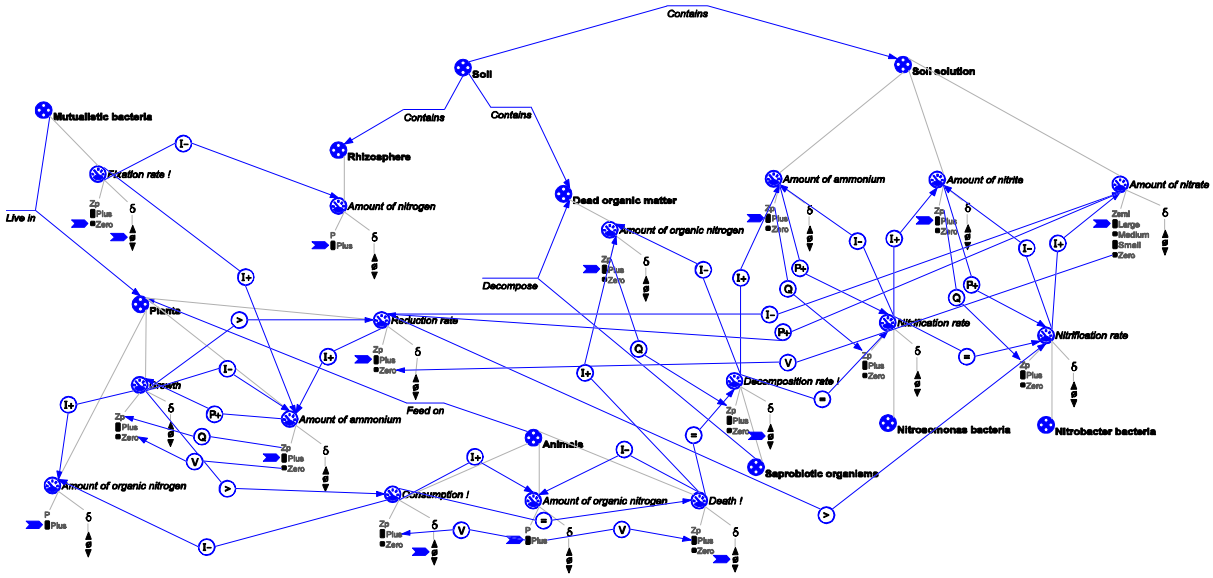

Figure 3.3 Model expression for Nitrogen cycle LS4 built in the basic causal differentiation model learning space of the DynaLearn software.

3.4.3. Scenarios and simulations

The scenario presented in Nitrogen cycle LS4 (Table 3.3 and Figure 3.3) highlights that growth of plants acts to reduce the amount of nitrate in the soil solution (in the absence of mutualistic bacteria). In such a case the amount of nitrate in the soil can become limiting to growth. The three possible end states shown in this simulation indicate that growth can become limited by the amount of nitrate available (in either Large, Medium or Small amount) (Figure 3.4). In this case the assimilation of nitrate into the plant matches the rate at which nitrification bacteria can replace it from decaying organic matter. Alternatively the scenario could be run in the presence of mutualistic bacteria, which are able to fix atmospheric nitrogen gas into ammonium. In such a case the growth of the plant is no longer restricted by the availability of nitrate in the soil.

Table 3.3 Scenario information – causes and conditions for simulating Nitrogen cycle LS4

Type	Details
Exogenous control	Fixation rate (Mutualistic bacteria) *Steady* Decomposition rate (Saprobiotic bacteria) *Steady* Consumption (Animals) *Steady* Death (Animals) *Steady*
(In)equality	Consumption = Death (Animals) Decomposition rate (Saprobiotic organisms) = Nitrification rate (Nitrosomonas bacteria) Nitrification rate (Nitrosomonas bacteria) = Nitrification rate (Nitrobacter bacteria) Growth > Reduction rate (Plants) Growth (Plants) > Consumption (Animals)
Ambiguity	None

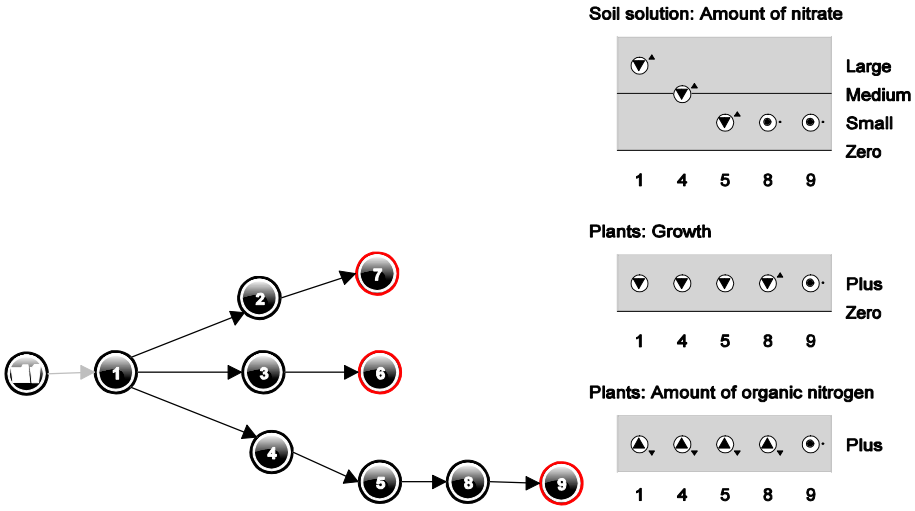

Figure 3.4 Behaviour path and value history for the full simulation of Nitrogen cycle LS4

3.5. Phosphorus cycle LS4

3.5.1. Concepts and goals

This causal differentiation model represents the key elements and processes involved in the phosphorus cycle. The model includes both the biotic and geological sides of the cycle. Cycling of phosphorus through the local biotic side of the system is far quicker than the movement of phosphorus through the geological component of the system. An important comparison of the phosphorus cycle with the other nutrient cycles is the absence of an atmospheric component to the cycle. The entities, quantities and quantity spaces used in this model (and re-used in Plant growth phosphorus LS4) are summarised in Table 3.4.

Table 3.4 Entities, quantities and quantity spaces (QS) used in the model Phosphorus cycle LS4 and Plant growth phosphorus LS4

Entity	*Quantities*	*QS*	*Remarks*
Earth			
Soil	Amount of phosphorus	Zp	
	Leaching	Zp	Loss of phosphorus from the soil due to run-off in the hydrological cycle
Rock	Amount of phosphorus	P	
	Erosion	Zp	Breaking down of rocks and dissolving of nutrients by rainfall
Sediments	Amount of phosphorus	Zp	
	Compaction	Zp	Creation of rocks over a geological timeframe
Oceans	Amount of phosphorus	Zp	
	Sedimentation	Zp	Solid materials containing phosphorus falling out of solution
Animals	Amount of phosphorus	Zp	
	Consumption	Zp	
	Death	Zp	
Plants	Amount of phosphorus	Zp	
	Assimilation	Zp	
	Death	Zp	
	Yield	Zsml	
Dead organic matter	Amount of phosphorus	Zp	
Decomposers	Decomposition	Zp	
Farmer	Fertilisation	Zp	Agent

Zsml {Zero, Small, Medium, Large}

3.5.2. Model expression

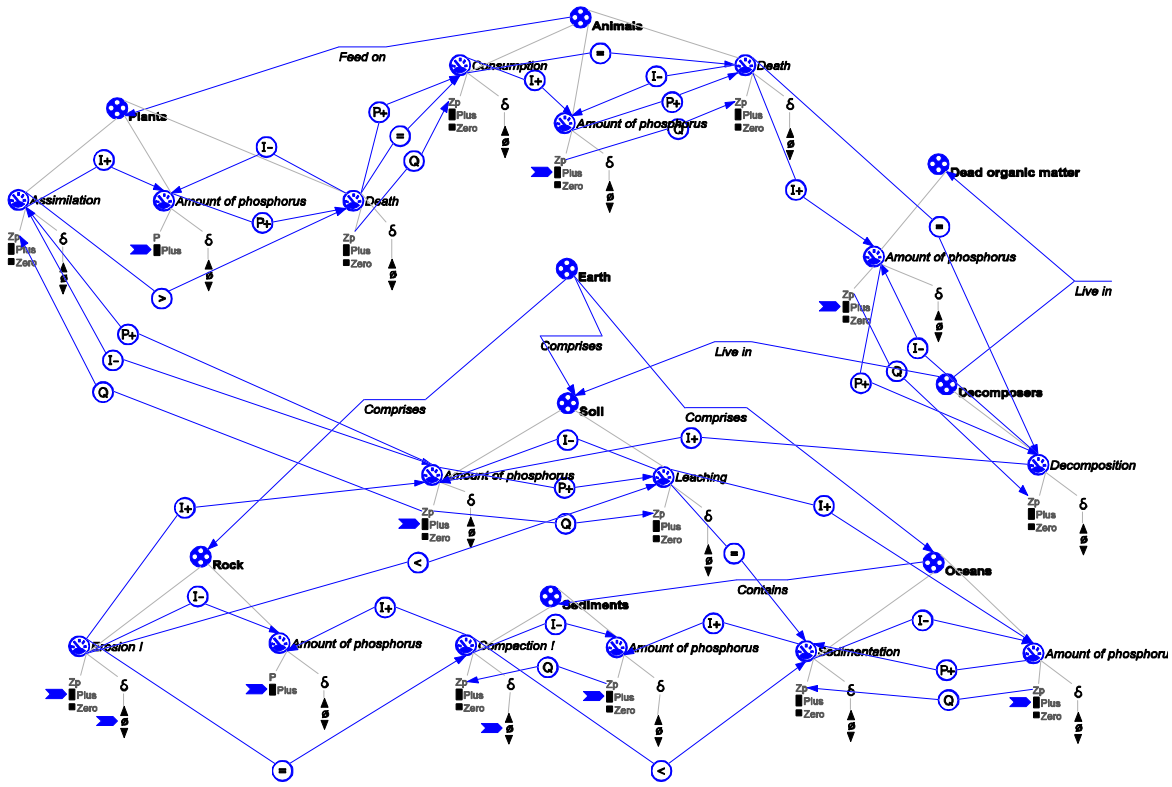

Figure 3.5 Model expression for Phosphorus cycle LS4 built in the causal differentiation model learning space of the DynaLearn software.

3.5.3. Scenarios and simulations

Scenarios for this model generates very complicated and long simulations that currently are both time and memory consuming. As such they are currently difficult to generate and explore. Therefore, details are not presented here. This model will be explored further as part of the advanced topics and models. It is probable that translation of the concepts in this model into the more advanced learning spaces may allow the generation and control of more manageable simulations.

Table 3.5 Scenario information – causes and conditions for simulating Phosphorus cycle LS4

Type	Details
Exogenous control	Erosion (Rock) *steady* Compaction (Sediments) *steady*
(In)equality	Erosion (Rock) = Compaction (Sediments) Compaction (Sediments) < Sedimentation (Oceans) Sedimentation (Oceans) = Leaching (Soil) Erosion (Rock) < Leaching (Soil) Assimilation (Plants) > Death (Plants) Consumption = Death (Animals) Death (Animals) = Decomposition (Decomposers)
Ambiguity	None

3.6. Plant growth phosphorus LS4

3.6.1. Concepts and goals

This causal differentiation model considers the relationship between nutrient availability (phosphorus) and Growth/Yield in plants. The model represents that plant growth consumes the phosphorus from the soil. The model also considers the action of a Farmer agent who fertilises the soil.

3.6.2. Model expression

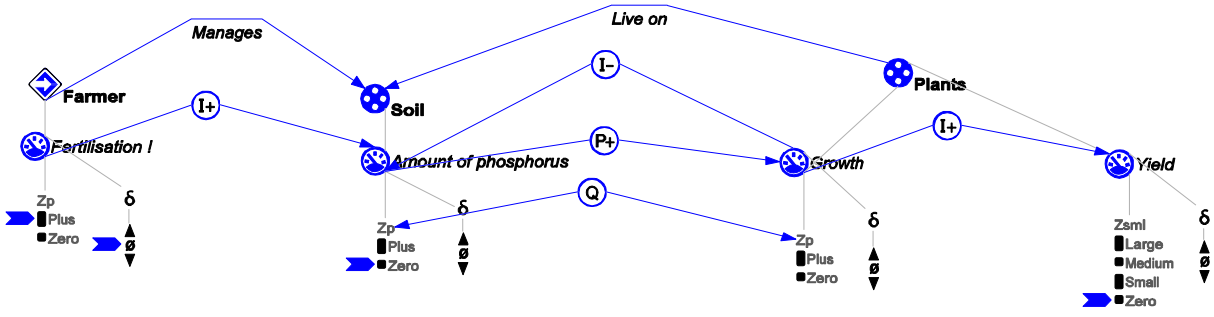

Figure 3.6 Model expression for Plant growth phosphorus LS4 built in the causal differentiation model learning space of the DynaLearn software.

3.6.3. Scenarios and simulations

This model can be simulated with or without the action of the Farmer agent fertilising the soil (Table 3.6). In the scenario where the farmer does not undertake fertilisation the plant growth consumes the phosphorus from the soil and as the amount of phosphorus declines so does the growth (Figure 3.7). Eventually both the growth and the amount of phosphorus in the soil become zero and plant yield becomes stable. This simulation has three end states with yield stabilising in either the small, medium or large value. This occurs because there is no way to define how much phosphorus is in the soil in such a way that the final amount of yield could be related to it (for example it is difficult in LS4 [or even LS6]) to express that a small amount of phosphorus produces a small yield).

Table 3.6 Scenario information – causes and conditions for simulating Plant growth phosphorus LS4

Type	Details
Exogenous control	Fertilisation (Farmer) zero OR plus *Steady*
(In)equality	None
Ambiguity	None

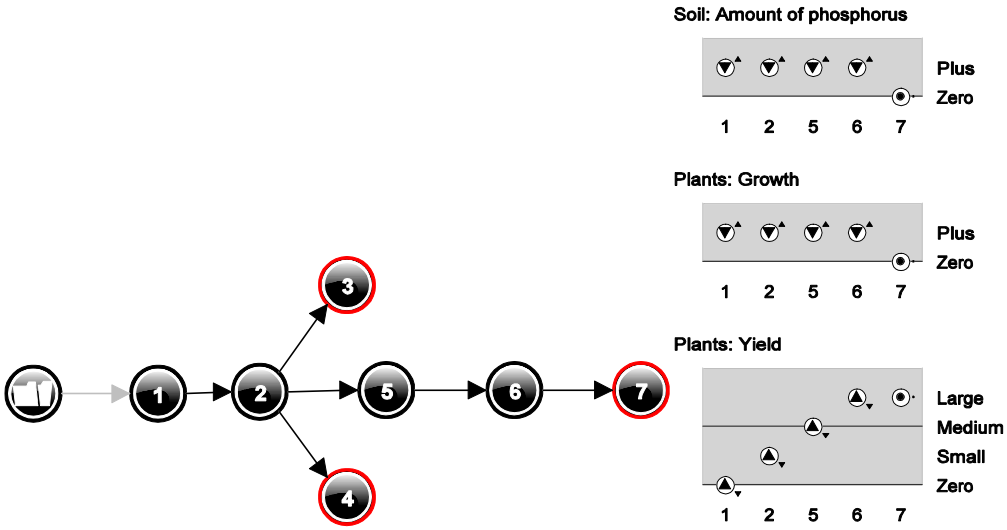

Figure 3.7 Behaviour path and value history for the full simulation of scenario 1 – Zero fertilisation in Plant growth phosphorus LS4

In the alternative scenario the fertilisation of the soil by the farmer results in a single end state with a large (and increasing) yield achieved as growth is maintained (Figure 3.8). In this case, whilst growth is still limited by the availability of phosphorus as a nutrient growth continues because the amount of phosphate in the soil is replenished by constant fertilisation.

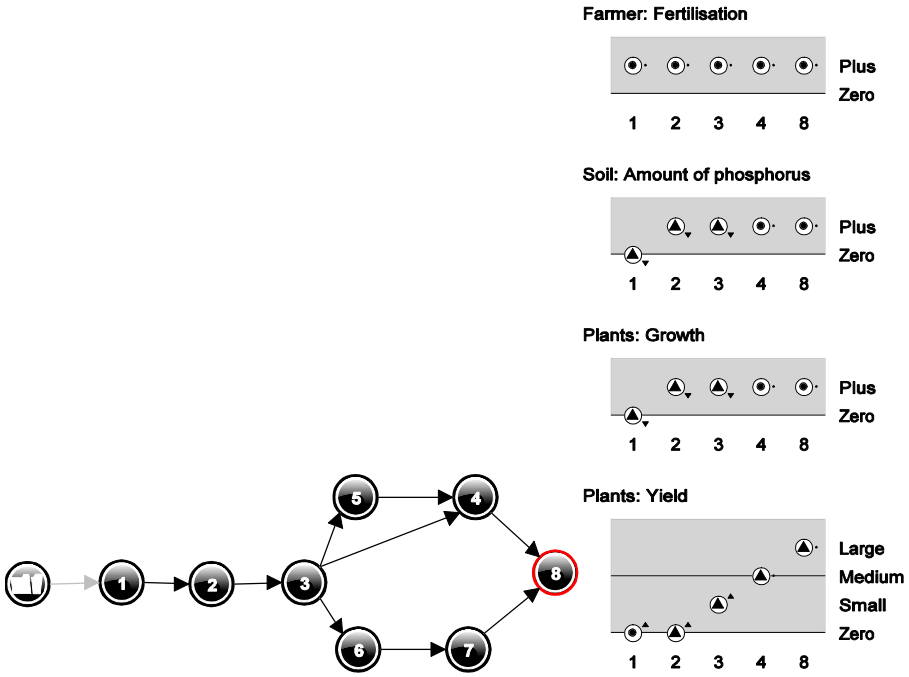

Figure 3.8 Behaviour path and value history for the full simulation of scenario 2 – farmer fertilises soil in Plant growth phosphorus LS4

3.7. Conclusions and future development

- Develop links between the basic topics of nutrient cycling and the advance Agro-ecology topics to explore the concepts involved in agriculture and fertilisation.
- Develop models in the advanced learning spaces (LS5 Conditional Knowledge and LS6 Generic and reusable knowledge).
- Develop models that explore themes of nutrient availability as a limiting factor in agricultural production and link to agricultural concepts such as crop rotation.
- Link the topic and models to themes linked with nutrient enrichment of freshwaters e.g. eutrophication and pollution.

4. Adaptation to Environmental stress

4.1. Topic and model metadata

Topic	Adaptation to environmental stress		
Author	R Noble	**Version(s)**	DL v0.6.12
Models	Homeostasis_LS4.hgp		
Target users	A Level		

4.2. Topic rationale

4.2.1. Background

There are almost no environments on earth which exhibit constant conditions. As such life has evolved to be able to cope with both extreme and fluctuating conditions. In general animals have evolved two strategies for coping with changing environmental conditions; either conforming to the external conditions or regulating their internal environment to maintain optimum internal conditions in the face of changing external conditions. Regulators attempt to maintain optimum conditions through homeostasis. Homeostasis can be seen in osmoregulation of biota in saline and freshwater environments and in regulation of body temperature (Withers 1992).

Animals exhibit three main adaptive approaches to changing environmental conditions:

- Behavioural – where the animal alters behaviour or location to avoid unfavourable conditions or attempt to alter the local conditions to better suit their needs (cooperative social behaviour or bioturbation)
- Morphological – the morphology of an organism may change in response to seasonal changes in the environment (e.g. leaf shape, fur etc.) (Dorit *et al.* 1991)
- Physiological – some organisms are capable of adapting physiologically to new conditions (acclimation).

Animals that regulate their internal conditions do so at an energetic cost (Campbell 1993).

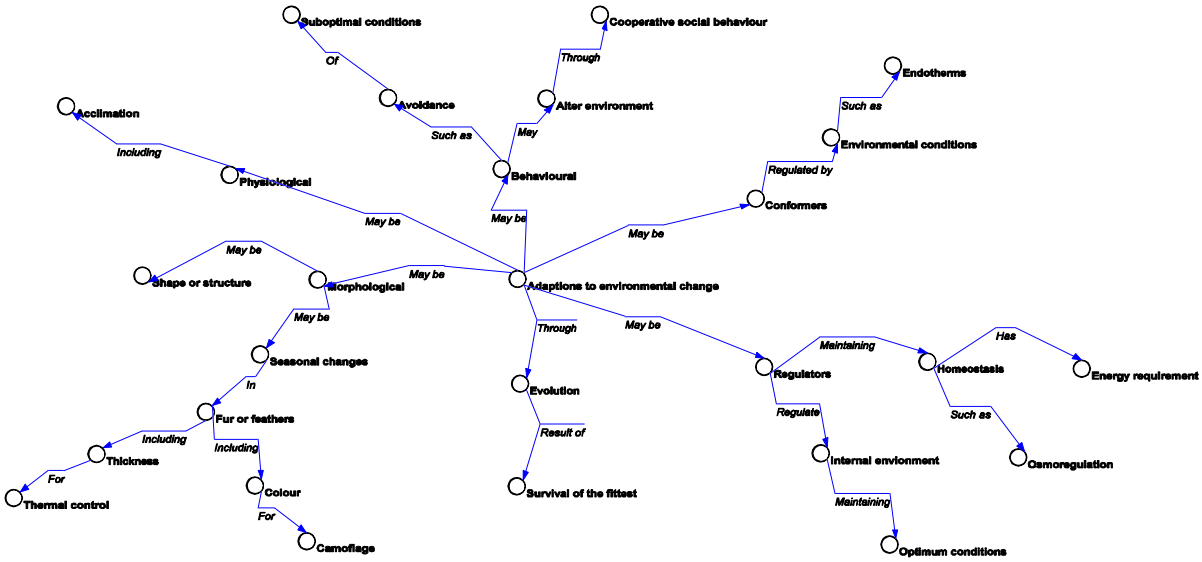

Figure 4.1 Concept map of the adaption to environmental change topic prepared in the concept map learning space of the DynaLearn software.

4.2.2. Key themes

- Animals either regulate their internal environment or conform to the conditions of the surrounding environment
- Homeostasis as the means for maintaining internal conditions
- Adaption may be behavioural, physiological or morphological
- Adaption may occur over a short time-scale (acclimation) or a longer evolutionary time scale

4.2.3. General contents and ingredients

Table 4.1 Entities, quantities and quantity spaces (QS) used in the model Homeostasis LS4.

Entity	***Quantities***	***QS***	***Remarks***
Environment	Temperature	*Zsos*	
	Temperature differential	*Mzp*	Temperature gradient between the environment and the organism
Organism	Optimal body temperature	*Zsos*	
	Body temperature	*Zsos*	
	Heat stress	*Mzp*	Prevailing conditions whether organism is heating up or cooling down due to environmental temperature
	Metabolic response	*Mzp*	Range of responses that act to regulate body temperature e.g. shivering

4.3. Homeostasis LS4

4.3.1. Concepts and goals

This causal differentiation model represents the concept of homeostasis in the context of regulation of an animal's body temperature at an optimum level. Body temperature is regulated as a balance of the inputs/outputs of heat through Heat stress and the metabolic activities that regulate heat production and loss within the body. Heat stress is itself represented as the difference between the optimum body temperature and the actual body temperature (using a calculus). Body temperature has a tendency to change with environmental conditions through the temperature differential between the environmental temperature and the body temperature (determined using a calculus). The metabolic response of the organism acts to maintain the body temperature at the optimum value.

4.3.2. Model expression

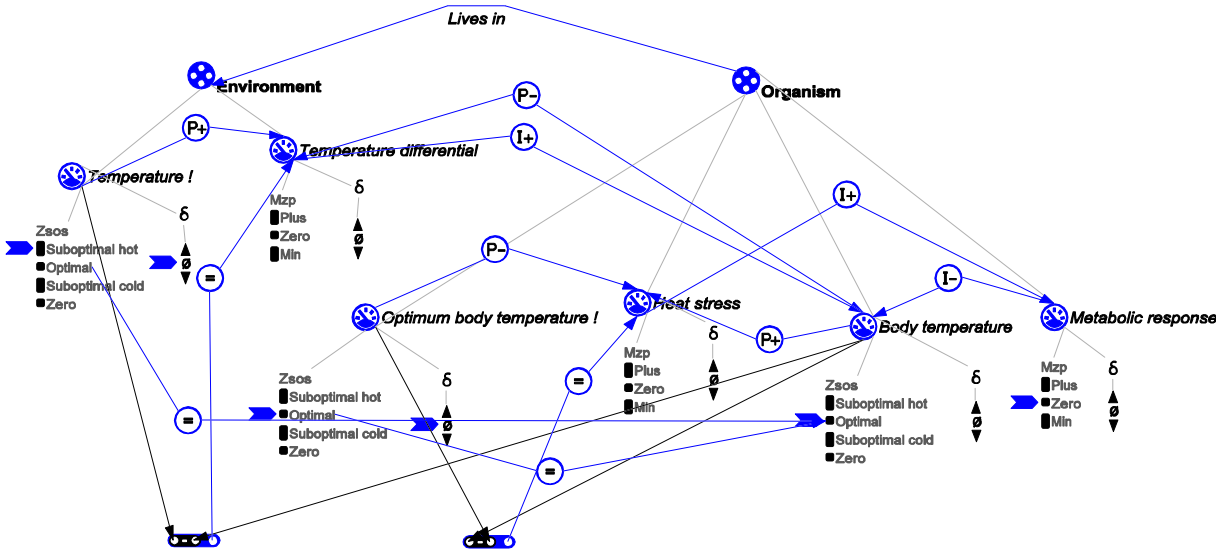

Figure 4.2 Model expression for Homeostasis LS4 built in the basic causal model learning space of the DynaLearn software.

4.3.3. Scenarios and simulations

Homeostasis LS4 can be simulated to represent a scenario where the external temperature of the environment is higher than the optimal body temperature and acts to increase the internal body temperature (Table 4.2 and Figure 4.2).

Table 4.2 Scenario information – causes and conditions for simulation of Homeostasis LS4

Type	Details
Exogenous control	Temperature (Environment) *Sub-optimal hot, steady* Body temperature *Optimal* Metabolic response *Zero*
(In)equality	*na*
Ambiguity	*na*

This scenario generates a simulation which contains cyclical behaviours (Figure 4.3). These cyclical behaviours are a representation of homeostasis acting as a feedback mechanism that acts to maintain optimum body temperature. Optimum body temperature is not maintained exactly or constantly, there is a constant oscillation of body temperature around the optimum value caused by fluctuating levels of metabolic activity that act to either increase or decrease body temperature (Figure 4.4).

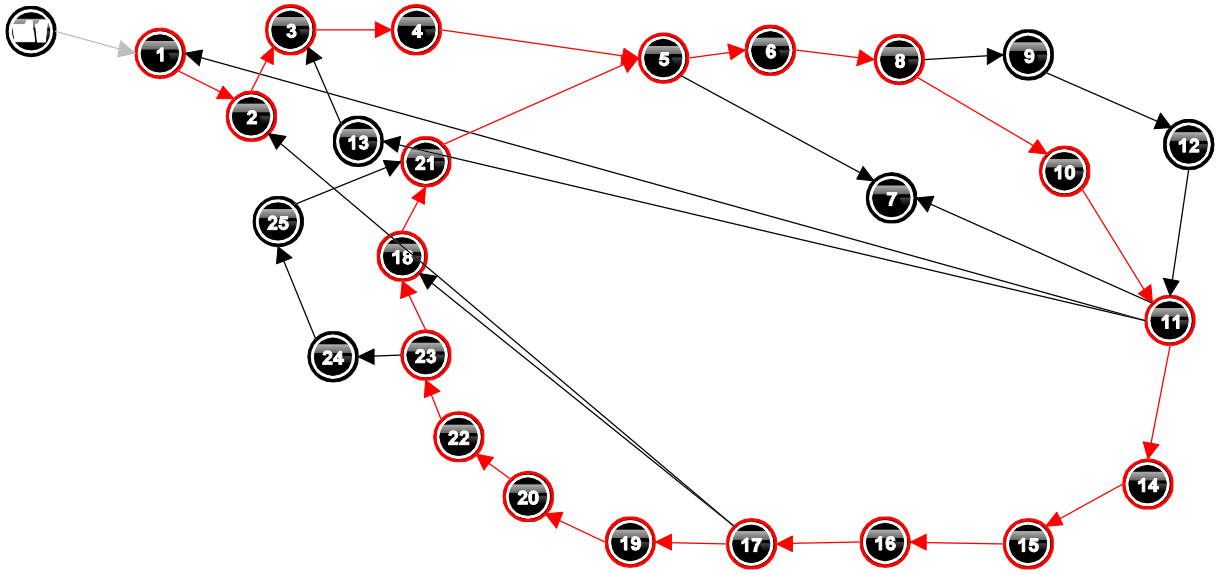

Figure 4.3 Behaviour path for the full simulation of Homeostasis LS4, a behaviour path including cyclical behaviour is highlighted.

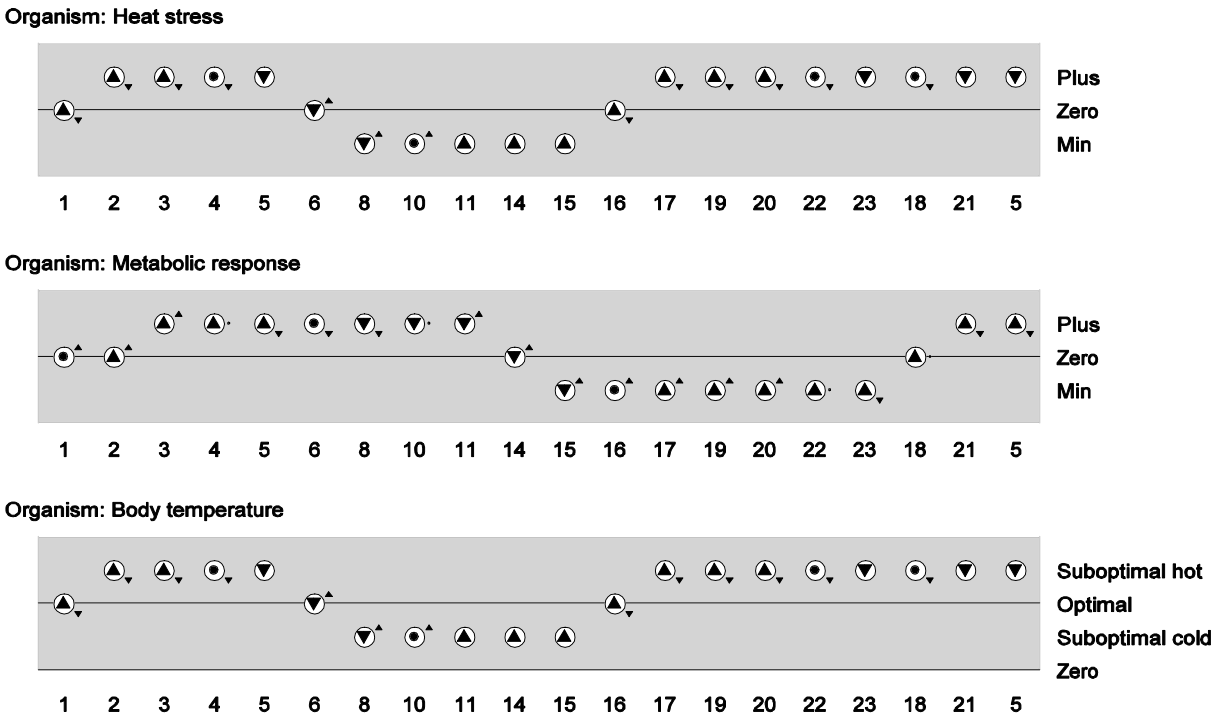

Figure 4.4 Value history of a cyclical behaviour path in LS4.

4.4. Conclusions and future development

- Develop models in the advanced learning spaces (LS5 Conditional Knowledge and LS6 Generic and reusable knowledge).
- Develop topic materials to highlight the links between homeostasis, osmoregulation and topics such as diffusion and osmosis and climate change.
- Develop models of other common physiological mechanisms for adapting to changing environmental conditions.

5. Evolution

5.1. Topic and model metadata

Topic	Evolution		
Author	R Noble	Version(s)	DL v0.6.12
Models	Micro-evolution LS2.hgp Trait frequency LS2.hgp Fitness LS3.hgp Community diversity basic LS2.hgp		
Target users	A Level		

5.2. Topic rationale

5.2.1. Background

The concept of evolution has been described as the theory that binds together all other biological and ecological concepts. Evolution is interaction of all the processes that change biodiversity (species or communities) over time. This can be viewed at the genetic, population and community level. Key components of evolution are heritability, descent with modification and the selection for increased species fitness and adaption to the environment. Selection can be driven by environmental pressure or non-random mating patterns. Darwinian evolution considers the relationship between population over production (most species produce more off-spring than can survive), inherent variability between individuals and competition and the struggle for existence. These traits lead to the concept of survival of the fittest and natural selection. As such evolution can be seen as the interaction between environmental and population variability.

At the scale of the population gene pool the genetic diversity of a population can change over time through gene flow (from external populations), mutation, non-random mating and natural selection. Survival of the fittest, of individual fitness, is considered as the relative contribution an individual makes to the following generation and the persisting gene pool of the population. As such selection can act to increase the frequency of beneficial and successful traits in individual variability at the expense of deleterious or less competitive traits.

Over geological time biodiversity can change through the extinction or creation of new species. New species can evolve from a common ancestor through natural selection and adaption to environmental conditions under a number of isolation mechanisms (habitat, spatial, temporal, behavioural or mechanical) or through genetic bottle necks (catastrophic events) and the founder effect (a small number of individuals exploiting a new and isolated environment) (Campbell 1993; Pickering 2009; Gregory 2009).

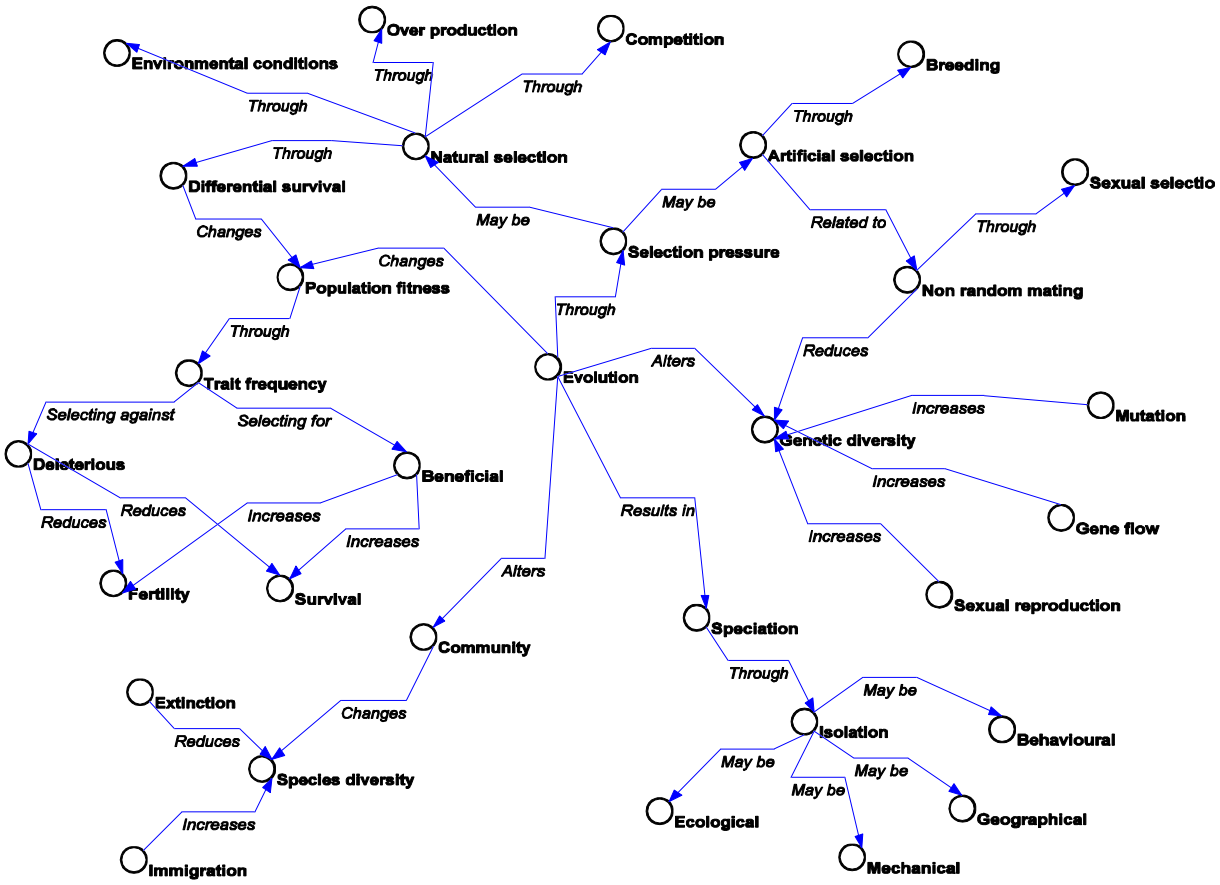

Figure 5.1 Concept map of the evolution topic prepared in the concept map learning space of the DynaLearn software.

5.2.2. Key themes

- Evolution of community structure through speciation, extinction and species redistribution.
- The key processes affecting the genetic diversity of a species/population as a foundation for the process of speciation.
- The role of environmental selection in driving the genetic structure (genotypes, phenotype and traits) of a population.

5.2.3. General contents and ingredients

All of the models developed in different learning spaces for the Evolution topic comprise a suite of entities and associated quantities that are re-used or modified. The entities and quantities used are summarised in Table 5.1. Not all entities and quantities are used in all models.

Table 5.1 Entities, quantities and quantity spaces (QS) used in the models Micro-evolution LS2, Trait frequency LS2, Fitness LS3 and Community diversity basic LS2.

Entity	Quantities	QS	Remarks
Population	Mutation	*na*	Random genetic change
	(Natural) Selection	*na*	Process acting to cause differential survival between different individual traits in a population
	Non random mating	*na*	Sexual selection or breeding
	Genetic diversity	*na*	
	Sexual reproduction	*na*	Reproduction with meiosis
	Fitness	*na*	
Neighbour population	Gene flow	*na*	
Humans	Artificial selection	*na*	Breeding for desired traits
Trait	Frequency	*na*	
Environment	Selection pressure	*na*	Acting to cause different survival rates of different traits in a population
Species		*na*	
Genotype	Survival	*na*	
	Fertility	*na*	
	Frequency	*Zlmha*	
Community	Speciation	*na*	Process of new species formation
	Species diversity	*na*	Species richness in a community
	Invasion	*na*	
	Extinction	*na*	Loss of a species either through selection or catastrophic events

Zlmha {Zero, Low, Medium, High, All}

5.3. Micro-evolution LS2

5.3.1. Concepts and goals

Micro-evolution LS2 is a basic causal model of the main processes that affect the genetic diversity of a population. The model contains three processes that increase genetic diversity (sexual reproduction, mutation & gene flow from a neighbour population) and two processes acting to decrease genetic diversity (non-random mating & natural selection). This model of micro-evolution at the genetic level is the foundation for the process of speciation and community evolution.

5.3.2. Model expression

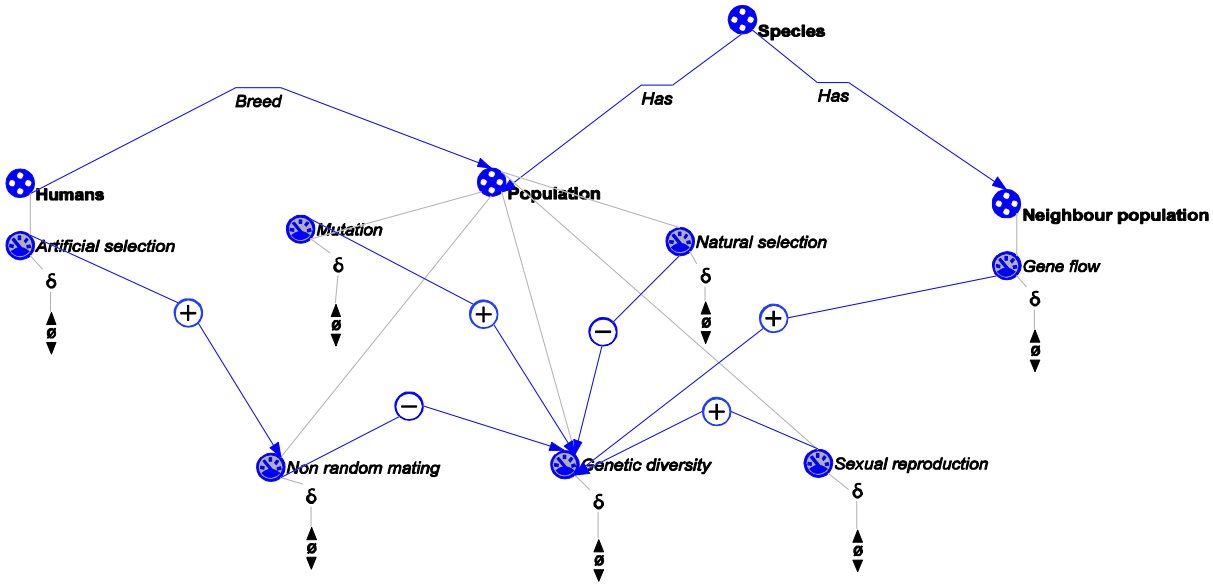

Figure 5.2 Model expression for Micro-evolution LS2 built in the basic causal model learning space of the DynaLearn software.

5.3.3. Scenarios and simulations

This model can be simulated in LS2 to consider increases/decreases in any of the key processes affecting genetic diversity.

5.4. Trait frequency LS2

5.4.1. Concepts and goals

Train frequency LS2 is a basic causal model representing the action of selection pressure from the environment acting on the fitness of a population to survive in the prevailing environmental conditions. Selection works by altering the relative frequency of different traits some of which are beneficial to survival and some of which are deleterious to survival and will therefore be selected against. A population with a higher frequency of beneficial traits will have a greater fitness than one where the deleterious trait has a higher frequency

5.4.2. Model expression

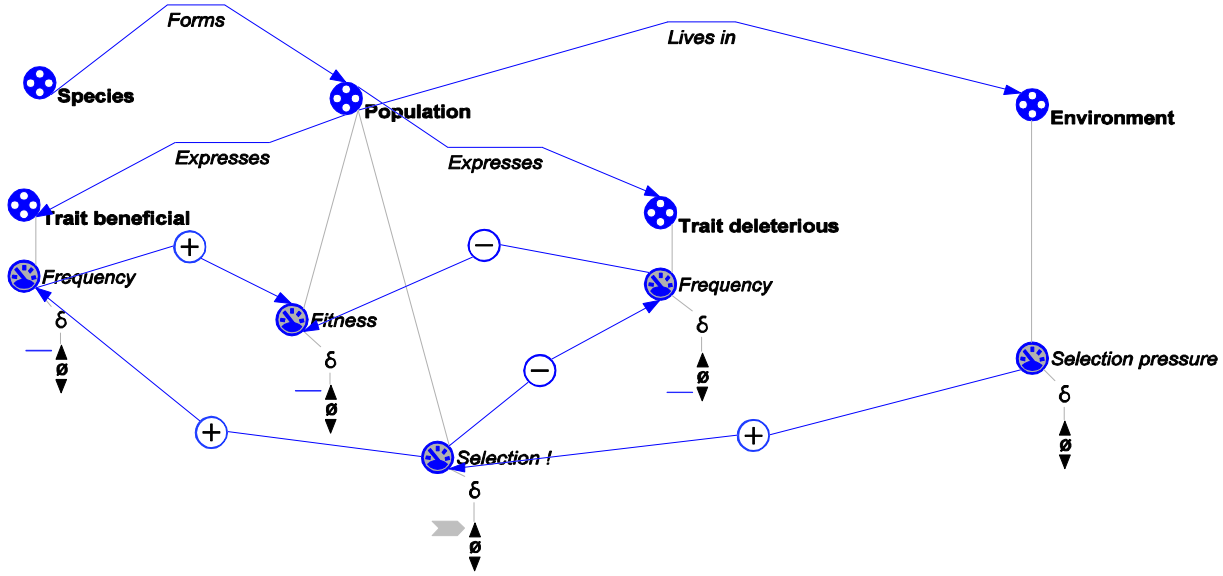

Figure 5.3 Model expression for Trait frequency LS2 built in the basic causal model learning space of the DynaLearn software.

5.4.3. Scenarios and simulations

This model can be simulated in LS2 to consider the effects of increasing/decreasing selection pressure (Table 5.2). If environmental selection pressure is increasing then population selection is increasing resulting in an increasing frequency of beneficial traits and a decreasing frequency of deleterious traits. The net result of which is an increasing population fitness (Figure 5.3).

Table 5.2 Scenario information – causes and conditions for simulation of Trait frequency LS2

Type	**Details**
Exogenous control	Selection pressure (Environment) *increase*
(In)equality	*na*
Ambiguity	*na*

5.5. Fitness LS3

5.5.1. Concepts and goals

This model expands on “Traits frequency LS3” in a basic causal model with state graph where the mechanism for selection includes the concept that it acts through either or both of survival and fertility of a particular genotype that relates to a specific trait (modelled as an attribute). In this model the frequency of a genotype is given a quantity space of {Zero, Low, Medium, High, All} indicating the frequency of the genotype in the population in relation to the frequency of other genotypes. In this

case there is also an inverse correspondence between the quantity spaces of the two genotype frequencies to show that if there is a high frequency of one genotype there must be only a low frequency of the other genotype.

5.5.2. Model expression

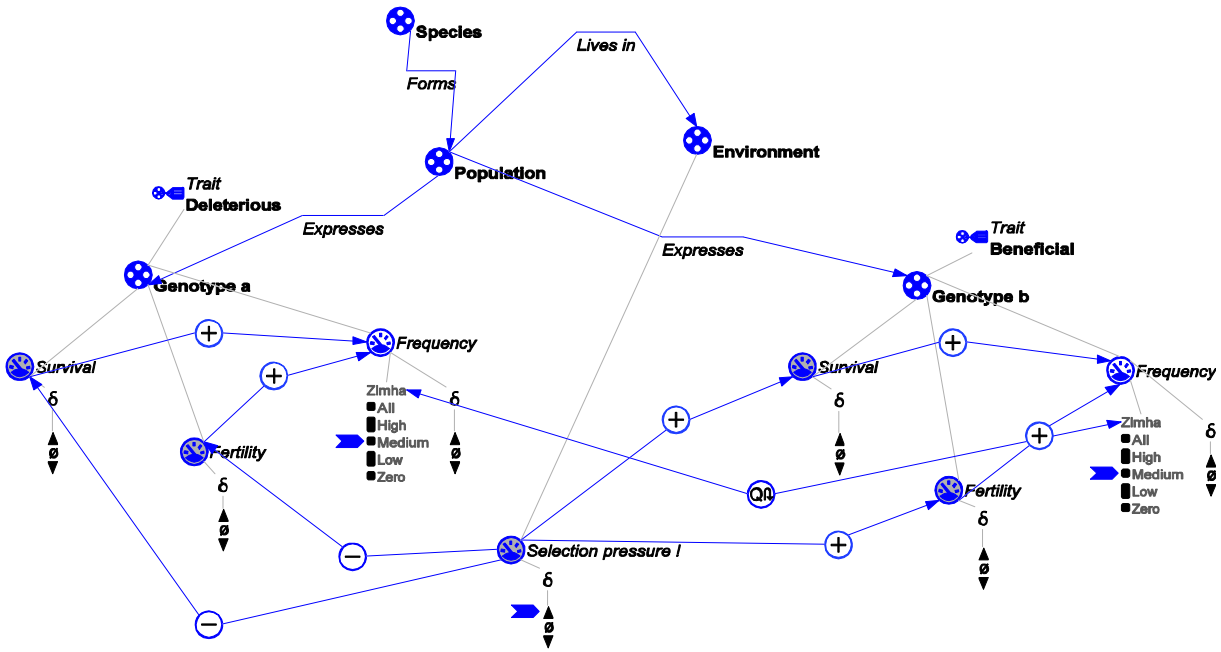

Figure 5.4 Model expression for Fitness LS3 built in the basic causal model learning space of the DynaLearn software.

5.5.3. Scenarios and simulations

This model can simulate the effect of increasing selection pressure on the frequency of two genotypes (Table 5.3). In this case the frequency of genotype a (deleterious trait) is selected against and decreases whilst the frequency of genotype b (beneficial trait) increases (Figure 5.5). Note at this point the simulation will not continue to a point where both quantities are in the extreme points of their quantity spaces.

Table 5.3 Scenario information – causes and conditions for simulation of Fitness LS3

Type	**Details**
Exogenous control	Selection pressure (Environment) *increase*
(In)equality	None
Ambiguity	None

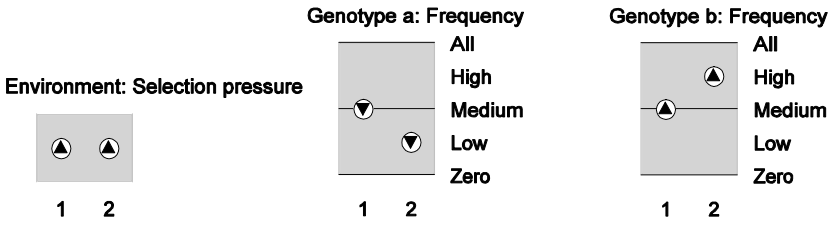

Figure 5.5 Behaviour path and value history for the full simulation of Fitness LS3.

5.6. Community diversity basic LS2

5.6.1. Concepts and goals

This basic causal model represents the key processes that change the species diversity of a community in the short time scale (species Invasion), short/long-term (extinction) and over geological time (speciation).

5.6.2. Model expression

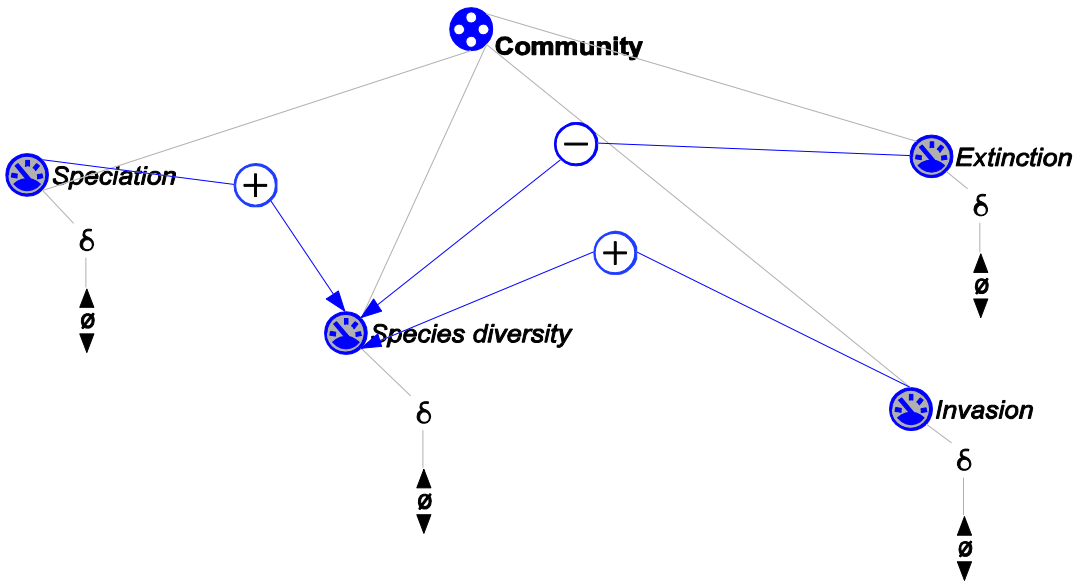

Figure 5.6 Model expression for Community diversity basic LS2 built in the basic causal model learning space of the DynaLearn software.

5.6.3. Scenarios and simulations

This model can be simulated to look at the effect of speciation, extinction and invasion on species diversity.

5.7. Conclusions and future development

- Develop models in the advanced learning spaces (LS5 Conditional Knowledge and LS6 Generic and reusable knowledge).
- Identify common student misconceptions about evolution and identify whether suitable conceptual models can be developed to overcome these.

6. Decomposition

6.1. Topic and model metadata

Topic	Decomposition		
Author	R Noble	Version(s)	DL v0.6.12
Models	Decomposition basic LS2.hgp Decomposition basic LS4.hgp Decomposition available nutrients LS3.hgp Decomposition available nutrient LS4.hgp		
Target users	A level		

6.2. Topic rationale

6.2.1. Background

Decomposition and the soil food-web is a fundamental topic in environmental science that contains concepts that underpin processes in further topics such as nutrient cycling. The role of saprobiotic fungi and bacteria as decomposers, in association with detritivore organisms, for recycling organic matter is critical to other concepts such as feedbacks in climate change and the impacts and treatment of organic pollution. Decomposition and the soil food web are important processes in the biosphere for the flow of energy through ecosystems. In contrast to the typical primary producer-consumer food web up to 80% of productivity in an ecosystem may pass through the decomposer pathway. In systems where aerobic decomposition is inhibited (cold, wet or acidic systems) only around 10% of organic material may be recycled. In these systems organic material and nutrients accumulate as peat (Begon, Townsend & Harper 2006; Pickering 2009).

Figure 6.1 presents a concept map of decomposition as a process that recycles dead and waste organic matter releasing carbon dioxide and nutrients in the process.

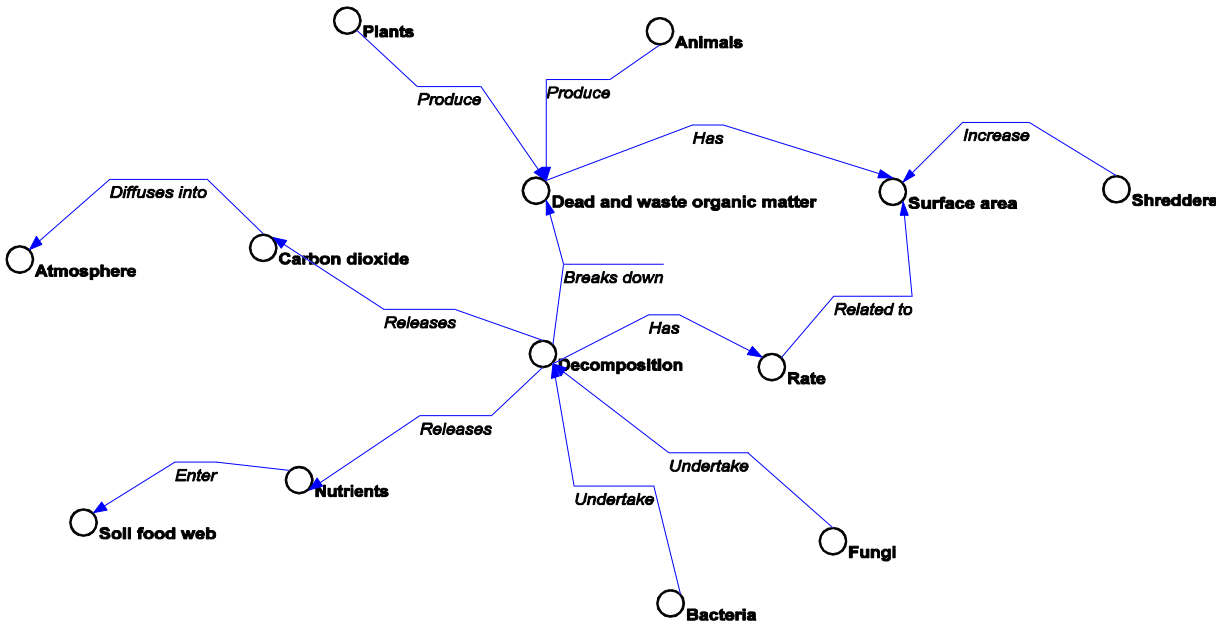

Figure 6.1 Concept map of the decomposition topic prepared in the concept map learning space of the DynaLearn software.

6.2.2. Key concepts

- Decomposition as a process for releasing carbon and nutrients from dead organic matter.
- Availability of nutrients related to the rate of decay and activity of decomposers.
- Growth of plants is limited by the availability of nutrients – as determined by the decomposition process.

6.2.3. General contents and ingredients

All of the models developed in different learning spaces for the Decomposition topic comprise a suite of entities and associated quantities that are re-used or modified. The entities and quantities used are summarised in Table 6.1. Not all entities and quantities are used in all models.

Table 6.1 Entities, quantities and quantity spaces (QS) used in the models Decomposition basic LS2, Decomposition basic LS4, Decomposition available nutrients LS3 and Decomposition available nutrients LS4.

Entity	***Quantities***	***QS***	***Remarks***
Atmospheric carbon dioxide	Consumption	*Zp*	CO_2 uptake by photosynthesis
	Production	*Zp*	In some models only decay considered as a net source of CO_2
	Amount	*P*	
Plants	Photosynthesis	*Zp*	
	Growth	*Zp*	Conversion of CO_2 and nutrients into biomass
	Death	*Zp*	
	Respiration	*Zp*	
	Amount	*P; Zp; Zmsl*	Biomass
Animals	Respiration	*Zp*	
	Death	*Zp*	
Soil			
Dead organic matter	Production	*Zp*	Source not always specified and set to a constant value
	Decay	*Zp*	
	Amount	*Zsml*	
Decomposers	Activity	*Zp*	The combination of saprobiotic organisms and shredders
	Amount	*Zp*	
Soil nutrients	Consumption	*Zp*	
	Production	*Zp*	
	Amount	*Zp; Zmsl*	

Zsml {Zero, Small, Medium, Large}

6.3. Model – Decomposition basic LS2

6.3.1. Concepts and goals

Decomposition basic LS2 is a causal model that represents the key aspects of decomposition in the perspective of its role in the breakdown of dead organic matter and the recycling of carbon and other nutrients in the ecosystem. The model highlights the main processes involved in the production, consumption and recycling of dead organic matter, soil nutrients and atmospheric CO_2.

6.3.2. Model expression

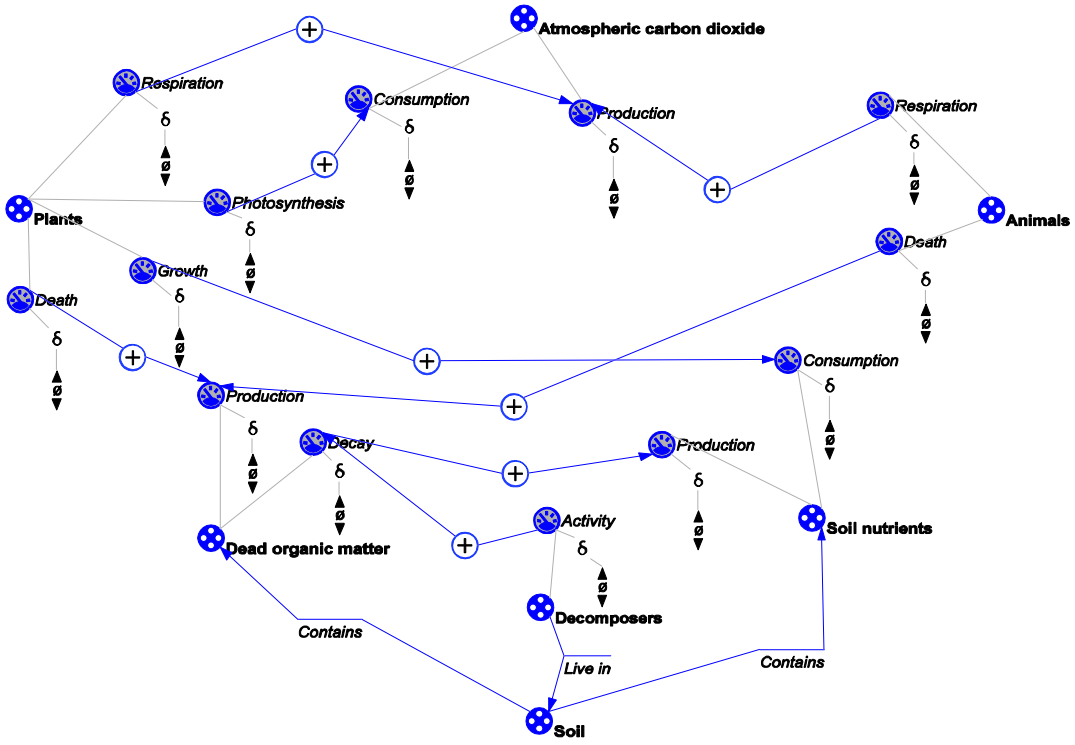

Figure 6.2 Model expression for Decomposition basic LS2 built in the basic causal model learning space of the DynaLearn software.

6.3.3. Scenarios and simulations

This model acts more as a representation of the system rather than as a model that can be simulated to address a particular issue or scenario associated with the topic. However, the model expression could be used to simulate various “what if?” scenarios based around the relationships between the quantities.

6.4. Decomposition basic LS4

6.4.1. Concepts and goals

Decomposition basic LS4 is a causal differentiation representation of decomposition in the context of recycling nutrients and making them available for plant growth. The model considers the balance of the production and decay of dead organic matter and the release of soil nutrients and uptake of

nutrients (growth of plants). The model makes the assumption that the amount of nutrients in the soil is controlled by the balance of consumption by plant growth and the production by the decomposition of dead organic matter.

6.4.2. Model expression

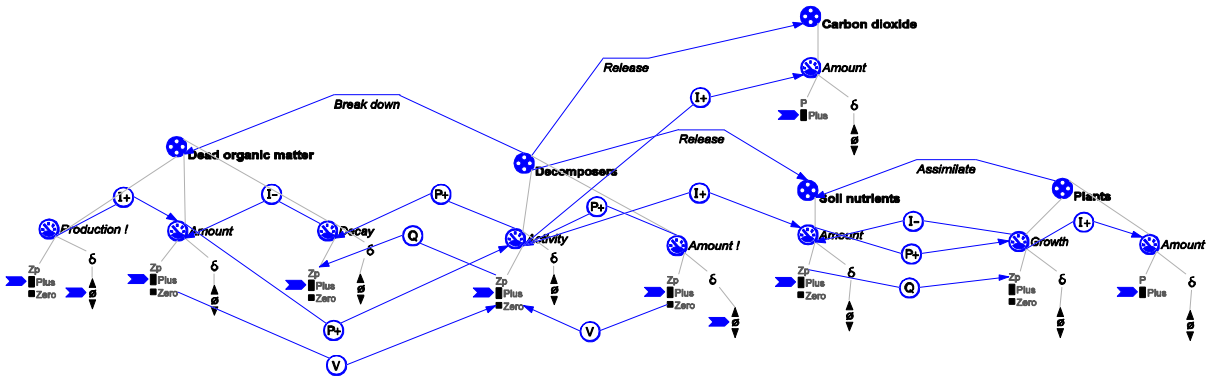

Figure 6.3 Model expression for Decomposition basic LS4 built in the causal differentiation learning space of the DynaLearn software.

6.4.3. Scenarios and simulations

The scenario applied to this model allows the software to consider all possible balances between production and decay and between decomposer activity and growth (Table 6.2). Ultimately in the end state [5] the system has a tendency to enter equilibrium where the consumption and production of soil nutrients and the production and decay of dead organic matter are in balance (Figure 6.4). In such a case it can be seen that the growth of plants can be restricted by the production and availability of nutrients which itself is limited by the activity of the decomposer organisms.

Table 5.2 Scenario information – causes and conditions for simulation of Decomposition basic LS4

Type	**Details**
Exogenous control	Production (Dead organic matter) *steady* Amount (Decomposers) *steady*
(In)equality	None
Ambiguity	Relative size of Production and Decay (Dead organic matter) Relative size of Growth (Plants) and Activity (Decomposers)

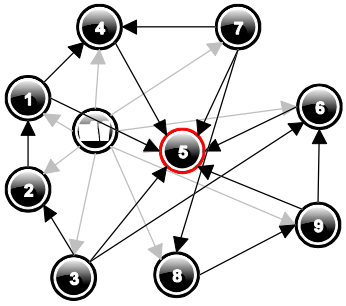

Figure 5.4 Full simulation behaviour paths for Decomposition basic LS4 with one end state [5].

6.5. Decomposition available nutrients LS3

6.5.1. Concepts and goals

Decomposition available nutrients LS3 is a basic causal model with qualitative values for the amount of dead organic matter and the amount of soil utrients. The model represents the activity of decomposers in recycling carbon and nutrients and making them available for growth of plants.

6.5.2. Model expression

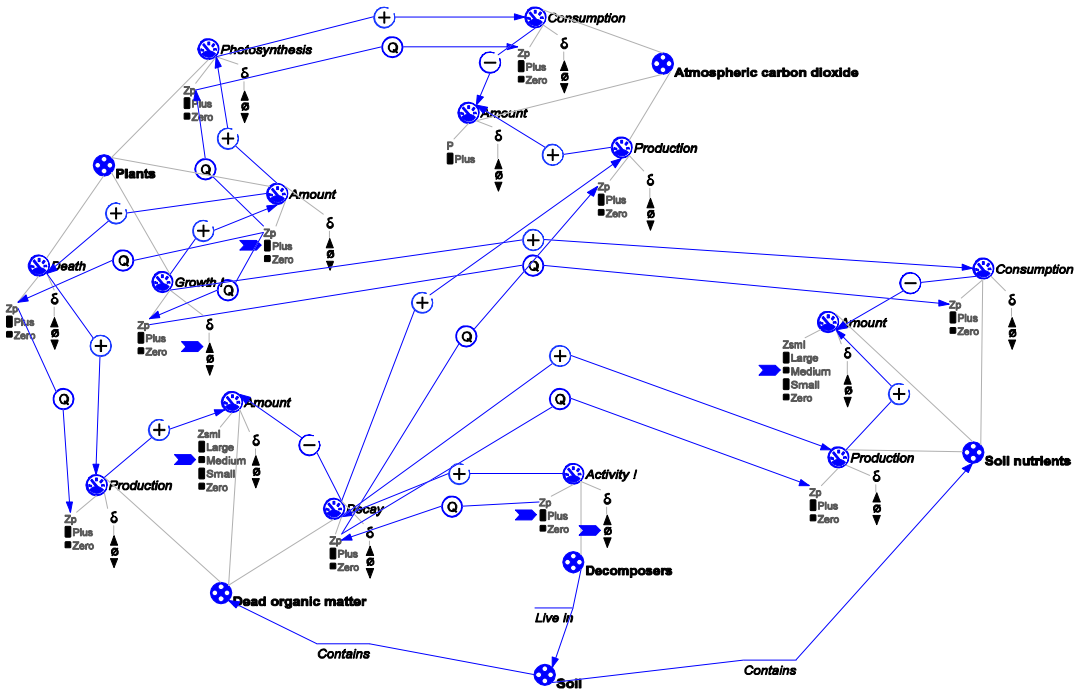

Figure 6.5 Model expression for Decomposition available nutrients LS3 built in the basic causal model state graph learning space of the DynaLearn software.

6.5.3. Scenarios and simulations

The scenario presented here shows the effects of increasing plant growth whilst the rate of decay remains the same (Table 6.3). In this case the consumption of soil nutrients and the amount and death of plants both increase. Since the rate of decay remains the same there is a build up of dead organic matter (Figure 6.6).

Table 6.3 Scenario information – causes and conditions for simulation of Decomposition available nutrients LS3

Type	**Details**
Exogenous control	Growth (Plants) *increases* Activity (Decomposers) *steady*
(In)equality	*na*
Ambiguity	*na*

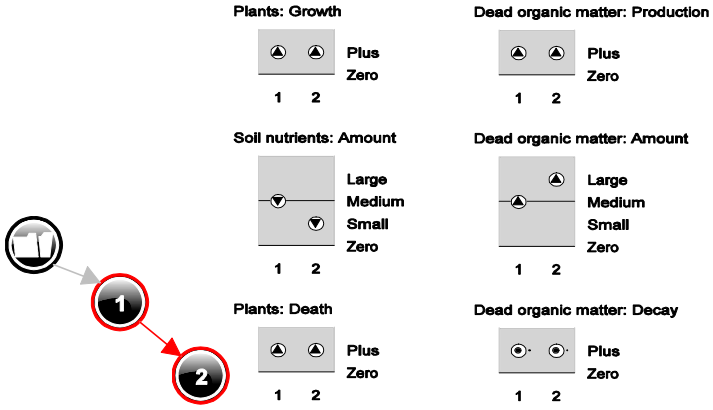

Figure 6.6 Behaviour path and value history of selected quantities in Decomposition available nutrients LS3 under a full simulation.

6.6. Decomposition available nutrients LS4

6.6.1. Concepts and goals

The goal of this model is to represent the system as defined in Decomposition available nutrients LS3 except with full causal differentiation of influences and proportionalities. Each component of the model (plants, dead organic matter, soil nutrients, atmospheric carbon dioxide) has a pair of competing influences related to the production and consumption of a state variable relating to the amount of the particular entity. The model aims to be able to explore concepts of recycling of nutrients and the availability of nutrients limiting plant growth.

6.6.2. Model expression

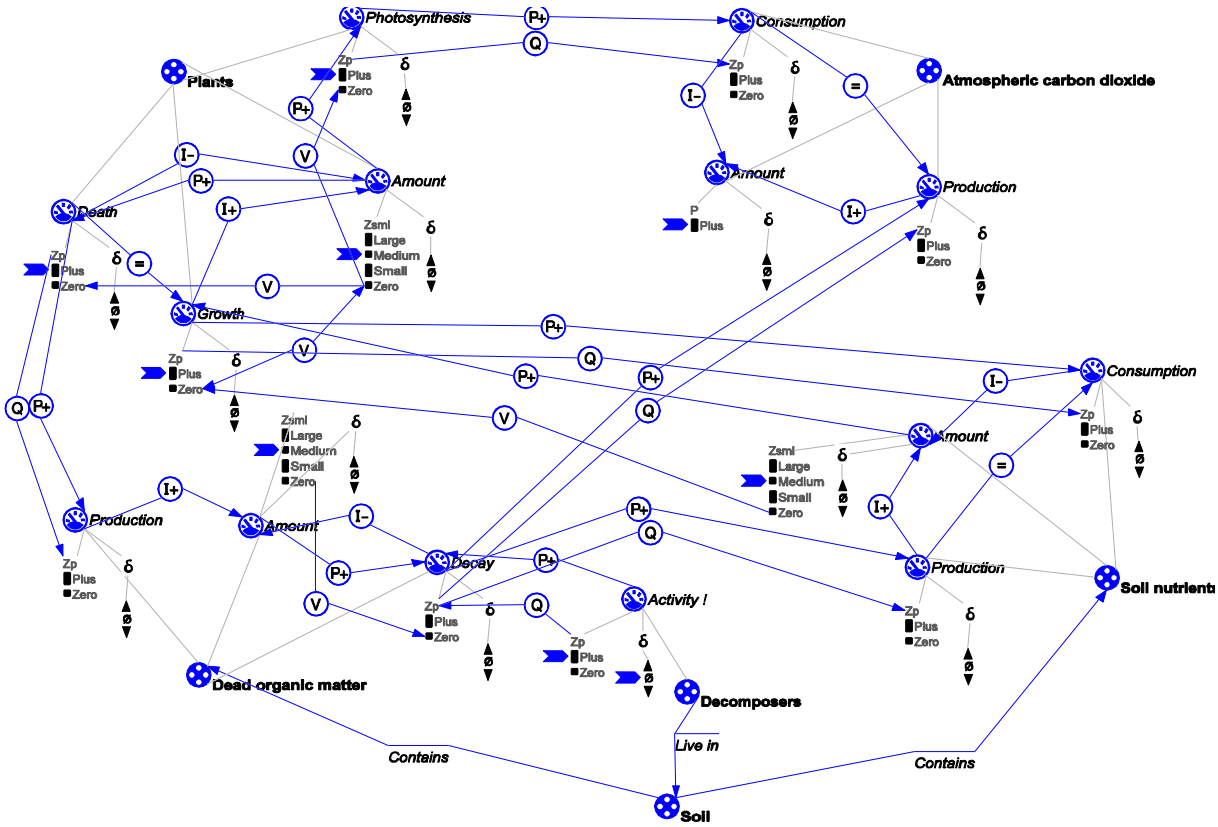

Figure 6.7 Model expression for Decomposition basic LS4 built in the causal differentiation learning space of the DynaLearn software.

6.6.3. Scenarios and simulations

The three behaviour paths generated in this example scenario triggered by ambiguity between production and decay of dead organic matter (Table 6.4) represent a stable situation, a situation where decay > production (dead organic matter) and decay < production (Figure 6.8). At the moment this results in a steady state, a state with everything increasing and a path with everything decreasing. Ideally the simulation would produce paths where growth would become limited by available nutrients as nutrients become locked up either within the plants, the atmosphere or in dead organic matter. This is because the model expression currently acts as an open system with no limitations on the amount of stored carbon in the atmosphere.

Table 6.4 Scenario information – causes and conditions for simulation of Decomposition basic LS4

Type	**Details**
Exogenous control	Activity (Decomposers) *steady*
(In)equality	Production = Consumption (Soil nutrients) Death = Growth (Plants) Production = Consumption (Atmospheric carbon dioxide)
Ambiguity	Relative size of Production versus Decay (Dead organic matter)

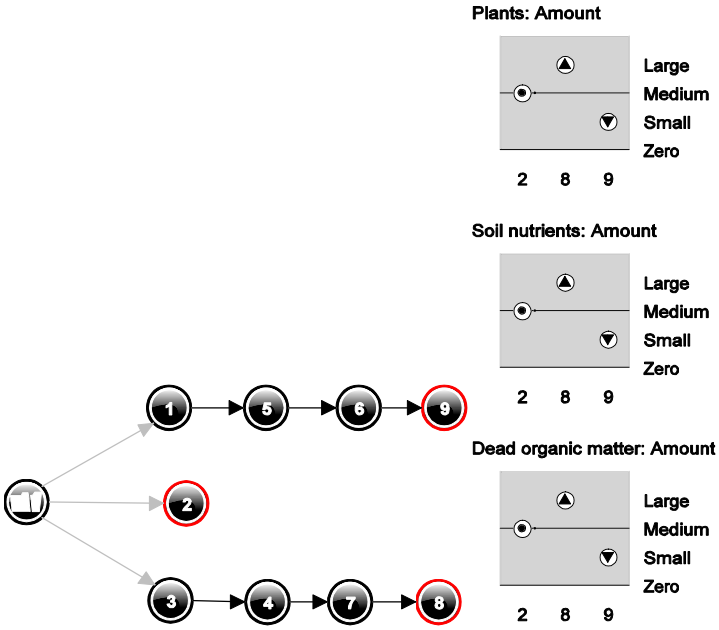

Figure 6.8 Behaviour paths and end states given by Decomposition available nutrients LS4.

6.7. Conclusions and future development

- Develop models in the advanced learning spaces (LS5 Conditional Knowledge and LS6 Generic and reusable knowledge).
- Develop topic materials to explore the links between decomposition, nutrient cycling, resource use, climate change and the reduce, re-use, recycle topic.
- Explore models that could represent the decomposition rates of different types of materials, or under different environmental conditions.

7. Reduce, Re-use, Recycle

7.1. Topic and model metadata

Topic	Reduce, re-use, recycle		
Author	R Noble	**Version(s)**	DL v0.6.12
Models	Reduce reuse recycle LS4.hgp		
Target users	A Level		

7.2. Topic rationale

7.2.1. Background

Reduce, re-use and recycle are three approaches to sustainable waste management. They can be seen as a hierarchy of desirable waste management strategies each with a particular approach and benefit (Figure 7.1).

- Reduce is an approach that aims to reduce the societal demand that drives the exploitation of natural resources and the production of waste in the first place. In many cases reduction in demand is the only viable way to maintain the sustainability of exploiting some threatened resources that have limited or slow re-growth or reproduction (e.g. fossil fuels).
- Re-use is a waste management strategy that attempts to restrict the amount of good ending up as waste by repairing them or re-using components for new alternative uses.
- Recycle is a waste management strategy that aims to extract raw materials from waste, as such this approach has a cost in terms of energy for extracting the raw materials.

These waste minimisation strategies aim to extract the maximum possible benefits from resources whilst at the same time generating the minimum amount of waste. As such the concept of the three R's has clear links with the sustainable management of natural resources.

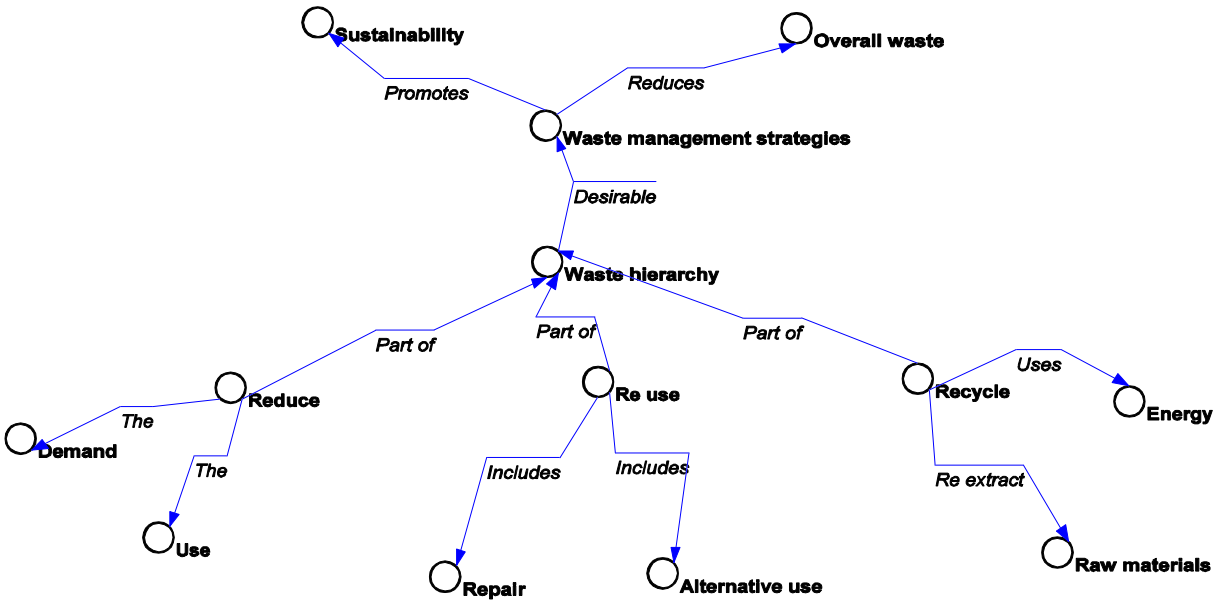

Figure 7.1 Concept map of the reduce re-use recycle topic prepared in the concept map learning space of the DynaLearn software.

7.2.2. Key themes

- The three R's as a hierarchy of preferred waste management strategies
- Sustainable resource use by balancing exploitation with production
- The key differences between recycling, re-use and reduction of demand as waste management strategies

7.2.3. General contents and ingredients

Table 7.1 Entities, quantities and quantity spaces (QS) used in the model Reduce re-use recycle LS4.

Entity	***Quantities***	***QS***	***Remarks***
Natural resources	Natural production	*Zp*	Processes that create natural resources
	Amount	*P*	
Producers	Exploitation	*Zp*	The consumption of natural products to generate goods and services
	Stock	*P*	The supply of goods available
Consumers	Demand	*Zp*	The requirement of consumers for new goods
	Goods	*P*	Goods in active use by consumers
	Disposal	*Zp*	Wastage of goods when old, unwanted or broken
Waste	Amount	*P*	
Society	Reuse	*Zp*	Conversion of old goods into new uses or re-fitting or mending for original use
	Recycling	*Zp*	Conversion of waste into raw materials for production of new goods

7.3. Reduce reuse recycle LS4

7.3.1. Concepts and goals

The model Reduce reuse recycle LS4 represents the production chain from a natural resource to the producers that exploit the resource, to the consumers whose demand for goods drives production and exploitation, to the generation of waste from old, unwanted or broken goods. The model also explicitly represents recycling as the process of converting waste back into raw materials and re-use as the process of creating new goods from old goods or the reconditioning/repair of broken goods. Reduce as a waste management strategy is not explicitly represented as this would occur when the demand of the consumers is reducing. The model represents the sustainability of resources by balancing the natural production of goods against the rate at which they are exploited.

7.3.2. Model expression

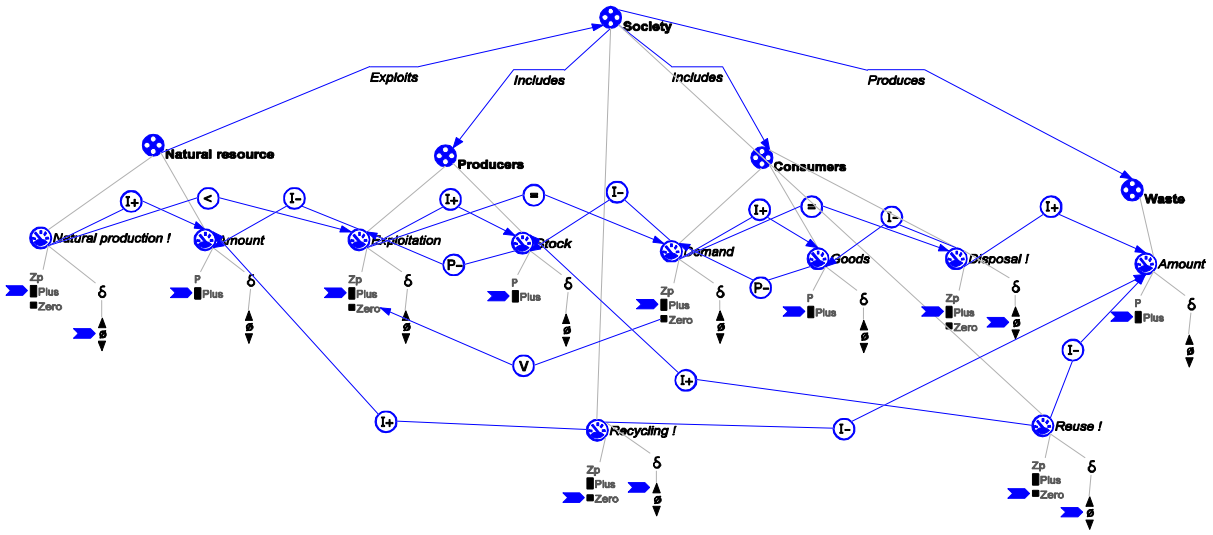

Figure 7.2 Model expression for Reduce reuse recycle LS4 built in the basic causal model learning space of the DynaLearn software.

7.3.3. Scenarios and simulations

Reduce reuse recycle LS4 can be used to simulate the impact of the 3 R's on the production of waste and the sustainability (amount) of natural resources. In the scenario represented here the impact of increasing recycling is considered (Table 7.2).

Table 7.2 Scenario information – causes and conditions for simulation of Reduce reuse recycle LS4.

Type	Details
Exogenous control	Natural production steady Recycling zero, increasing Reuse zero steady See Figure 7.2 for other value assignments
(In)equality	*Exploitation > Natural production* *Demand = Exploitation* *Disposal = Demand*
Ambiguity	*na*

Initially in this simulation the amount of waste is increasing and the amount of natural resources is decreasing as the exploitation rate of the producers is greater than the rate at which natural production replenishes the amount of natural resources (unsustainable resource use). As the amount of recycling increases the amount of waste starts to decrease and the amount of natural resource stabilises and then starts to increase (Figure 7.3).

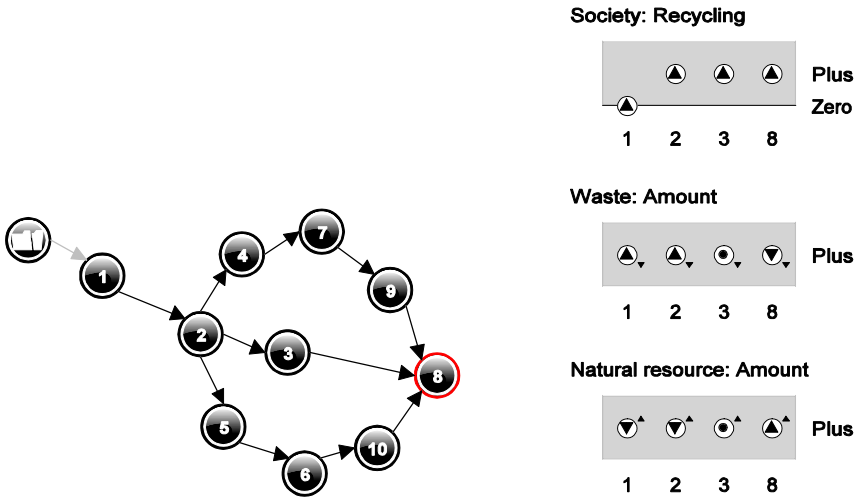

Figure 7.3 Behaviour path and value history for Reduce reuse recycle LS4, with increasing levels of recycling.

7.4. Conclusions and future development

- Develop models in the advanced learning spaces (LS5 Conditional Knowledge and LS6 Generic and reusable knowledge).
- Develop course materials and models to explore the links between this topic and topics centred on sustainability and resource exploitation.

8. Human Development Index

8.1. Topic and model metadata

Topic	Human Development Index		
Author	R Noble	**Version(s)**	DL v0.6.12
Models	Human Development Index LS2		
Target users	A Level		

8.2. Topic rationale

8.2.1. Background

The Human Development Index (HDI) is a standardised statistic used by the United Nations Development Programmes to rank countries by their level of human development into developed, developing or under developed. The index is a composite statistic ranging from 0 to 1 calculated from measures of life-expectancy, education and economic development (Gross Domestic Product per capita and purchasing parity). The index was developed as a way of re-focussing development aid and thinking away from a purely economic perspective to a human-centred approach. The index was developed as a simple measure of development that would include both economic development and development of human wellbeing (Figure 8.1).

The index is calculated from:

- Life expectancy at birth (an index of health and longevity)
- Knowledge and educational development
    - Gross enrolment ratio in all levels of education
    - Adult literacy rate
- natural logarithm of gross domestic product per capita at purchasing power parity (index of the standard of living).

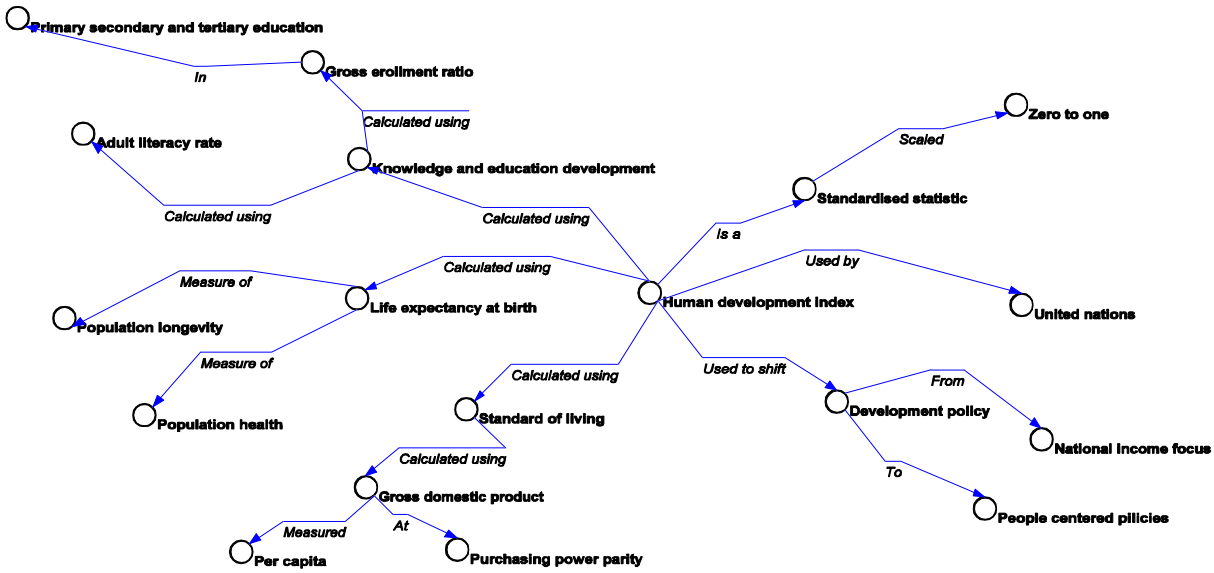

Figure 8.1 Concept map of the Human Development Index topic prepared in the concept map learning space of the DynaLearn software.

8.2.2. Key themes

- HDI as a standardised index scoring 0-1 as a measure of development of nations
- The reasons why the index was developed and how it is used
- The factors taken into account in calculating the index

8.2.3. General contents and ingredients

Table 3.1 Entities, quantities and quantity spaces (QS) used in the model Human Development Index LS2.

Entity	*Quantities*	*QS*	*Remarks*
Nation	Adult literacy rate		
	Gross education enrolment rate		
	Knowledge and education development		
	Human Development Index		
	Life expectancy at birth		Measure of healthcare
	Standard of living		Measured using gross domestic product

8.3. Human Development Index LS2

8.3.1. Concepts and goals

The basic causal model presented here is a qualitative representation of the calculation of the human development index.

8.3.2. Model expression

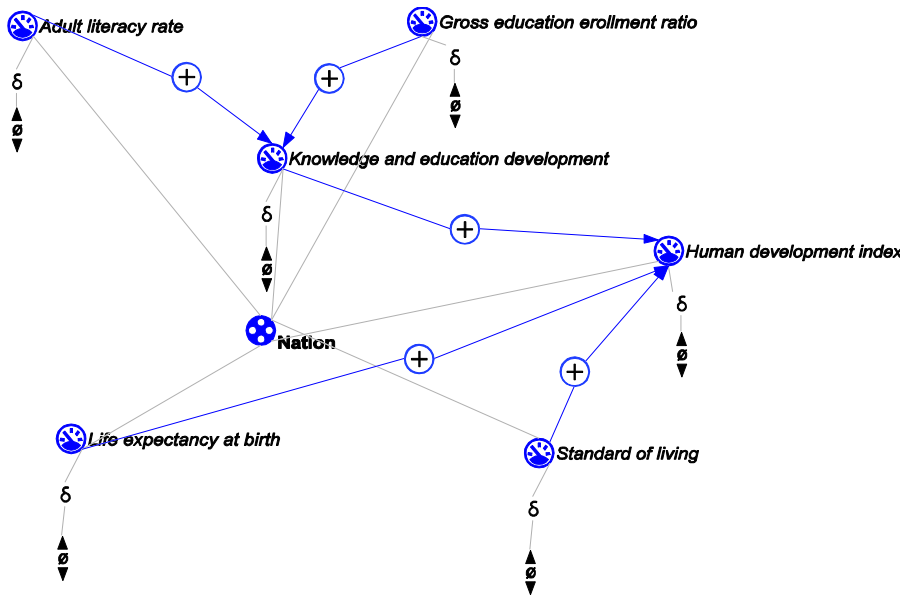

Figure 8.2 Model expression for Human Development Index LS2 built in the basic causal model learning space of the DynaLearn software.

8.3.3. Scenarios and simulations

This model can represent how the human development index changes as the level of development of a nation changes as represented by the changing values of the four measures of development used.

8.4. Conclusions and future development

- Develop models in the advanced learning spaces (LS5 Conditional Knowledge and LS6 Generic and reusable knowledge).
- Develop topic materials and models that deal with other concepts in human development.

9. Agro-ecology systems

9.1. Topic and model metadata

Topic	Agro-ecology systems		
Author	R Noble	**Version(s)**	DL v0.6.12
Models			
Target users	A Level		

9.2. Topic rationale

9.2.1. Background

Agro-ecology is a multi-faceted concept that has many definitions depending on the context in which it is used. In general agro-ecology can be seen as the study of the activity of agriculture and its role in the world. As such, it can be seen as the scientific study of agriculture, the application of ecological sciences and principles to agriculture and an interdisciplinary framework in which agriculture operates. Agro-ecology recognises that agriculture does not exist on its own but occurs within a framework of ecological, economic and social contexts.

Agro-ecology is concerned with all varieties of agro-ecosystems and is not generally restricted to one farming approach or paradigm. Agro-ecological studies are often concerned with the four aspects of agriculture within ecological, social and economic contexts those of productivity, stability, sustainability and equitability.

Given this background agro-ecology is fundamental multi-disciplinary studying the relationships between ecology, sociology, economics and agricultural production with all agro-systems at a variety of spatial and temporal scales. Therefore, the study of agro-ecology requires an understanding of the fundamental concepts relating to production, nutrient cycling, soil ecology, environmental quality and interactions between plants and animals.

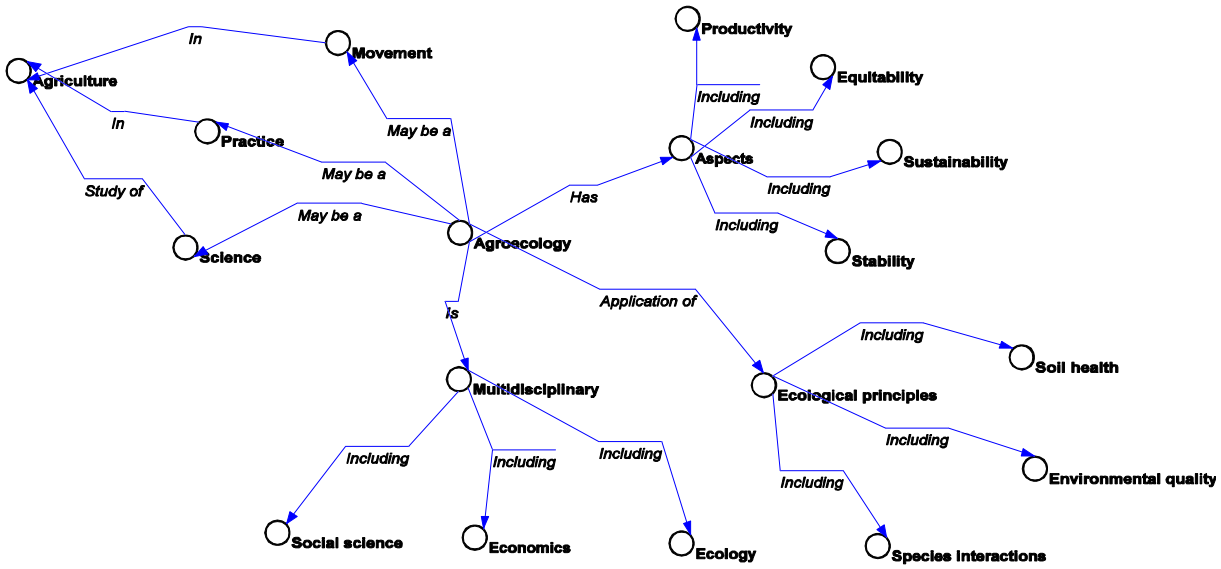

Figure 9.1 Concept map of the agro-ecology topic prepared in the concept map learning space of the DynaLearn software.

9.2.2. Key themes

- Agro-ecology as the scientific study of agriculture
- Application of fundamental ecological principles to agriculture
- Importance of sustainability
- Multi-disciplinary approach combining social, economic and ecological aspects

9.2.3. General contents and ingredients

Table 9.1 Entities, quantities and quantity spaces (QS) used in the model Soil erosion LS2.

Entity	***Quantities***	***QS***	***Remarks***
Crop	Stubble length		Amount of crop left after harvest
Soil	Cover		Land surface covered by vegetation
	Exposure to rain		
	Surface flow velocity		Overland flow of water
	Soil loss		Soil erosion
	Nutrient run-off		Leaching of nutrients from the soil
	Soil health		The ability of a soil to support crops

9.3. Soil erosion LS2

9.3.1. Concepts and goals

Agro-ecology relies on the understanding of environmental and ecological processes that interact with agriculture. The aim of an agro-ecological system is to maximise production whilst at the same time as minimising external inputs of nutrients. One approach to doing this is to minimise the loss of nutrients from the soil through crop rotation and low tillage practices that reduce soil erosion, nutrient run off and declines in soil quality. Soil erosion LS2 represents how altering the level at which crop stubble is left after harvest, and during times of fallow, can affect the level of soil erosion and nutrient run-off from the landscape.

9.3.2. Model expression

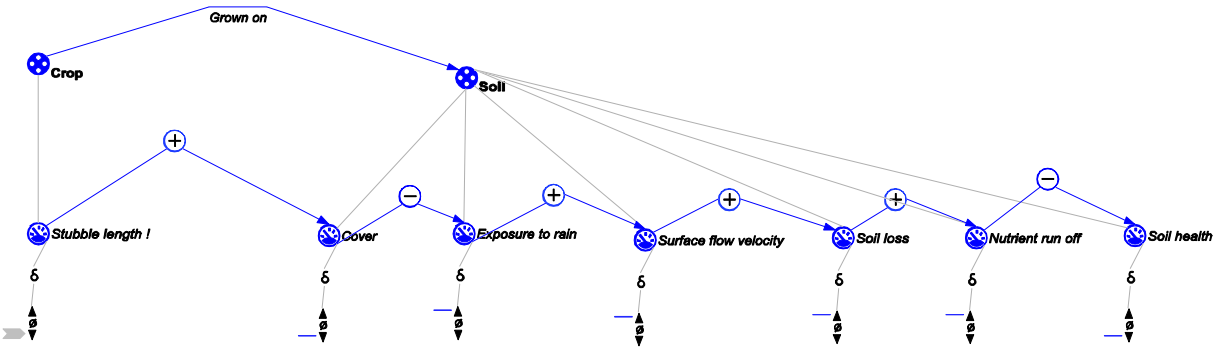

Figure 9.2 Model expression for Soil erosion LS2 built in the basic causal model learning space of the DynaLearn software.

9.3.3. Scenarios and simulations

In the simulation presented above the declining stubble length results in reducing cover for the soil, increasing exposure of the soil to rain and increasing surface flow velocities. This results in an increase in soil loss and nutrient run-off and a reduction in soil health (Figure 9.2).

9.4. Conclusions and future development

- Develop models in the advanced learning spaces (LS5 Conditional Knowledge and LS6 Generic and reusable knowledge).
- Develop models that consider topics in agriculture such as landscape impacts, soil health and productivity and the four themes in agro-ecology (equitability, productivity, sustainability and stability).
- Develop topic materials exploring the links with other topics such as nutrient cycling and resource exploitation.

10. Fishery

10.1. Topic and model metadata

Topic	Fishery		
Author	R Noble	**Version(s)**	DL v0.6.12
Models	Fishery LS4.hgp Fishery LS6.hgp (adapted from a model developed by F. Linnebank & G. Dante)		
Target users	A Level		

10.2. Topic rationale

10.2.1. Background

Fisheries are used as a topic in A level Biology and Environmental Science to explore the themes related to sustainable use of natural resources. The fishery theme contains many concepts related to population dynamics, resource exploitation and human impact on the environment. Studies of fisheries concentrate on a number of key issues:

- The impacts of fisheries on the ecosystem, the habitats (e.g. destructive fishing methods) and the population status of target and non-target species. Of particular concern are the impacts of fishing on non-target individuals or species. Fishing methods are all selective in terms of the sizes and species of fish they catch. The bycatch and discard of under-sized or non target species has severe implications for the sustainability of stocks and the functioning of aquatic ecosystems through food chain effects.

- Fisheries can be management through a number of input and output controls. One of the most used methods is determination of allowable catches through the application of stock recruitment and population dynamics models. Maximum sustainable yield is a fishery management concept that has underpinned the development of much of the current fisheries management strategies. MSY theory relies on the concept of logistic population growth, where the potential growth and recruitment in a stock occurs at about 30-50% of the maximum possible stock size in the absence of exploitation. This theory would suggest that catches could be maintained at this point where the highest potential for recovery could sustain high catches. Despite the widespread use of MSY in the past there are a number of limitations in its applicability to many fish stocks, especially where their life histories and stock-recruitment relationships are not well known (King 1995; Begon, Townsend & Harper 2006).

The study of fisheries science at A level and undergraduate level focuses on many of the methods of fisheries management, their assumptions and requirement (Figure 10.1).

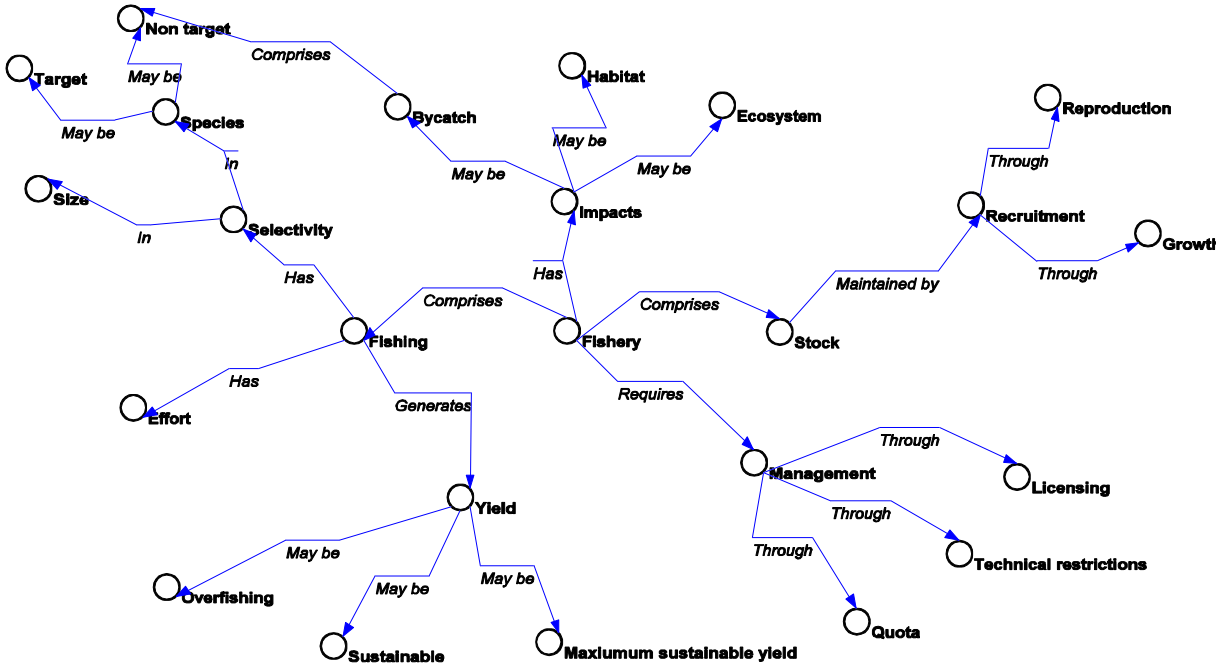

Figure 10.1 Concept map of the Fishery topic prepared in the concept map learning space of the DynaLearn software.

10.2.2. Key themes

- The impacts of fishing on stocks and the environment
- The sustainability of fish stocks
- Use of population dynamics models for fishery management purposes – Maximum sustainable yield and logistic growth models
- Fishery methods and selectivity
- Fishery management tools (e.g. quota, closed areas, closed seasons, licensing).

10.2.3. General contents and ingredients

Table 10.1 Entities, quantities and quantity spaces (QS) used in the models Fishery LS4 and Fishery LS6.

Entity	***Quantities***	***QS***	***Remarks***
Fishery	Effort	*Zp*	
	Sustainability	*Uezo*	
Fish stock	Abundance	*Zp*	
	Production	*Zp*	
	Natural mortality	*Zp*	

Uezo {Unexploited, exploited, zero (sustainable), over-exploited)

10.3. Fishery LS4

10.3.1. Concepts and goals

Fishery LS4 is a causal differentiation model that represents the sustainability of fishery exploitation as a balance between the recruitment of new individual to the fish stock through natural production and the loss of individuals from the stock through natural mortality and fishing mortality (represented as fishing effort). The fishery is unsustainable when the fishing effort and catch is greater (combined with natural mortality) is greater than the recruitment to the stock through natural production.

10.3.2. Model expression

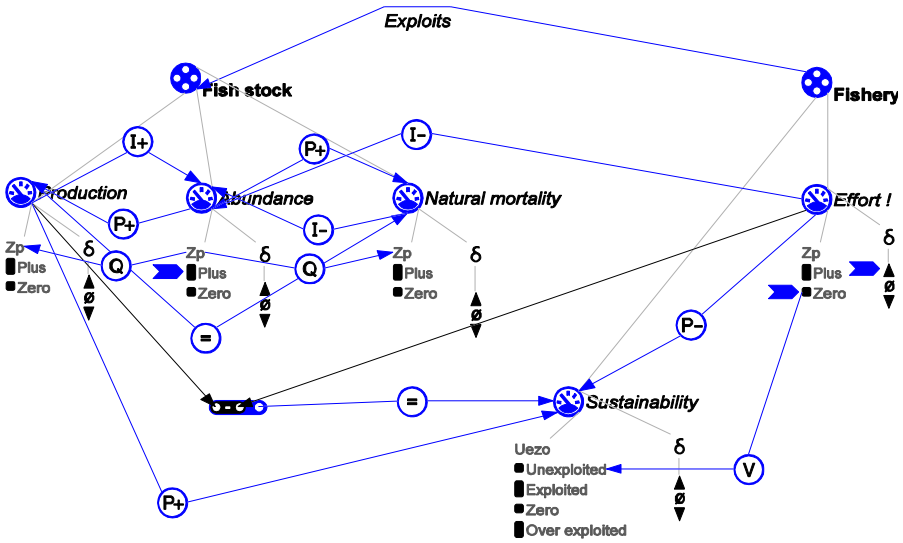

Figure 10.2 Model expression for Fishery LS4 built in the causal differentiation model learning space of the DynaLearn software.

10.3.3. Scenarios and simulations

This model can be simulated to represent a scenario where a new fishery is created to exploit a new fish stock. In the scenario presented here fishing effort increases without regulation (Table 10.2).

Table 10.2 Scenario information – causes and conditions for simulation of Fishery LS4.

Type	**Details**
Exogenous control	Effort (Fishery) *zero, increasing* Abundance (Fish stock) *plus*
(In)equality	*Production = Natural mortality*
Ambiguity	*na*

As fishing effort increases without regulation the effort eventually exceeds the natural production and the abundance of the fish stock declines. As the fish stock declines the increasing fishing effort results in the fishery being over exploited (Figure 10.3).

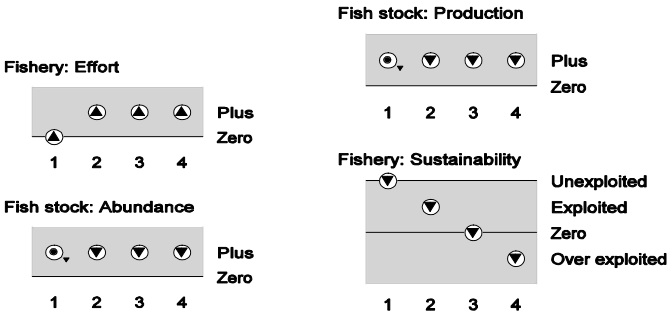

Figure 10.3 Value history of a full simulation of Fishery LS4 with an increasing fishing effort.

10.4. Fishery LS6

10.4.1. Concepts and goals

Fishery LS6 is a model that represents the concept of logistic population growth and the concept of maximum sustainable yield in fisheries management. The suit of child model fragments (Figure 10.5) based on the general Fishery model fragment (Figure 10.4) captures the dynamics of logistic growth using conditional information to regulate how the catch and the net growth rate change with increasing or decreasing abundance of the fish stock. Logistic growth is represented as the net growth rate attains its highest value when the stock abundance is at its critical level.

10.4.2. Model expression

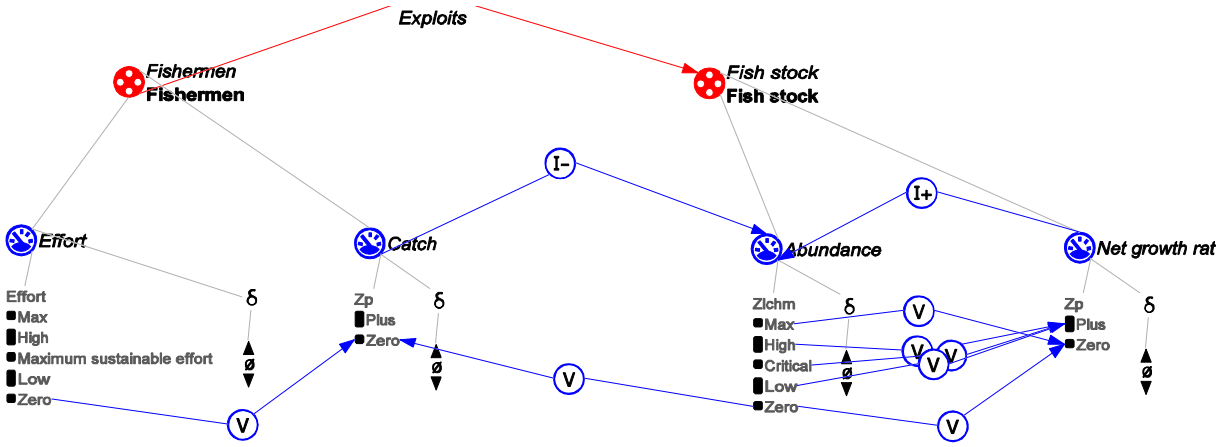

Figure 10.4 Model fragment “Fishery” for Fishery LS6 built in the generic and re-useable knowledge learning space of the DynaLearn software.

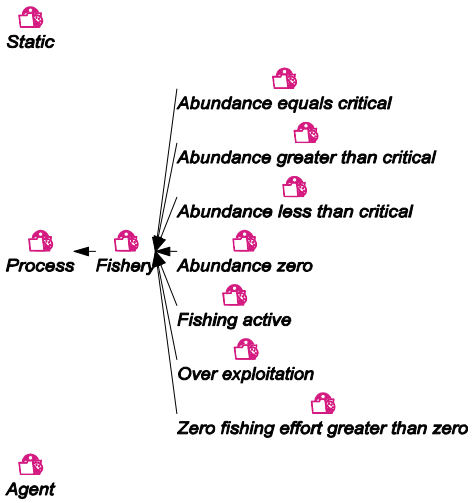

Figure 10.5 Hierarchy of model fragments based on the parent fragment "Fishery" for Fishery LS6 built in the generic and re-useable knowledge learning space of the DynaLearn software.

10.4.3. Scenarios and simulations

This model simulates the development of a new fishery where fishing effort increases without regulation (Table 10.3).

Table 10.3 Scenario information – causes and conditions for simulation of Fishery LS6

Type	**Details**
Exogenous control	Abundance (Fish stock) max Effort (Fishermen) zero, increasing
(In)equality	*na*
Ambiguity	*na*

In this simulation the stock abundance declines as fishing effort increases. However in contrast to Fishery LS4 the growth rate of the stock increases to a maximum value when the abundance reaches critical (the theoretical point of MSY). The fishery would be sustainable at this point however effort continues to increase. Following this as the stock declines the catch (per unit effort) in the fishery decreases as the stock is over exploited. Fishing effort increases to a point where the stock has become extinct (Figure 10.6).

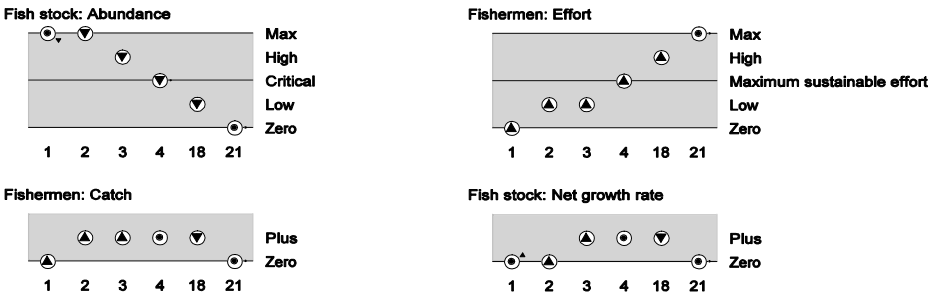

Figure 10.6 A behaviour path from the full simulation of Fishery LS6 showing over fishing and logistic population growth.

10.5. Conclusions and future development

- Develop models in the advanced learning spaces (LS5 Conditional Knowledge and LS6 Generic and reusable knowledge).
- Develop a model for MSY and logistic population growth that encapsulates the causal reasoning behind the behaviour of logistic growth currently presented in Fishery LS6.
- Create models that represent the mechanisms of fisheries management practices.
- Develop course materials that explore the links between fishery and other topics such as sustainability, population dynamics and resource exploitation.

11. Photosynthesis

11.1. Topic and model metadata

Topic	Photosynthesis		
Author	R Noble	Version(s)	DL v0.6.12
Models	Photosynthesis basic LS2.hgp Photosynthesis biochemistry LS3.hgp Photosynthesis and respiration LS4.hgp		
Target users	A level		

11.2. Topic rationale

11.2.1. Background

Photosynthesis is the key biological process of capturing and converting inorganic carbon dioxide into organic carbon compounds. Autotrophic organisms, such as green plants, capture light energy and store it as chemical compounds ATP and $NADPH_2$ (Light Reaction – non-cyclic phosphorylation) which are then used as the reduction power for converting inorganic carbon dioxide into organic carbon compounds that are the basis of biomass production and chemical energy storage. Photosynthesis can be seen as the inverse or cellular respiration in that photosynthesis is the capture and storage of carbon and chemical energy whereas respiration is a chemical process of releasing chemical energy. In both cases oxygen and carbon dioxide are key chemicals involved in the process (Campbell 1993; Pickering 2009).

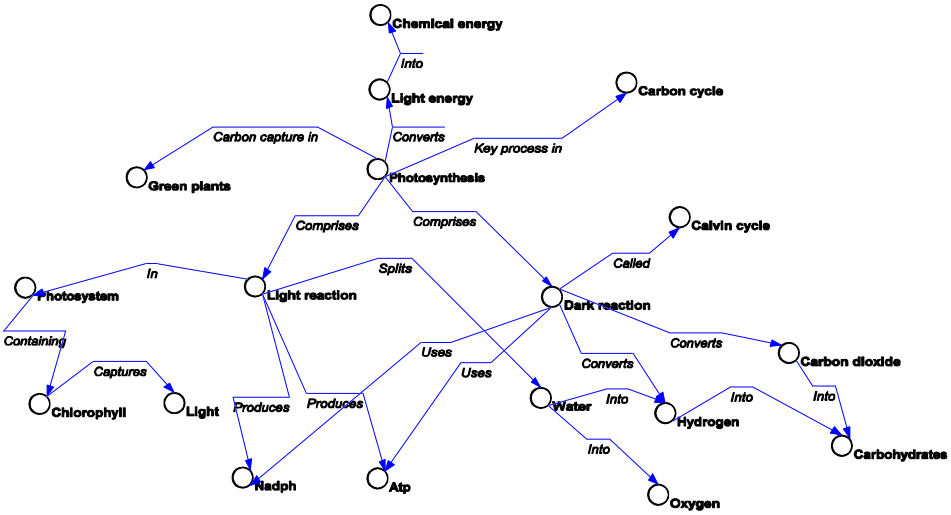

Figure 11.1 Concept map of the photosynthesis topic prepared in the concept map learning space of the DynaLearn software.

11.2.2. Key themes

- Photosynthesis as a process requiring light energy and carbon dioxide producing organic carbon and oxygen.
- Photosynthesis as a process with a light dependent reaction and a light-independent reaction.
- Photosynthesis and respiration as a chemical process affecting the concentrations of oxygen and carbon dioxide in the environment.

11.2.3. General contents and ingredients

All of the models developed in different learning spaces for the Photosynthesis topic comprise a suite of entities and associated quantities that are re-used or modified. The entities and quantities used are summarised in Table 11.1. Not all entities and quantities are used in all models.

Table 11.1 Entities, quantities and quantity spaces (QS) used in the models Photosynthesis basic UL2, Photosynthesis biochemistry UL3 and Photosynthesis and respiration UL4.

Entity	Quantities	QS	Remarks
Light	Intensity	*Zp*	Source of energy
Aquatic (Green) plants	Photosynthesis Respiration	*Zp* *Zp*	Autotrophic organisms
Lake	Oxygen concentration	*Zsss*	Example of an environment
Oxygen	Production Consumption Amount	*Zp* *Zp* *Zp*	By product of photosynthesis
Carbon dioxide	Consumption	*Zp*	Inorganic form of carbon in the environment
Water	Consumption	*Zp*	Photolysis of water provides electrons for the light-dependent reaction in the photosystems
Carbohydrate	Production	*Zp*	Final product of photosynthesis used for biomass production and chemical energy storage
Photosystem	Activity	*Zp*	Location of biochemical process of non-cyclic phosphorylation synthesising ATP (stored energy) and $NADPH_2$ ("reducing power" for the Calvin cycle
Calvin cycle	Activity	*Zp*	Biochemical process of carbon dioxide fixation into organic carbon compound glucose phosphate
NADPH	Production Consumption	*Zp* *Zp*	Chemical required for reduction process in the Calvin cycle
ATP	Production Consumption	*Zp* *Zp*	Adenosine triphosphate - cellular chemical energy
Glucose phosphate	Production	*Zp*	Product of the Calvin cycle, a precursor to carbohydrate

Zsss {Zero, Some, Saturated, Super saturated}

11.3. Photosynthesis basic LS2

11.3.1. Concepts and goals

This is a basic causal model to show the relationship between light intensity and the production and consumption of the chemicals involved in photosynthesis in green plants (autotrophs). This model makes no differentiation between the light and dark reactions involved in photosynthesis.

11.3.2. Model expression

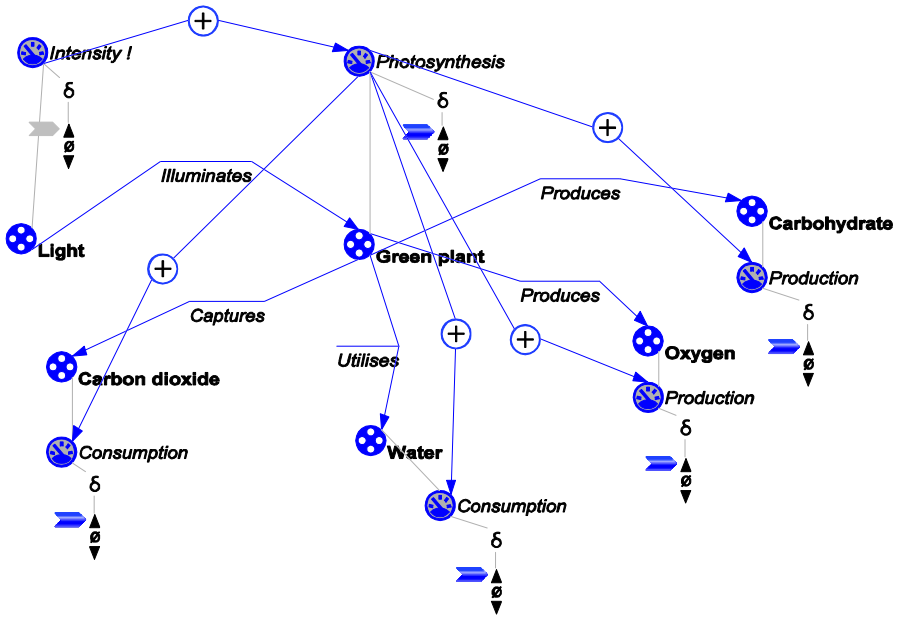

Figure 11.2 Model expression for Photosynthesis basic LS2 built in the basic causal model learning space of the DynaLearn software.

11.3.3. Scenarios and simulations

This model can be used to simulate the effect of increasing or decreasing light Intensity (Table 11.2).

Table 11.2 Scenario information – causes and conditions for simulating Photosynthesis basic LS2

Type	Details
Exogenous control	Intensity (Light) *increase*
(In)equality	*na*
Ambiguity	*na*

11.4. Photosynthesis biochemistry LS3

11.4.1. Concepts and goals

Photosynthesis biochemistry LS3 is a causal model with state graph considering the role of the light-dependent (photosystem) and light-independent (Calvin cycle) reaction in the overall process of photosynthesis in green plants. This model focuses on the production and consumption of the different precursors and products of the two different reactions. In this model only the production and consumption of the chemicals is considered.

11.4.2. Model expression

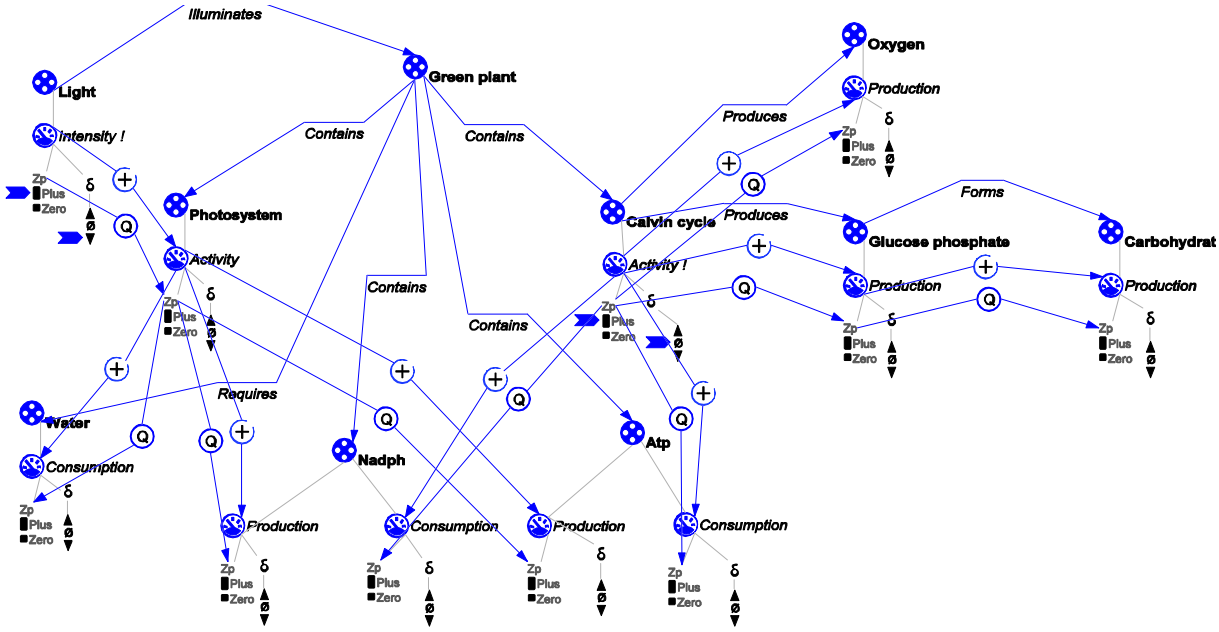

Figure 11.3 Model expression for Photosynthesis biochemistry LS3 built in the basic causal state graph model learning space of the DynaLearn software.

11.4.3. Scenarios and simulations

The scenario given above (Table 11.3 and Figure 11.3) runs a simulation of decreasing light Intensity. The simulation shows the relationship between light intensity and the activity of the photosystem and the consumption of water, the trapping of light energy and the production of Nadph ($NADPH_2$) and ATP. Both of which are then consumed by the Calvin cycle activity.

Table 11.3 Scenario information – causes and conditions for simulating Photosynthesis biochemistry LS3

Type	Details
Exogenous control	Intensity (Light) *decrease* Activity (Calvin cycle) *steady*
(In)equality	*na*
Ambiguity	*na*

11.5. Photosynthesis and respiration LS4

11.5.1. Concepts and goals

This model considers the effect of changing light Intensity on the balance of respiration and photosynthesis activity on the production and consumption of oxygen in the environment. This is done in the context of a lake and the oxygen concentration in the water (Wetzel 2001).

11.5.2. Model expression

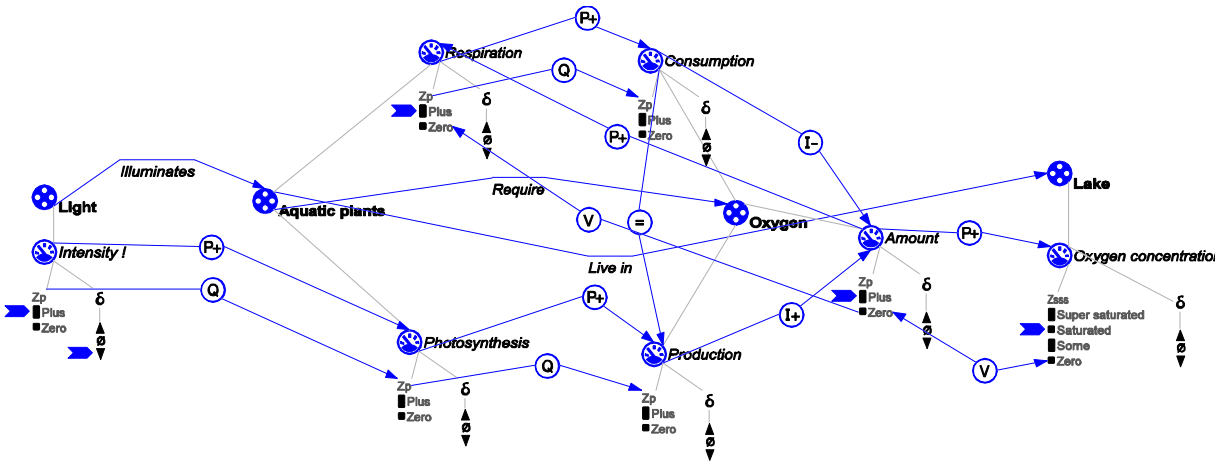

Figure 11.4 Model expression for Photosynthesis and respiration LS4 built in the causal differentiation model learning space of the DynaLearn software.

11.5.3. Scenarios and simulations

The scenario represented above (Figure 11.4 and Table 11.4) starts in a situation where the production and consumption of oxygen by photosynthesis and respiration respectively are equal. In this situation the amount of oxygen and its concentration in the lake are steady. In this scenario there is an exogenous decrease in light intensity which reduces photosynthesis, this results in consumption

of oxygen by respiration being greater than the production by photosynthesis. This has a net effect of reducing the oxygen concentration in the lake.

Table 11.4 Scenario information – causes and conditions for simulating Photosynthesis and respiration LS4

Type	Details
Exogenous control	Intensity (Light) *decrease*
(In)equality	Consumption = Production (Oxygen)
Ambiguity	None

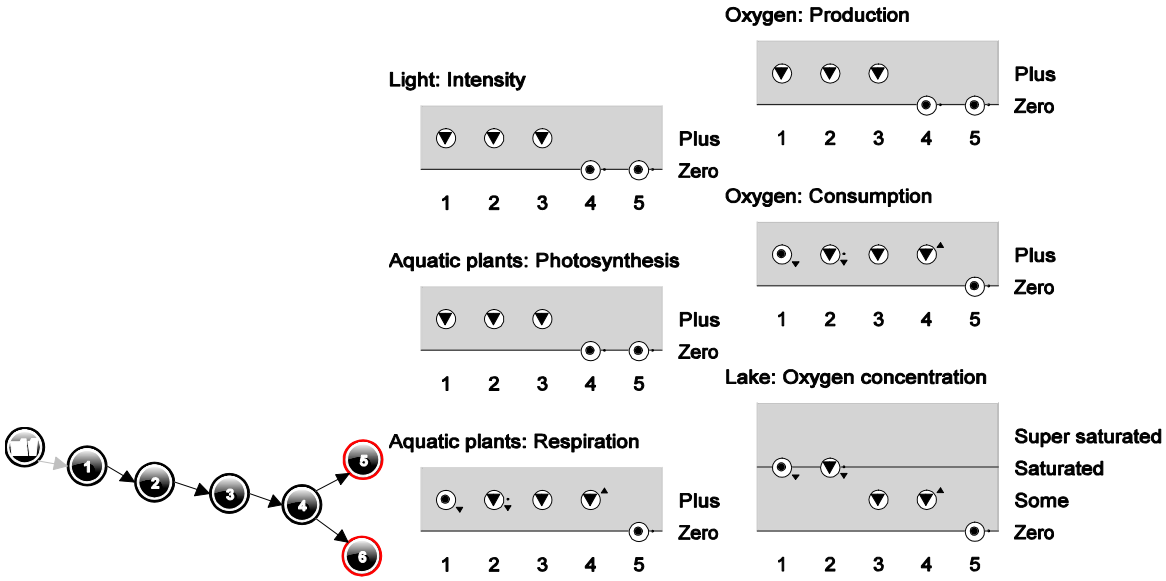

Figure 11.5 Behaviour path and value history for the full simulation of Photosynthesis and respiration LS4

11.6. Conclusions and future development

- Develop models in the advanced learning spaces (LS5 Conditional Knowledge and LS6 Generic and reusable knowledge).
- Develop advanced models that explore diel and seasonal fluctuations in oxygen concentrations on lakes.
- Develop topic materials that explore the links between photosynthesis and advanced topics such as climate change.

12. Aerobic respiration

12.1. Topic and model metadata

Topic	Aerobic respiration		
Author	R Noble	**Version(s)**	DL v0.6.12
Models	Respiration basic LS2.hgp Photosynthesis and respiration LS4.hgp (See Section 11)		
Target users	A Level		

12.2. Topic rationale

12.2.1. Background

Aerobic respiration is the key biological process of releasing chemical energy from organic carbon compounds. Cellular respiration in organisms comprises glycolysis of glucose (carbohydrate) and a number of other chemical processes that convert carbohydrate into ATP which is then used as an energy source for many other cellular processes. Energy is released from these compounds by oxidation hence aerobic respiration consumes oxygen and produces carbon dioxide as a by product. Respiration can be seen as the inverse of photosynthesis in that photosynthesis is the capture and storage of carbon and chemical energy where as respiration is a chemical process of releasing chemical energy. In both cases oxygen and carbon dioxide are key chemicals involved in the process (Campbell 1993; Withers 1992; Pickering 2009).

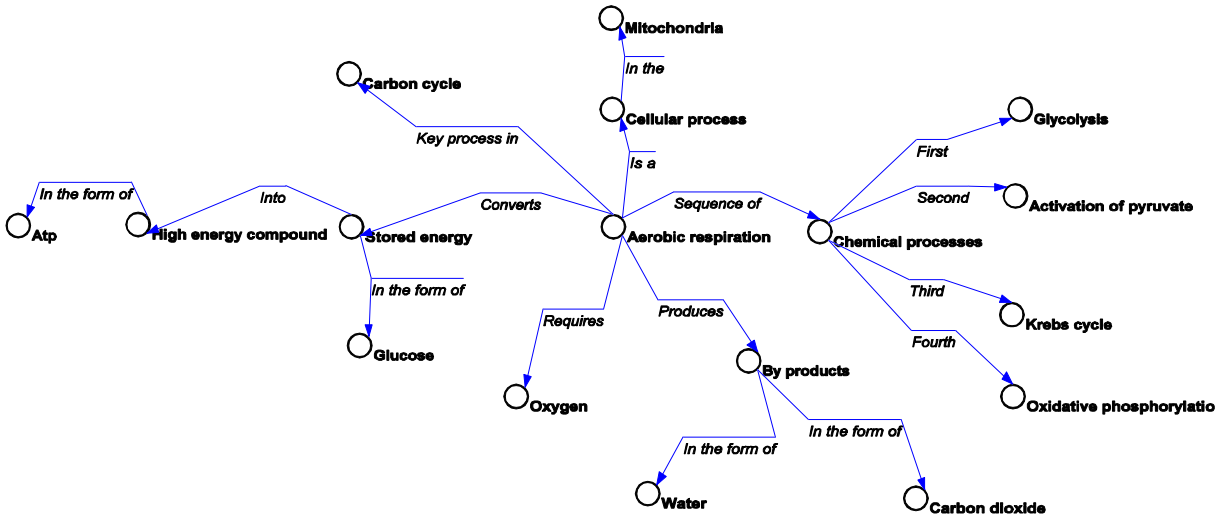

Figure 12.1 Concept map of the aerobic respiration topic prepared in the concept map learning space of the DynaLearn software.

12.2.2. Key themes

- Respiration as a process requiring oxygen and glucose and producing carbon dioxide and energy
- Photosynthesis and respiration as a chemical process affecting the concentrations of oxygen and carbon dioxide in the environment

12.2.3. General contents and ingredients

Table 12.1 Entities, quantities and quantity spaces (QS) used in the models Respiration basic LS2 and Photosynthesis and respiration LS4 (see Section 11).

Entity	Quantities	QS	Remarks
Light	Intensity	*Zp*	Source of energy
Aquatic (Green) plants	Photosynthesis Respiration	*Zp* *Zp*	Autotrophic organisms
Lake	Oxygen concentration	*Zsss*	Example of an environment
Organism	Respiration		
Oxygen	Production Consumption Amount	*Zp* *Zp* *Zp*	Required by respiration and by product of photosynthesis
Carbon dioxide	Consumption Production	*Zp*	Inorganic form of carbon in the environment
Water	Consumption Production	*Zp*	Photolysis of water provides electrons for the light-dependent reaction in the photosystems By product of oxidation in respiration
Carbohydrate	Production Consumption	*Zp* *Zp*	Final product of photosynthesis used for biomass production and chemical energy storage
Chemical energy	Production	*Zp*	Adenosine triphosphate - cellular chemical energy

12.3. Respiration basic LS2

12.3.1. Concepts and goals

This is a basic causal model of the relationships in the respiration process. The model shows the consumption and production of the inputs and outputs of the cellular respiration process.

12.3.2. Model expression

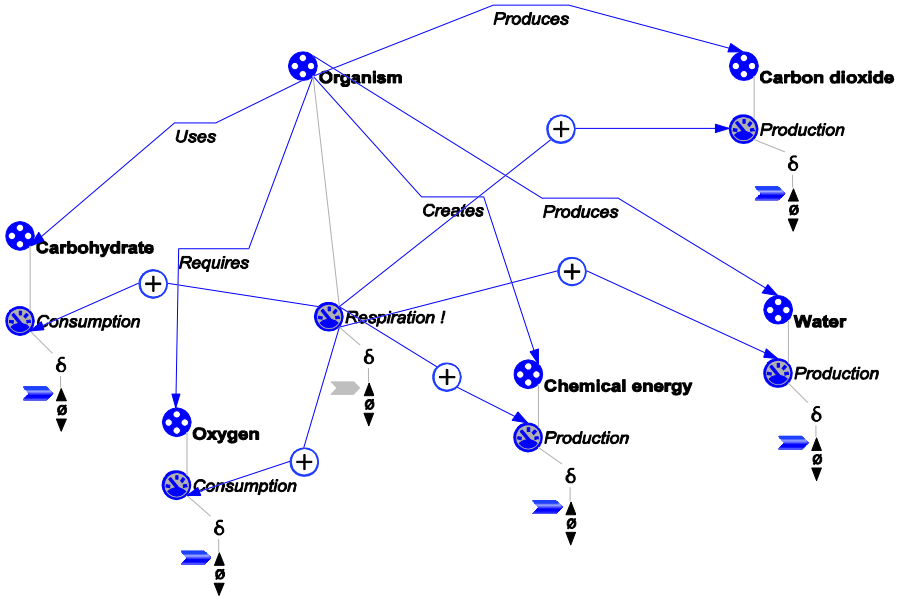

Figure 12.2 Model expression for Respiration basic LS2 built in the basic causal model learning space of the DynaLearn software.

12.3.3. Scenarios and simulations

In LS2 this model can consider the effects of increasing/decreasing respiration and its effects on production and consumption in the respiration process (Figure 12.2 and Table 12.2). If respiration increases then the consumption of oxygen and carbohydrate increases and the production of water and carbon dioxide also increase.

Table 12.2 Scenario information – causes and conditions for simulation of Respiration basic LS2.

Type	**Details**
Exogenous control	Respiration (increasing)
(In)equality	*na*
Ambiguity	*na*

12.4. Conclusions and future development

- Develop models in the advanced learning spaces (LS5 Conditional Knowledge and LS6 Generic and reusable knowledge).
- Develop models that relate respiration to other topics such as adaption to environmental stress, climate change and nutrient cycling.

13. Diffusion and Osmosis

13.1. Topic and model metadata

Topic	Diffusion and Osmosis		
Author	R Noble	Version(s)	DL v0.6.12
Models	Diffusion one sided LS2.hgp Osmosis one sided LS2.hgp Cellular diffusion and osmosis LS4.hgp		
Target users	A level		

13.2. Topic rationale

13.2.1. Background

Cellular diffusion and osmosis are key drivers in cellular processes and cell regulation. Diffusion is the movement of solute molecules or ions down a concentration gradient from a region of high concentration to a region of low concentration. Osmosis is the special case of the diffusion of water, in the case of water the molecules move down a water potential gradient (a measure of the free kinetic energy of water in the system). In all systems with a semi-permeable membrane molecules with unrestricted movement will be constantly flowing across the membrane. The rate at which molecules move across the membrane is dependent on the rate at which molecules collide with the membrane (with molecules constantly moving at random in the solution). Areas with higher concentration will have a higher collision rate with the membrane than areas with low concentration, hence resulting in a difference between the rate of inflow and outflow of molecules in the cell (Withers 1992; Pickering 2009).

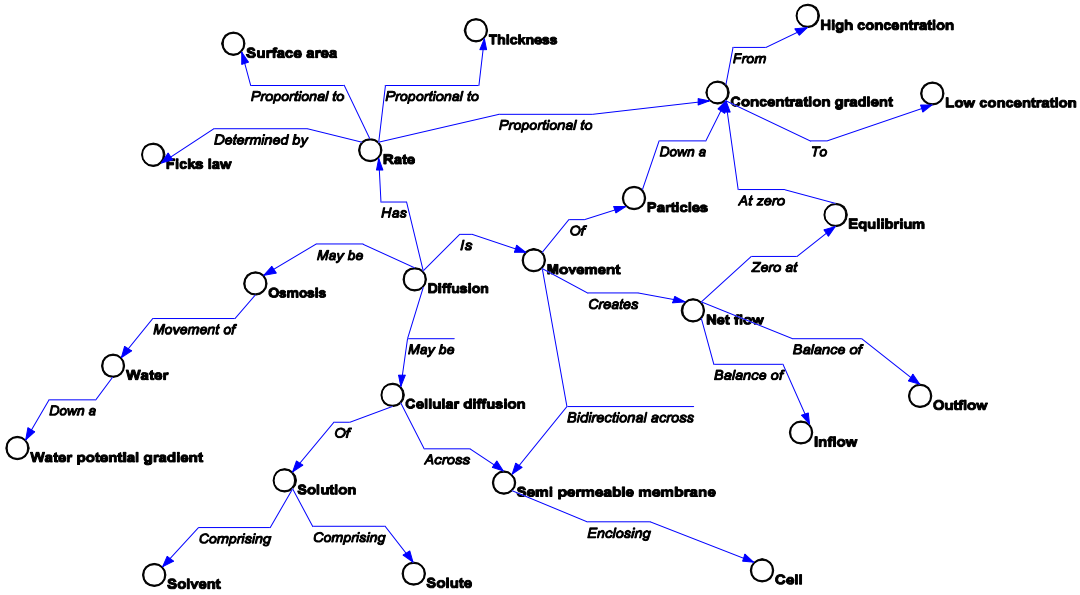

Figure 13.1 Concept map of the diffusion and osmosis topic prepared in the concept map learning space of the DynaLearn software.

13.2.2. Key themes

- Movement of molecules across a membrane down a concentration gradient.
- Osmosis as the diffusion of water.
- Osmosis/diffusion as the net balance of inflows and outflows.
- Equilibrium characterised by equal inflow and outflow NOT by no flow.

13.2.3. General contents and ingredients

All of the models developed in different learning spaces for the diffusion and osmosis topic comprise a suite of entities and associated quantities that are re-used or modified. The entities and quantities used are summarised in Table 13.1. Not all entities and quantities are used in all models.

Table 13.1 Entities, quantities and quantity spaces (QS) used in the models Diffusion one sided LS2, Osmosis one sided LS2 and Cellular diffusion and osmosis LS4.

Entity	Quantities	QS	Remarks
Membrane	Encounter rate	*na*	Frequency at which molecules collide with the membrane
	Diffusion	*na*	Movement of solute molecules
	(Flow in/Out)	*Zp*	
	Surface area	*na*	
	Osmosis	*na*	Movement of water molecules
	(Flow in/Out)	*Zp*	
Solution	Concentration	*Zp*	
Solvent	Amount	*Zp*	
	Osmotic potential	*Zp*	Free kinetic energy of water in a solution
Solute	Amount	*Zp*	

13.3. Diffusion one sided LS2

13.3.1. Concepts and goals

This causal model represents the interaction between a solution and a permeable membrane but in consideration of a single solution. In this model diffusion is represented as the movement of molecules across the membrane. The rate of movement is determined by the concentration of the solution (itself determined by the amount of solvent and solute) and the surface area of the membrane.

13.3.2. Model expression

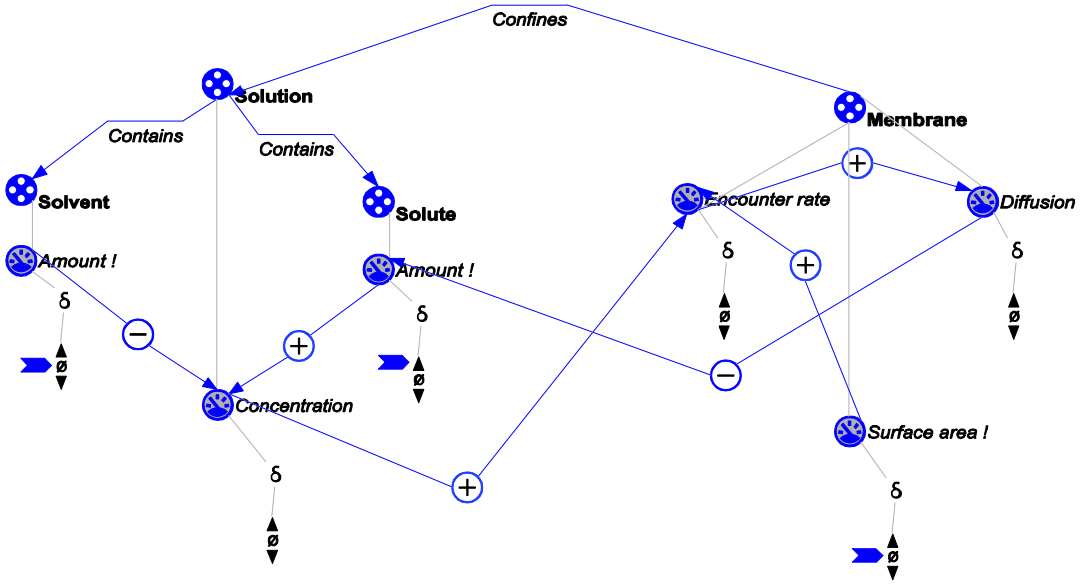

Figure 13.2 Model expression for Diffusion one sided LS2 built in the basic causal model learning space of the DynaLearn software.

13.3.3. Scenarios and simulations

This model can be used to simulate the effects of changing the concentration of the solution and/or the surface area of the membrane. An increase in the concentration of the solution will cause an increase in the encounter rate of molecules with the membrane and result in a faster diffusion rate.

Table 13.2 Scenario information – causes and conditions for simulation of Diffusion one sided LS2

Type	Details
Exogenous control	Amount (Solvent) *steady* Amount (Solute) *increase* Surface area (Membrane) *steady*
(In)equality	*na*
Ambiguity	*na*

13.4. Osmosis one sided LS2

13.4.1. Concepts and goals

This causal model represents the interaction between a solution and a permeable membrane but in consideration of a single solution. In this model osmosis is represented as the movement of water molecules across the membrane. The rate of movement is determined by the osmotic potential of the solute (itself determined by the concentration of the solution) and the surface area of the membrane.

13.4.2. Model expression

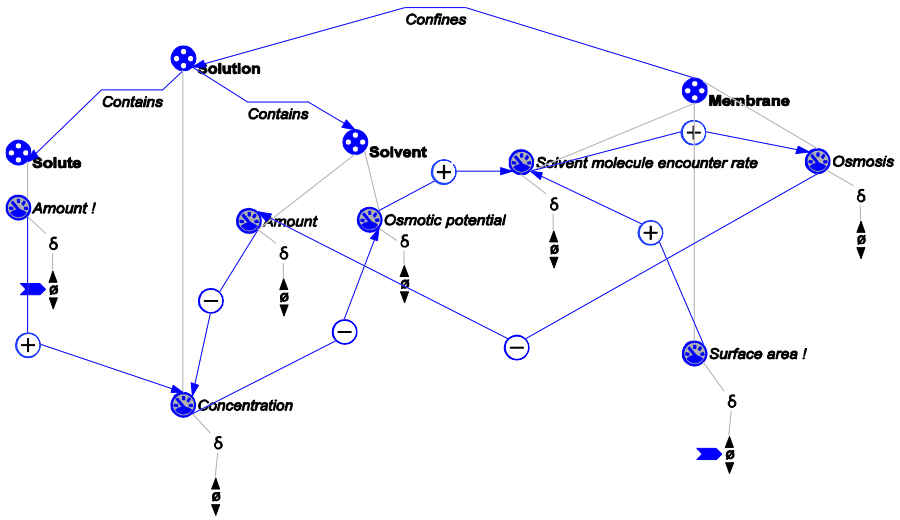

Figure 13.3 Model expression for Osmosis one sided LS2 built in the basic causal model learning space of the DynaLearn software.

13.4.3. Scenarios and simulations

This model can be used to simulate the effects of changing the concentration of the solution and/or the surface area of the membrane on the osmotic movement of water molecules. An increase in the concentration of the solution will cause a decrease in the osmotic potential and consequently a

decrease in the encounter rate of solvent molecules (water) with the membrane and result in a slower osmosis rate.

Table 13.3 Scenario information – causes and conditions for simulation of Osmosis one sided LS2

Type	Details
Exogenous control	Amount (Solute) *steady* Amount (Solvent) *increase* Surface area (Membrane) *steady*
(In)equality	*na*
Ambiguity	*na*

13.5. Cellular diffusion and osmosis LS4

13.5.1. Concepts and goals

This causal differentiation model represents cellular diffusion across a semi-permeable cell membrane. It makes three key assumptions: 1) the surface area of the cell membrane doesn't change; 2) cell pressure/turgor doesn't affect the osmotic potential and; 3) the flow of water molecules and the flow of solute molecules across the membrane occur at the same speed/rate. In this model the state of the system is controlled by the net balance of four flows; the in/out osmotic flow and the in/out diffusion flow.

13.5.2. Model expression

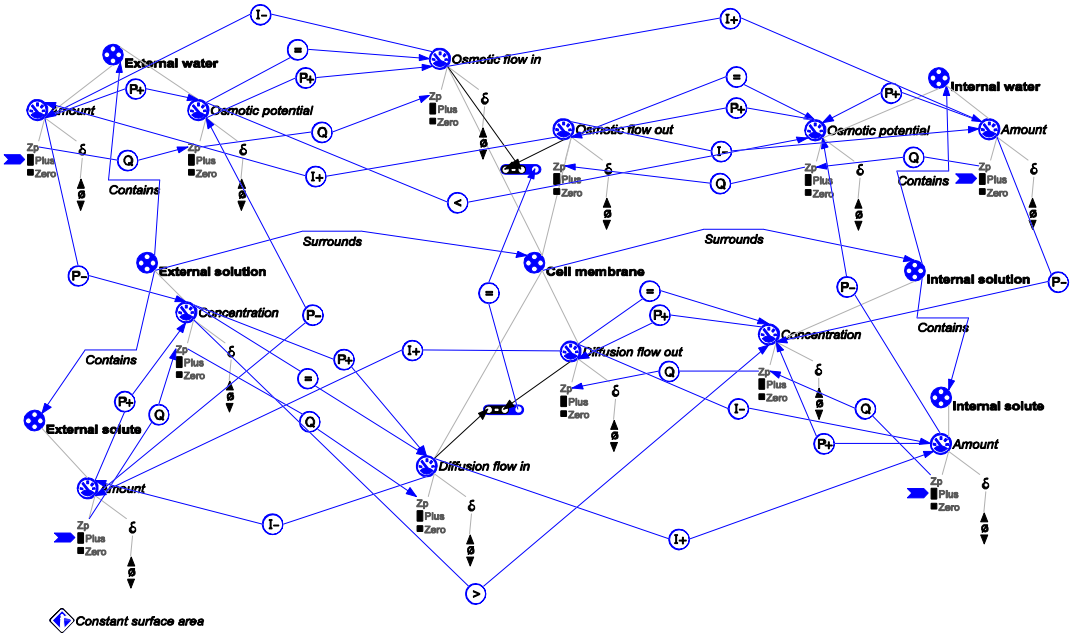

Figure 13.4 Model expression for Cellular diffusion and osmosis LS4 built in the basic causal model learning space of the DynaLearn software.

13.5.3. Scenarios and simulations

The scenario above indicates a situation where the concentration of the external solution is greater than the concentration of the internal solution (Table 13.4). The system moves to a situation where the concentrations become equal and the inflow of solvent and solutes are equal to the outflow of solute and solvents from the cell (Figures 13.5 and 13.6).

Table 13.4 Scenario information – causes and conditions for simulating Cellular diffusion and osmosis LS4

Type	Details
Exogenous control	None
(In)equality	Osmotic potential (External water) < Osmotic potential (Internal water) Concentration (External solution) > Concentration (Internal solution)
Ambiguity	None

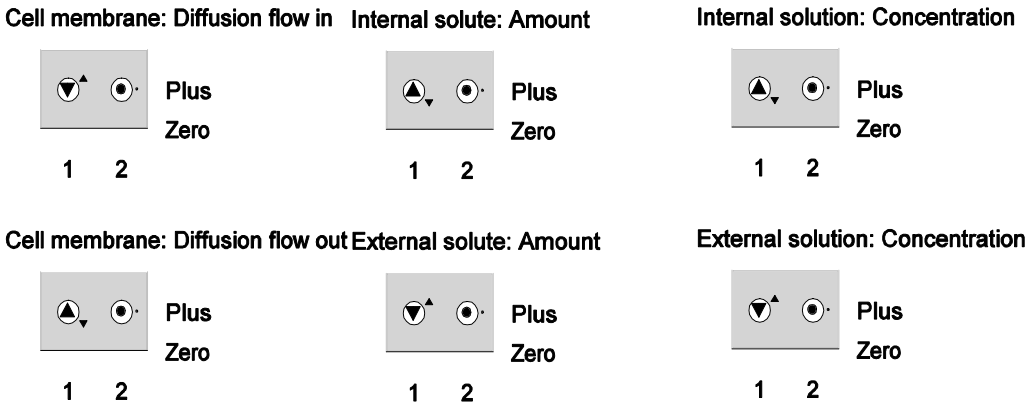

Figure 13.5 Behaviour path and value history for the full simulation of Cellular diffusion and osmosis LS4

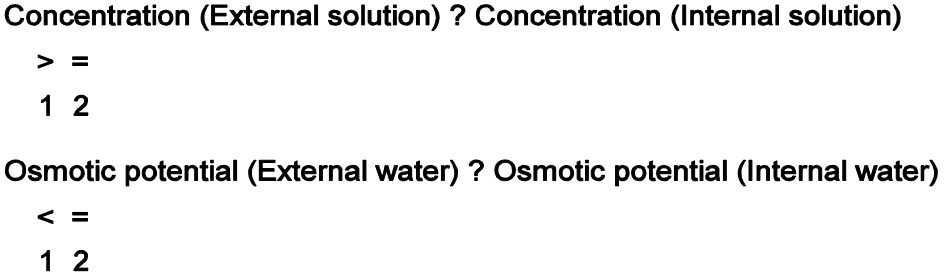

Figure 13.6 Equation history for assigned (in)equality statements in the full simulation of Cellular diffusion and osmosis LS4

13.6. Conclusions and future development

- Develop models in the advanced learning spaces (LS5 Conditional Knowledge and LS6 Generic and reusable knowledge).
- Develop models that explore biological contexts of diffusion and osmosis such as osmoregulation and active transport.
- Develop topic materials that highlights diffusion and osmosis concepts underpinning advanced topics such as adaption to environmental stress, homeostasis etc.
- Identify common student misconceptions and whether conceptual models could address these problems.

14. River rehabilitation

14.1. Topic and model metadata

Topic	River rehabilitation		
Author	R Noble	**Version(s)**	DL v0.6.12
Models	River rehabilitation LS2.hgp		
Target users	A Level		

14.2. Topic rationale

14.2.1. Background

Humans have modified and exploited rivers and river systems for their needs for many hundreds if not thousands of years. The modification of river systems and catchments through forestry, agriculture, land drainage, flood defence, hydropower generation and water resource management have greatly altered the physical and chemical environment of river systems. In particular the damage caused to the physical structure and chemical quality of rivers during the industrial revolution led to significant damage to the ecology of some rivers. In more recent times environmental management and a drive for sustainable use of resources and conservation of freshwater environments has led to efforts to restore, rehabilitate or enhance the ecological quality of rivers. Most recently the EU Water Framework Directive has legally formalised the future sustainable management of water resources and the maintenance or re-establishment of good ecological conditions in all rivers. The WFD aims to achieve this through monitoring ecological conditions in rivers and implementing a range of appropriate rehabilitation, restoration or mitigation measures where conditions fail to meet the good standards required.

River restoration generally has the aim of restoring the form and functioning of a river system back to a pre-disturbance condition. However, it is often very difficult determine what those conditions and functions should be. It is generally agreed that it is also impossible to restore a system to a pre-disturbed state, with the state created post-“restoration” representing a new ecological system with a form and function very different to pre-disturbance conditions. As such it is important to differentiate between restoration (an attempt to re-create a previous condition), rehabilitation (amelioration of an impact understanding that the result will not match previous conditions), enhancement (modification to meet an objective not necessarily based on previous conditions) and mitigation of impacts (compensation for the impact without addressing the impact itself).

The amelioration of human impacts on river ecosystems requires an understanding of the catchment level processes and activities that regulate and determine the natural physical and chemical conditions within the river system. As such the topic requires underpinning by core topics such as hydrology,

hydraulics, biogeochemical cycles, sediment transport and species ecology and requirements (Cowx & Welcomme 1998).

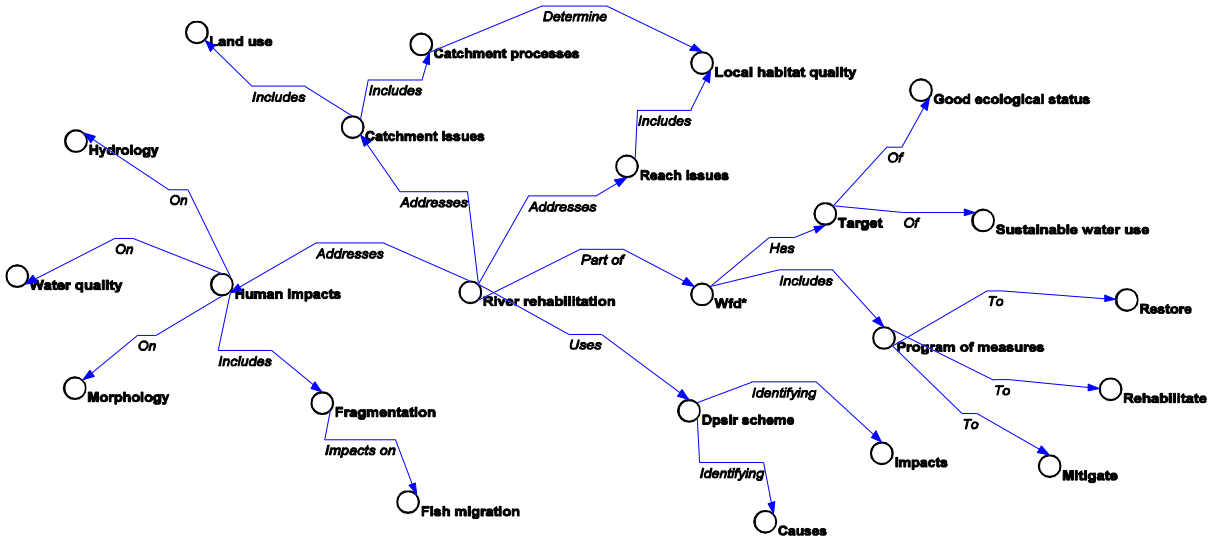

Figure 14.1 Concept map of the river rehabilitation topic prepared in the concept map learning space of the DynaLearn software.

14.2.2. Key themes

- The difference between rehabilitation, restoration and mitigation
- The role of the Water Framework directive in the future of sustainable river management
- The role of hydro-geomorphological catchment processes in creating and maintaining river habitats
- The impacts of different human activities on river ecosystems and the methods required to ameliorate them

14.2.3. General contents and ingredients

Table 14.1 Entities, quantities and quantity spaces (QS) used in the model River rehabilitation LS2.

Entity	*Quantities*	*QS*	*Remarks*
Catchment	Intensity of land use		The impacts of human activities on river catchments
	Integrity of catchment processes		The processes at a catchment level that determine the morphology, hydrology and water quality of a river at a reach scale
River	Habitat quality		The local quality of river hydro-morphology and water chemistry
	Ecological status		The response of biotic quality elements
Society	Requirement for rehabilitation		Society's perceived enthusiasm and drive to rehabilitate rivers
	Rehabilitation activity		The amount of rehabilitation undertaken by society

14.3. River rehabilitation LS2

14.3.1. Concepts and goals

This basic causal model represents the links between detrimental human activities at a catchment scale and the impacts on hydro-geomorphological catchment processes that create and maintain habitat quality in rivers. The model represents how declining habitat quality has an impact on the ecological status of the river (the biota). Through the Water Framework Directive society is driven to respond to declining ecological status by undertaking a programme of measures to rehabilitate the river and ameliorate the impacts of water use.

14.3.2. Model expression

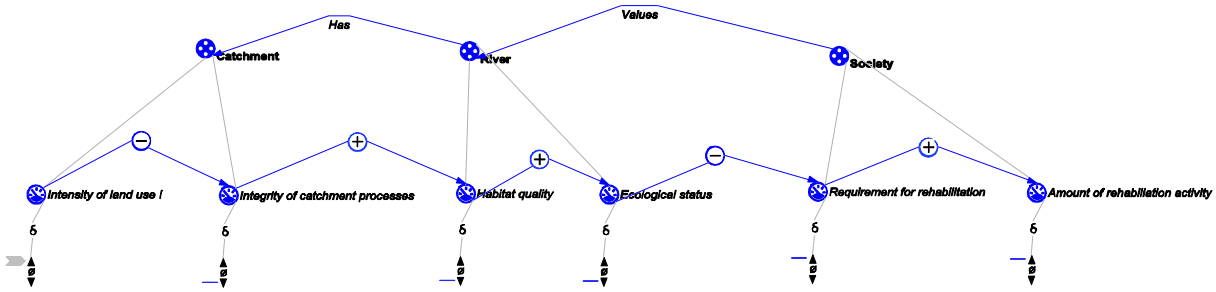

Figure 14.2 Model expression for River rehabilitation LS2 built in the basic causal model learning space of the DynaLearn software.

14.3.3. Scenarios and simulations

This model simulates the ideal response of society to declining ecological status of rivers by increasing the amount of rehabilitation work undertaken (Figure 14.2).

14.4. Conclusions and future development

- Develop models in the advanced learning spaces (LS5 Conditional Knowledge and LS6 Generic and reusable knowledge).
- Develop topic materials that link the river rehabilitation topic to topics related to catchment processes, river continuum concept, flood protection, integrated catchment management and then DPSIR scheme.
- Develop models that explore the different concepts of restoration, rehabilitation and mitigation of human impacts on river systems.

15. Greenhouse gases and Climate change

15.1. Topic and model metadata

Topic	Greenhouse gases and Climate change		
Author	R Noble	Version(s)	DL v0.6.12
Models	Greenhouse gases sources LS2.hgp Climate change LS2.hgp Climate change basic LS3.hgp Climate change LS4.hgp		
Target users	A level		

15.2. Topic rationale

15.2.1. Background

Given their current importance climate change and anthropogenic climate forcing are perhaps amongst the most fundamental topics to be understood within environmental science. Firstly, the greenhouse effect and the contribution of greenhouse gases to the conditions under which life has evolved are natural phenomena. Indeed the Gaia hypothesis postulates that life has altered the environment in which it has lived, creating conditions more conducive to survival. Secondly, anthropogenic climate forcing has been identified as a fundamental threat to biodiversity and future sustainability of the human population (acting through the relationship between climate and ecosystem services).

The greenhouse effect is the natural dynamic equilibrium of energy inputs and losses from the Earth's surface and the atmosphere. The processes affecting the heat balance of the atmosphere are greatly influenced by the concentration of greenhouse gases (carbon dioxide, methane, ozone, water vapour and aerosols). Greenhouse gases act to adsorb and re-radiate infrared radiation to the Earth's surface. This re-radiation of infrared has a warming effect on the atmosphere, which means that the surface of the earth is around 30°C warmer that it would be otherwise. Whilst most greenhouse gases have natural sources and their concentration is typically held in balance by natural processes (photosynthesis, respiration, fermentation, absorption by oceans etc), anthropogenic sources of these gases has lead to rises in concentrations and consequent climate forcing.

The potential extent of climate forcing is unclear as there are a number of feedback mechanisms related to natural processes that may both exacerbate and accelerate changes (positive feedbacks such as the ice-albedo mechanism, influences on water temperatures and ocean storage of carbon dioxide and the effect of temperature on the rate of decomposition) or may reduce or slow down the changes (negative feedbacks e.g. through increased evaporation and cloud cover or through increased primary production absorbing more carbon from the atmosphere) (Campbell 1993; Gregory et al. 2009; Pickering 2009).

Global climate change and warming may have great consequences for species distribution and biodiversity, especially for those species that are specialised to specific conditions or are in isolated habitats and are unable to move to more suitable conditions.

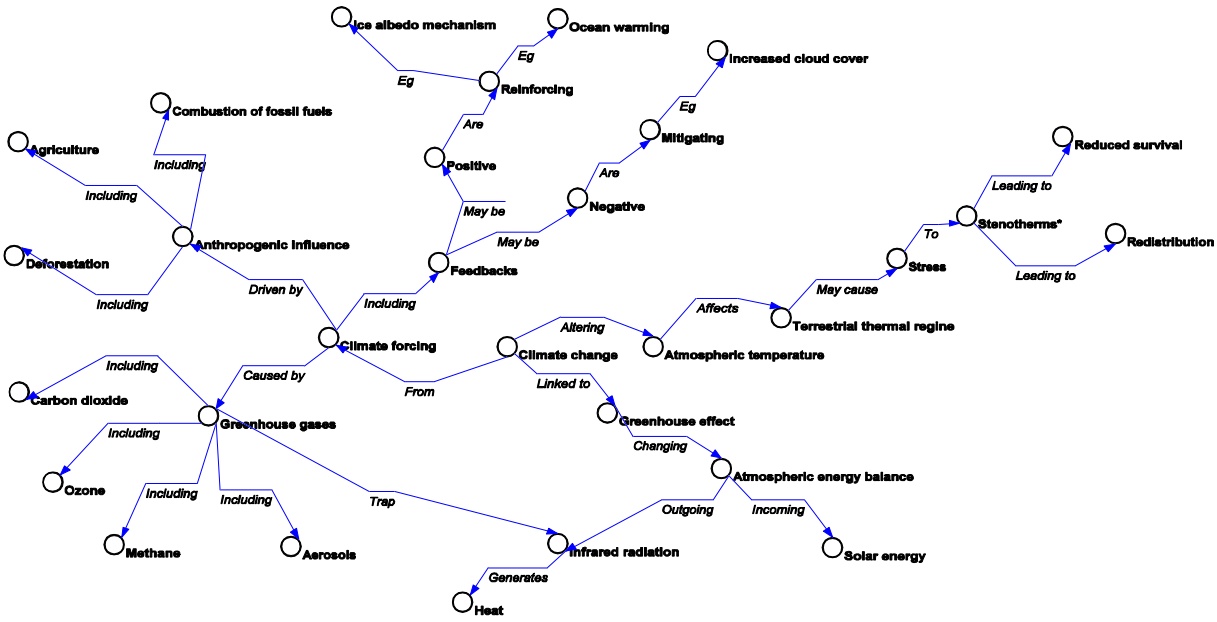

Figure 15.1 Concept map of the greenhouse gases and climate change topics prepared in the concept map learning space of the DynaLearn software.

15.2.2. Key themes

- Sources and sinks of the various natural and anthropogenic greenhouse gases.
- Relationship between greenhouse gases, infrared radiation and atmospheric temperature and climate.
- Role of greenhouse gases in climate change and possible consequences for sensitive species.

15.2.3. General contents and ingredients

All of the models developed in different learning spaces for the Greenhouse gases and climate change topic comprise a suite of entities and associated quantities that are re-used or modified. The entities and quantities used are summarised in Tables 15.1 and 15.2. Not all entities and quantities are used in all models.

Table 15.1 Entities, quantities and quantity spaces (QS) used in the model Greenhouse gases sources LS2

Entity	***Quantities***	***QS***	***Remarks***
Greenhouse gases		*na*	
Ozone	Production	*na*	
	Consumption	*na*	
Water	Production	*na*	
	Consumption	*na*	
Anthropogenic aerosols	Production	*na*	
	Consumption	*na*	
Carbon dioxide	Production	*na*	
	Consumption	*na*	
Methane	Production	*na*	
	Consumption	*na*	
Atmosphere	Rainfall	*na*	
	Photochemical reactions	*na*	Process of breaking down some greenhouse gases
Oceans	Absorption	*na*	
	Evaporation	*na*	
Earth		*na*	
Green plants	Amount	*na*	
	Photosynthesis	*na*	
Organic matter	Decay	*na*	Production of carbon dioxide
	Anaerobic fermentation	*na*	Process of methane production
Humans	Industry	*na*	Chemical industry production of aerosols
	Combustion of fossil fuels	*na*	
Animals	Amount	*na*	
	Ruminant fermentation	*na*	Methane production from agriculture

Table 15.2 Entities, quantities and quantity spaces (QS) used in the models Climate change LS2, Climate change basic LS3 and Climate change LS4

Entity	***Quantities***	***QS***	***Remarks***
Humans	(Carbon Dioxide) Emissions	*Zp*	
Atmosphere	Temperature (regime)	*Lnh*	Climatic regime
Greenhouse gases	Concentration	*Lnh*	
Atmospheric carbon dioxide	Production	*Zp*	Combination of decay and emissions
	Consumption	*Zp*	Combination of photosynthesis and absorption
	Concentration	*Lnh*	
(Retained) IR radiation	Amount (retained)	*Lnh*	Infrared re-radiated back to earth's surface
Heat	Amount	*Lnh*	
Earth			
Organic matter	Decay rate	*Zp*	
Green plants	Global biomass	*Zp*	
	Global photosynthesis	*Zp*	Sum of photosynthesis for the whole globe
Oceans	Carbon absorption	*Zp*	Transfer of carbon dioxide from atmosphere to ocean "carbon reservoir"
Aquatic habitat	Max Temperature	*Lnh*	Maximum seasonal water temperature in the lake
Fish population	Stress	*Level*	Heat stress for a thermally sensitive species
	Mortality	*Zp*	Mortality is the only impact of stress considered in this model
	Size	*Zsml*	Population size
	Reproduction	*Zp*	

Lnh {Low, Natural min, Natural, Natural max, High}; *Level* {Cold stress, Natural minima, Natural, Natural maxima, Heat stress}; *Zsml* {Zero, Small, Medium, High}

15.3. Greenhouse gases sources LS2

15.3.1. Concepts and goals

This basic causal model is a representation of the main processes involved in the production and consumption of the main atmospheric greenhouse gases. The model considers both natural processes and also the anthropogenic processes that are causing the changes in atmospheric composition and global climate change.

15.3.2. Model expression

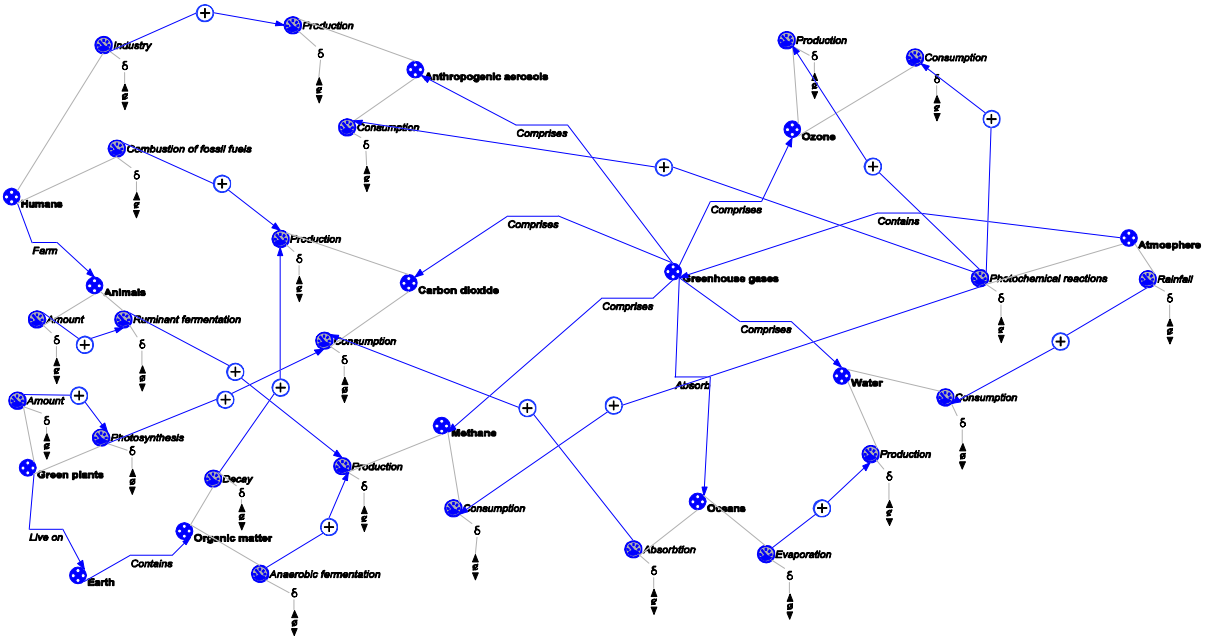

Figure 15.2 Model expression for Greenhouse gases sources LS2 built in the basic causal model learning space of the DynaLearn software.

15.3.3. Scenarios and simulations

This model represents the structure and relationships within the system. It can be simulated to consider the effects of increasing production of different greenhouse gases. The model may be more useful for students to explore “enabling conditions” rather than cause/effects. For example in most simulations students would have to control the derivatives of a number of variables to be able to make a judgement on the resulting behaviour.

15.4. Climate change basic LS3

15.4.1. Concepts and goals

This model represents the basic reasoning behind the relationship between anthropogenic emissions of greenhouse gases and the global atmospheric Heat balance. In the model the amount of Infrared radiation retained by the atmosphere (re-radiated back to the Earth's surface) is directly related to the concentration of greenhouse gases. An increase in the amount of retained infrared radiation leads to an increase in atmospheric heat production and consequently a rise in the average temperature regime. The choice of quantity space indicates that each quantity has 3 intervals to be considered – the natural range and then a range above and below the maximum and minimum values observed in the absence of anthropogenic disturbance {Low, Natural minima, Natural, Natural maxima, High}.

15.4.2. Model expression

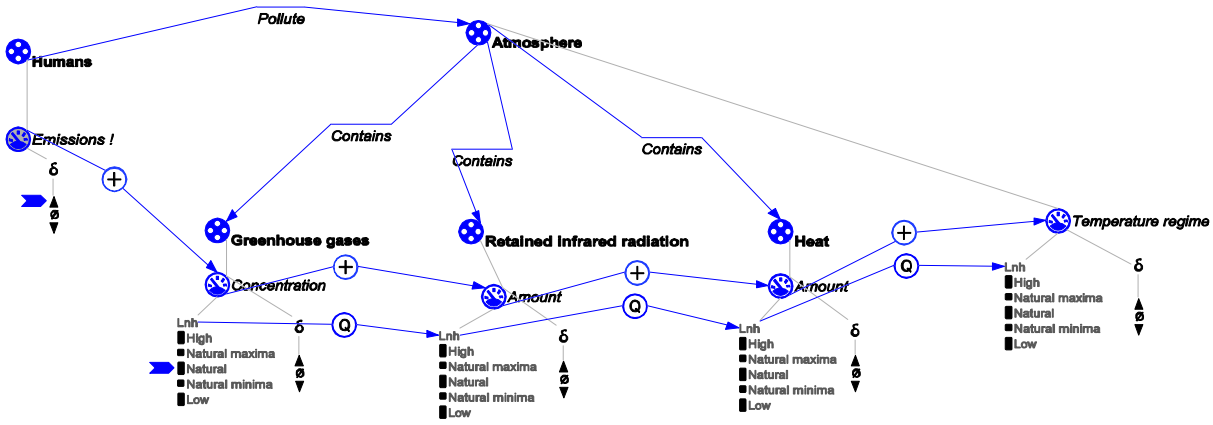

Figure 15.3 Model expression for Climate change basic LS3 built in the basic causal model with state graph learning space of the DynaLearn software.

15.4.3. Scenarios and simulations

Climate change basic LS3 can be simulated to consider the potential effects of increasing or decreasing anthropogenic emissions of greenhouse gases (Figure 15.3 and Table 15.3). In the case of increasing emissions the concentration of greenhouse gases increases resulting in increasing retention of infrared radiation warming of the atmosphere (Figure 15.4).

Table 15.3 Scenario information – causes and conditions for simulating Climate change basic LS3

Type	Details
Exogenous control	Emissions (Humans) *increase*
(In)equality	None
Ambiguity	None

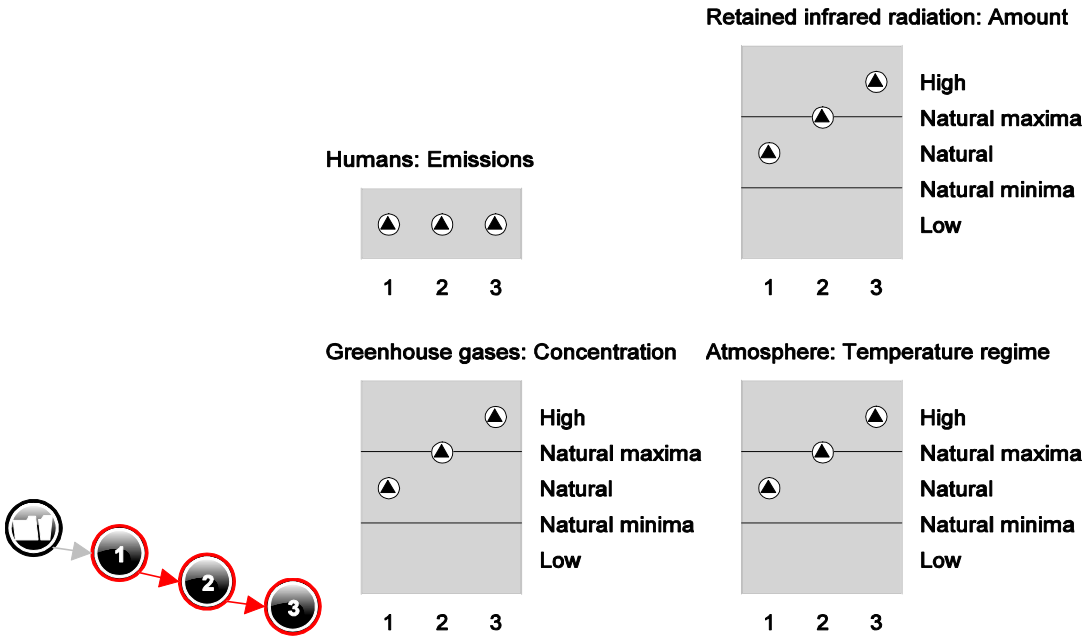

Figure 15.4 Behaviour path and value history of Climate change basic LS3

15.5. Climate change LS2

15.5.1. Concepts and goals

This basic causal model builds on the previous basic models to consider the role of carbon dioxide as a greenhouse gas and the consequence of changing atmospheric temperature for the survival of a population of a thermally sensitive fish species in a freshwater lake (closed system). The model considers that the population size is regulated by the balance between mortality and reproduction and that climate change will act on the species through increasing environmental stress affecting the population mortality. The model is assuming a closed system where emigration is impossible and the effect of climate change only affects a species though altered mortality. The model also considers the main sources and stores of atmospheric carbon dioxide.

15.5.2. Model expression

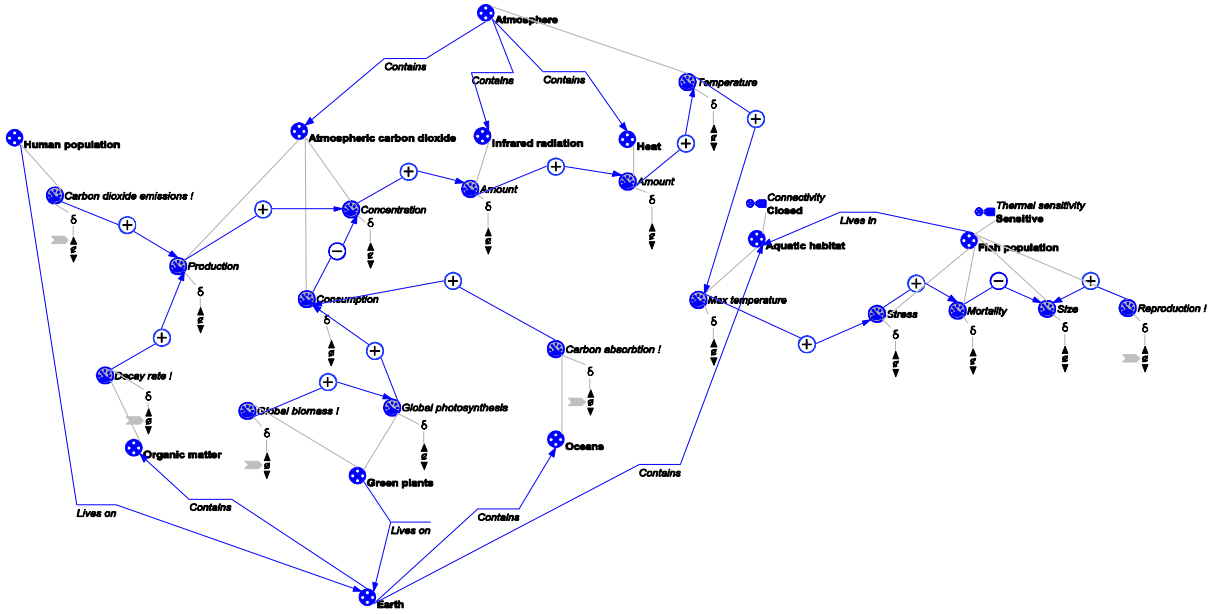

Figure 15.5 Model expression for Climate change LS2 built in the basic causal model learning space of the DynaLearn software.

15.5.3. Scenarios and simulations

This model can simulate the effect of increasing carbon dioxide emissions whilst considering the enabling conditions related to decay rate, photosynthesis and carbon absorption by oceans (Table 15.4). In the example above all three of these variables are set so they do not change in the simulation. As such an increase in emissions leads to an increase in the production of carbon dioxide in the atmosphere. This then has the consequence of elevating the atmospheric temperature and the temperature of the aquatic habitat. An increase in the temperature of the aquatic habitat causes an increase in the environmental stress acting on the species. Assuming that reproduction does not change then the increase of stress acts to increase the mortality rate and results in a decline in the size of the population (Figure 15.5).

Table 15.4 Scenario information – causes and conditions for simulating Carbon cycle LS2

Type	Details
Exogenous control	Reproduction (Fish population) *steady* Carbon dioxide emissions (Human population) *increase* Decay rate (Organic matter) *steady* Global biomass (Green plants) *steady* Carbon absorption (Oceans) *steady*
(In)equality	*na*
Ambiguity	*na*

15.6. Climate change LS4

15.6.1. Concepts and goals

This causal differentiation model builds on the basic causal model (Climate change LS2) and the quantity spaces from “Climate change basic LS3” to specifically represent the production and consumption of carbon dioxide and the population reproduction and mortality as pairs of competing rates acting on the system.

15.6.2. Model expression

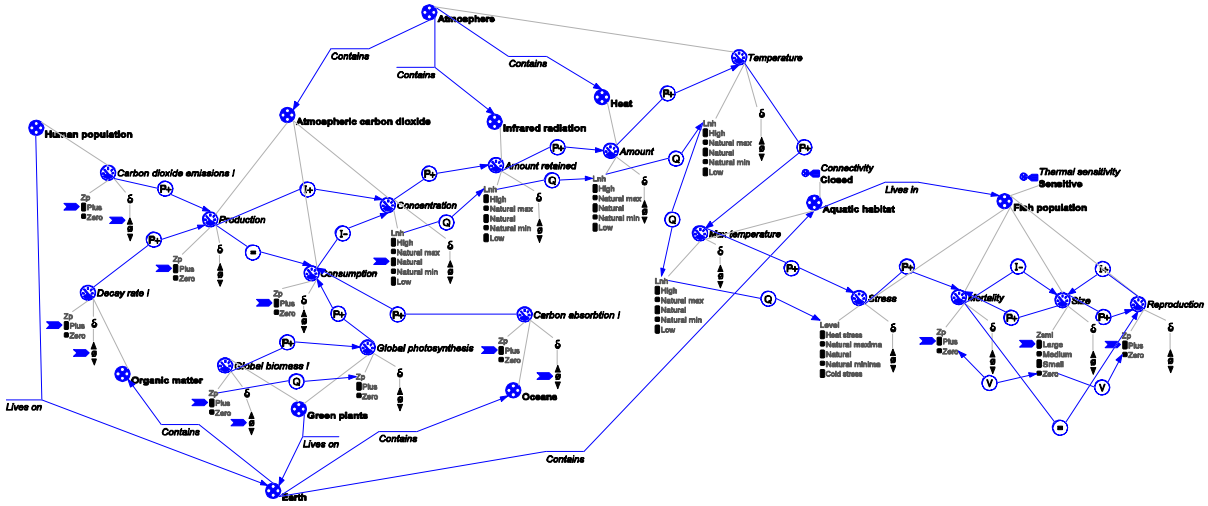

Figure 15.6 Model expression for Climate change LS4 built in the causal differentiation model learning space of the DynaLearn software.

15.6.3. Scenarios and simulations

The scenario presented here assumes stable levels of decay rate, global photosynthesis and carbon absorption by the oceans. Initially production and consumption of atmospheric carbon dioxide are equal ((in)equality statement) and the reproduction and mortality of the fish population are also equal (stable population). Increasing emissions of carbon dioxide (exogenous control) causes this balance to shift to a situation where production is in excess of consumption (Table 15.5).

Table 15.5 Scenario information – causes and conditions for simulating Climate change LS4

Type	Details
Exogenous control	Carbon dioxide emissions (Human population) *increase* Decay rate (Organic matter) *steady* Global biomass (Green plants) *steady* Carbon absorption (Oceans) *steady*
(In)equality	Mortality = Reproduction (Fish population) Production = Consumption (Atmospheric carbon dioxide)
Ambiguity	none

This scenario currently terminates in three end states (Figure 15.7) differentiated by the behaviour of the mortality of the fish population which is either plus and steady, increasing or decreasing (Figure 15.8). This is a consequence of the resolution of the balance of effects the proportionalities from size and stress on mortality. Ideally the population would decline (as shown in Figure 15.9) until extinct however this does not currently occur. This is a modelling issue that may not be possible to resolve in this learning space as it require the application of conditional knowledge to constrain possible behaviours.

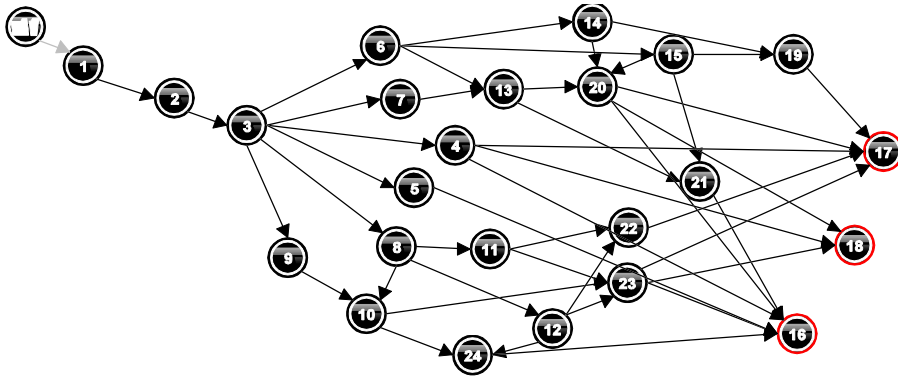

Figure 15.7 Behaviour path for the simulation of Climate change LS4 showing the three possible end states 16, 17, and 18.

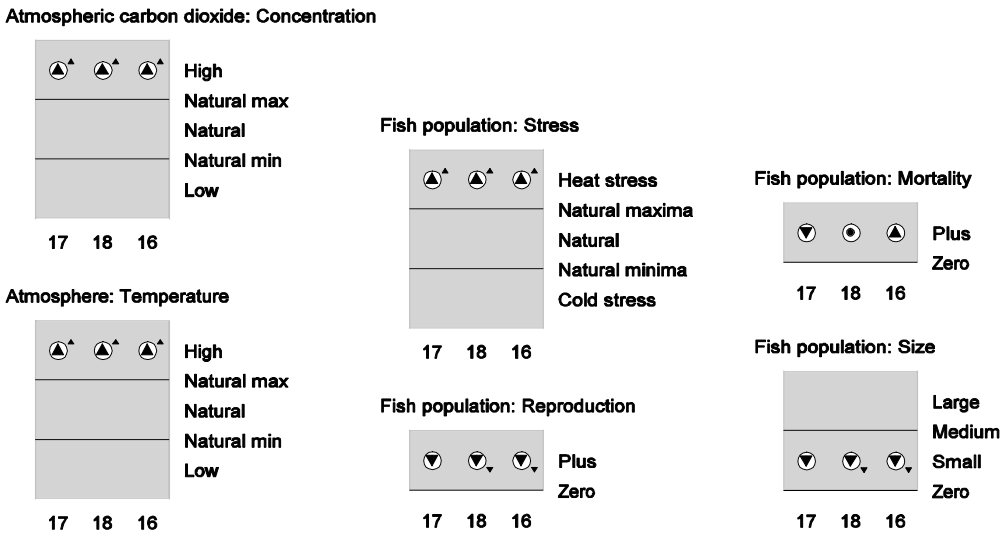

Figure 15.8 Values of key quantities in the three end states generated from Climate change LS4

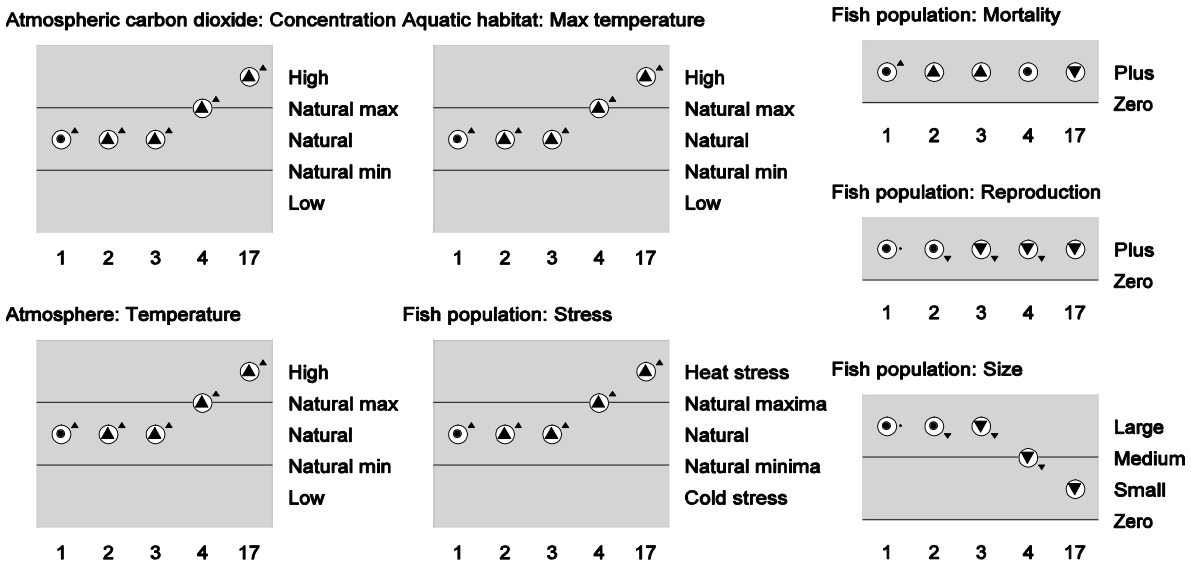

Figure 15.9 Value history of behaviour path [1, 2, 3, 4, 17] in the full simulation of Climate change LS4

15.7. Conclusions and future development

- Develop models in the advanced learning spaces (LS5 Conditional Knowledge and LS6 Generic and reusable knowledge).
- Develop models that explore the concepts of positive and negative feedback controls in climate forcing.
- Develop topic and curriculum materials to link green house gases and climate change to topics such as the effects of climate change in river systems, agriculture, forestry and water resource management.

16. Discussion

The models for the basic topics presented here provide a resource for the development and testing of the new technological aspects of the DynaLearn software. In particular the models will provide the means to test the ontology mapping and semantic technology for grounding of terms and model comparison. Additionally the semantic technology will enable the virtual character technology to generate appropriate individualised feedback to the modeller by locating similar models, suggesting items modelled by others who have used similar terms or by comparison of the student model with a norm model provided by teachers in a class-based exercise. In addition to these uses, the development and exploration of basic topics and models within the prototype DynaLearn software will be used to evaluate the capabilities of the new software, develop model building strategies that are most applicable to the new features, identify areas of the software that could be improved or changed, identify concepts, topics and modelling approaches that are suitable for further development (advanced topics and models for Task 6.4) and inform the development of the DynaLearn curricula for environmental science (Task 6.3 and 6.5).

The overarching new feature to the conceptual modelling environment in the DynaLearn software is the implementation of the different learning spaces, increasing the modelling vocabulary and formalisation from a basic concept map to a compositional qualitative reasoning model. These new learning spaces have enabled concepts and knowledge to be presented in different ways and at different levels of complexity. The use of learning spaces will enable a range of different modelling activities that will meet particular educational goals at different levels of complexity for a range of learning spaces. Meta-analysis of the models presented here highlights some of the strengths of each of the learning spaces in addition to some of the challenges of working in them.

The use of the basic causal modelling learning space (LS2) provides an opportunity for the formalisation of model expressions, moving beyond concept maps. This formalised 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 (e.g. Community diversity basic LS2 or Diffusion one sided LS2) to an elaborate diagram with numerous concepts involved (Climate change LS2). This ease of creating formalised representations that contain numerous concepts is a potential strength for certain modelling activities. However, models with numerous entities and quantities rapidly become difficult to simulate in this level, especially where the model is not purely linear in its reasoning (i.e. when ambiguous behaviour arises). Additionally, care must be taken in quantity and relationship descriptions when modelling in this learning space (and LS3) as the openness of the positive and negative relationships means that the choice of terms for entities and quantities will determine the accuracy of the logic described under different behaviours. For example it is logically correct to state that increasing growth leads to increasing size (a positive relationship from growth to size) however it is not logical to say that decreasing growth leads to decreasing size. It is for this reason that the models developed in LS2 here often consider production and consumption of entities rather than the amount to ensure that the model description remains logical under all possible behaviours. This attribute of working in LS2 is also a considerable strength with its potential as a tool to enable students to consider the logical form of relationships and causality in their models as a first step in recognizing the different forms of causality available in the causal differentiation learning space (LS4).

The use of the basic causal model with state graph learning space (LS3) is far more challenging than its conceptual simplicity would suggest. Fundamentally this is because the identification of real qualitative values and thresholds in ecological and environmental systems is difficult. In many cases the qualitative descriptions used in quantity spaces are a case of trying to semi-quantify variables as small or large etc. This semi-quantification approach is commonplace in everyday life, however it is

often of limited value in conceptual modelling as the way this is implemented often fails to represent what is meant by the values and how they relate to the concepts to be captured. Working with LS3 is therefore challenging both to students and to experts. However, appropriate consideration of real qualitatively different states and thresholds is a fruitful exercise, in particular as a precursor for working with conditional knowledge at UL5 and UL6.

The causal differentiation learning space (LS4) provides students with much of the functionality available in full qualitative modelling, but within a single model expression. This enables models of a range of sizes to be developed around the use of the different forms of qualitative causal relationships. The models presented here all use this learning space to represent that most systems can be viewed from the point of view of competing rates and the formation of equilibria. One important feature here is that large model expressions can easily become highly complicated and cluttered with modelling ingredients (influences, proportionalities, (in)equalities and correspondences) as such they can quickly become difficult to interpret (a major reason behind the use of a compositional modelling approach at LS6). Additionally, the larger more complicated models become difficult to simulate at LS4 with many of the simulations presented here having ambiguous end states or terminating earlier than expected. This is generally a modelling issue related to behaviours not moving to the extreme point values of quantities when influences (especially exogenous influences) and proportionalities are always active in the model (lack of conditional knowledge at this level). These issues with simulations in LS4 will need careful consideration in terms of focussing modelling activities for students and generating appropriate feedback through the semantic technology and virtual characters.

The development of models in the conditional knowledge learning space (LS5) has been limited due to technical issues with its implementation in the software. This learning space will be considered in detail during the development of advanced topics and models in task 6.4. The development and understanding of conditional knowledge is critical to working with full compositional qualitative models and is also vital for controlling and representing behaviours within simulations. Whilst the functionality and application of models in LS5 has not been tested in detail, the compositional approach to modelling available at LS6 is well known. However, its application to learning situations has perhaps received less attention. The compositional approach together with the use of hierarchy information and inheritance and re-use of knowledge provides a rich modelling language, however the learning benefits of these tools in terms of delivering domain concepts and knowledge is perhaps less well understood. Learning by modelling activities will certainly be developed in the learning space most appropriate for delivering the goals of the exercise. In this context it is clear that teachers may choose the most appropriate learning space to deliver the domain concepts and knowledge. Given this, the development of advanced topics and models in task 6.4 should perhaps focus on identifying what types of domain concepts can only be delivered using the more advanced learning spaces of the modelling tool. In this way the final DynaLearn curriculum will be able to provide both a repository and resource base of models and perhaps more importantly clear guidance to teachers what sorts of concepts are best handled by the different learning spaces.

17. Conclusion

- Special care must be taken when developing models in LS2 to maintain logical relationships between quantities (irrespective of in which direction the quantities are changing). This learning space has strong potential to use the vocabulary to aid students to identify where the relationships between amounts should be represented as direct influences (I's) or proportionalities (P's) in learning spaces 4, 5 and 6.

- The development of insightful quantity spaces in ecological systems is still limited and threshold values are often difficult to identify. However, good modelling should attempt to move away from quantity spaces with limited value beyond semi-quantification of values to really identify thresholds where behaviour changes within ecological systems. These threshold points are important for working in learning spaces 5 and 6 where conditional knowledge can be used to alter behaviours.

- Simulations at learning space 4 often produce behaviours that result in ambiguous or false end states. In most cases such behaviours would be controlled using conditional knowledge and additional knowledge fragments. Therefore, use of learning space 4 can not only be used to explore causal differentiation but thorough and well supported interrogation of simulation results could be used as a step towards identifying the need for conditional knowledge.

- Further topic and model development needs additional focus on the re-structuring of the delivery of the topics using the modelling approach. The re-structuring requires further exploration of the specific aspects of topics that could best be developed using the modelling approach. For each of the topics common misconceptions by students will be identified to see whether conceptual modelling could be used to remove these misconceptions.

- Further development of the topics and models will require development of advanced models in learning spaces 5 and 6 together with appropriate use of model expressions at the other learning spaces to represent key knowledge.

- Further development of topics in the curricula requires careful consideration and development of materials that create links between the topics. This should create pathways for students to explore and move between related topics.

References

AQA (2007a) GCE Environmental Studies Specification for AS exams 2009 onwards and A2 exams 2010 onwards (version 1.0). Assessment and Qualifications Alliance (AQA) Manchester UK.

AQA (2007b) GCE Biology Specification for AS exams 2009 onwards and A2 exams 2010 onwards (version 1.1). Assessment and Qualifications Alliance (AQA) Manchester UK.

Begon M., Townsend C.R. & Harper J.L. (2006) *Ecology: From individuals to ecosystems* 4th edition. Blackwell publishing ltd, UK, 738pp.

Bredeweg, B., Linnebank, F., Bouwer, A., Liem, J., 2009. Garp3 — Workbench for Qualitative Modelling and Simulation. *Ecological Informatics* **4**, 263–281.

Campbell N.A. (1993) *Biology* 3rd edition. Benjamin/Cummings Publishing Company Inc. 1190pp.

CCEA (2008) CCEA AS and A Level Biology from September 2008. www.ccea.org.uk

Cowx I.G. & Welcomme R.L. (eds) (1998) *Rehabilitation of Rivers for Fish*. Oxford: Fishing News Books, Blackwell Science, 260 pp.

Dorit R.L., Walker W.F. & Barnes R.D. *Zoology*. Saunders College Publishing, 1009pp.

Edexcel (2008) GCE Biology specification: Edexcel Advanced Subsidiary GCE in Biology (8BI01) - First examination 2009, Edexcel Advanced GCE in Biology (9BI01) - First examination 2010, Issue 3. Edexcel publications ltd, UK.

Gregory *et al.* (2009) *Environmental Sciences: A Student's Companion*. SAGE Publications Ltd. 441pp.

King M. (1995) *Fisheries biology, assessment and management*. Fishing News Books, Blackwell Science, 341 pp.

Pickering W.R. (2009) *AS and A level Biology through diagrams*. Oxford Revisions Guides. Oxford University Press, 213pp.

Salles *et al.* (2009) Deliverable D6.1: DynaLearn environmental science curriculum requirements. DynaLearn FP7 project 231526.

Wetzel R.G. (2001) *Limnology: Lake and River ecosystems*, 3rd edition. Elsevier Academic Press, 1005pp.

Withers A.L. (1992) *Comparative Animal Physiology*. Saunders College Publishing, 949pp.

e-mail: Info@DynaLearn.eu
website: www.DynaLearn.eu