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Curriculum for learning about Sustainable Development using Qualitative Reasoning

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Abstract

The European Union's Strategy for Sustainable Development calls for increased public involvement in the process of making decisions that affect sustainability. To support this aim, the NaturNet-Redime project seeks to improve public understanding of sustainable development concepts and cause-effect processes that affect it, especially environmental sustainability. This document describes the development and content of an online curriculum designed to facilitate individual learning about the interacting factors that affect sustainability in a variety of systems. This curriculum is centred on qualitative reasoning models that explore sustainable development situations in a five case studies, in addition to other models that explore specific sustainability issues. Here, we describe how content from these models is organised and presented to guide learners through an online landscape of sustainability concepts, helping them develop a deeper understanding of causal linkages between environmental, social, economic, and institutional aspects of sustainability. The curriculum takes advantage of resources provided within the Moodle course management system. Case studies are presented in web pages linked to lessons that highlight specific sustainability problems and solutions in specific systems. Glossaries automatically link specialised sustainability and modelling terms, which help learners assimilate knowledge and understanding in a manageable way. Themes and learning routes suggest sequences of Moodle resources to view that support learning about specific topics. We provide examples in the context of qualitative models related to indicators of environmental sustainability related to the Millennium Development Goals. Our preliminary evaluation of the online curriculum indicates that students find the lesson format helpful to learn about the interaction of multiple processes and how they affect sustainability.

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1. Introduction

A widely accepted definition of sustainable development (SD) is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [1]. Elaborating on the term “development”, Cunnigham and Cunningham [2] state that SD is “a real increase in well-being and standard of life for the average person that can be maintained over the long-term without degrading the environment or compromising the ability of future generations to meet their own needs.”

Sustainability is a concept under construction, and a universally accepted definition for it does not exist. Different paradigms to classify the relationship between environmental management and development may be identified [3]. Current ideas on SD include integration between economy and ecology (economic decisions should regard to their environmental consequences); intergenerational obligation (current decisions and practices should take account of their effect on future generations); social justice (everybody should have an equal right to an environment in which they can flourish); environmental protection (resources should be conserved and the non-human world should be protected); quality of life (a wider definition of human well-being beyond narrowly defined economic prosperity should be considered); participation (institutions should be restructured to allow all voices to be heard in decision making) [4].

To move beyond definitions and put these ideas into practice to make progress in meeting the EU’s Strategy for Sustainable Development (SSD) [5], people need to develop understanding about how their actions—and the actions of the greater society—interact with biological, physical, and chemical processes in the environment to affect the provision of good and services we all rely on.

The goal of the NaturNet-Redime (NNR) project is to develop a curriculum and learning materials that make expert knowledge about sustainability more accessible to decision makers and stakeholders. Because the SSD calls for more involvement of the public in decision making, this means everyone. Part of this project centres around developing qualitative reasoning (QR) models that can be simulated to explore causal processes that affect various factors related to SD.

The goal of this deliverable is to present our results for organising and optimising QR models about different aspects of SD into a structure that can guide learners through an online *landscape of sustainability concepts*. This structure takes advantage of the hierarchical and compositional nature of our QR modelling approach [6] to support development of a deeper understanding of causal linkages between environmental, social, economic, and institutional aspects of sustainability. By supporting development of this greater understanding, we hope to contribute to the SSD’s aim to build a constituency that is equipped to substantively contribute to the decision-making process and arrive at truly *sustainable* development solutions.

2. Requirements for a curriculum to support the strategy for sustainable development

There are at least three elements involved in every educational interaction: the content to be learned, the learner, and the teacher. A curriculum can be defined as the contents to be addressed in the interaction between learner and teacher and the order and manner in which the contents will be presented [7]. Curriculum can be *formal*, as in schools and universities, or *open*, where learning situations may occur in different places, such as homes and workplaces. A challenge for educators is to provide curricula that are appropriate and effective for these different situations [8].

Specifically, an adequate curriculum is one that:

1. matches features of the learner;

2. meets criteria of pre-defined goals;
3. addresses a defined area of content;
4. is presented in a way that facilitates knowledge capture by the learner.

Here, we provide a brief overview of these requirements, which are elaborated in later sections as required.

3. Features of learners

The target group of learners for a curriculum to support the SSD includes stakeholders, decision makers, and citizens. Only a small proportion of these potential learners are enrolled in or in close proximity to formal educational institutions. Hence, a curriculum to support the objectives of the SSD must be open, rather than formal. Whereas formal curricula are generally linear in their presentation of content, open curricula should be organised more like a web, where alternative learning routes through the content reflect the diverse interests and learning needs of our diverse target groups.

4. Goals for learning

In order to truly be active participants in decision making about SD, learners must achieve all six levels in Bloom's taxonomy of cognitive learning: knowledge, comprehension, application, analysis, synthesis, and evaluation [9]. The last two levels relate most closely to the specific goals of the SSD: learners must be able to *synthesize* so they can design, manage, propose, or plan activities that meet the challenges of SD; they must be able to *evaluate* in order to argue, assess, compare, defend, or support what specific alternative SD scenarios should be undertaken and what should not [9].

5. Area of content

Development of content for the SD Curriculum was guided by the *Guidelines for Sustainable Development Curriculum* (project deliverable D6.8). In that document, we outlined four main access points for learners to start using our online curriculum. These were:

1. Learn about basic concepts of Sustainable Development.
2. Learn how ecosystem services affect human well-being.
3. Explore case studies of SD in different regions.
4. Build your own QR model.

During the development process, these access points were reorganized into the five main categories of components, which are described in section 7.

6. Facilitation of knowledge capture learners

Artificial intelligence (AI) techniques like QR have important advantages for addressing issues of SD because they allow explicit representation of complex conceptual and causal relations between objects, ideas, and quantities even when numerical information are lacking [10, 11]. Struss [12] argues in favour of a model-based approach to environmental decision making and Eisenack and Petschel-Held [13] apply special QR techniques to interpret regional land-use changes due to small-holders agriculture in developing countries. Furthermore, AI and specifically QR is especially well suited for developing learner-centred educational materials because the explicit representations of causality facilitate developing a deep understanding of cause and effect in systems. Such explicit representations support features such as automatic

explanation generation in natural language, an important feature when learners are widely distributed geographically and distant from an actual ‘teacher’ [14].

7. Organisation of the Sustainable Development Curriculum

Following the requirements outlined in section 2, we implemented in the curriculum in Moodle (<http://moodle.org/>), an open source course management system, and can be accessed on the NaturNet-Redime portal (<http://portal.naturnet.org>¹). This section describes the presentation of content in the Moodle-based curriculum.

8. Interactive Qualitative Reasoning Models

We address many SD concepts in the context of five case studies that each provides a good example of a real-world SD situation. Additionally, we address concepts related to real-life policy issues on a broader scale, within the framework of the United Nations’ Millennium Development Goals (MDG). The following sections elaborate on these *content areas*, which implement access points 2 and 3 above in section 5. QR models from these content areas will support reasoning about cause and effect, an important advantage of the QR ontology [14]. Furthermore, the compositional modelling approach adopted by the Garp3 QR modelling and simulation workbench [6] facilitates re-use of model fragments between the different models. This supports learning because the same ideas will be encountered repeatedly in slightly altered or combined form as the learner explores the parts of the sustainability landscape captured in the models.

In selecting case studies, our goal was to provide a well-rounded sampling of the various types of issues that any SD scenario is likely to involve, including environmental, social, and economic factors. These case studies each centre on rivers and catchment areas because this facilitates our goal of developing different models that can be integrated. Some of the case studies are concerned with fundamental processes involving chemical, physical, and simple biological processes in streams. Other case studies are more integrative, including these basic processes, but also addressing sociological, management, and ecosystem-level processes.

Models from five case studies are being integrated as part of the landscape of concepts about sustainability: River Mesta, in Bulgaria (RM), Danube Delta in Romania (DD), Riacho Fundo in Brazil (RF), River Kemp in Austria (RK) and Rivers Trent and Ouse, in England (RT and RO). All these systems have been under strong anthropogenic influences and can be seen as representatives of a wide range of sustainability problems.

Although having very different water basins as starting points, the issues addressed in the NNR project can be used in curricula that deal with the integration between terrestrial (human) and aquatic ecosystems. These case studies involve society, governmental and non-governmental organisations, public policies, and planned actions of management. Besides providing support for discussions about impacts caused by human activities, the models may be used to develop arguments for or against specific conservation practices or alternative and sustainable economic activities such as tourism and exploitation of natural resources.

Within the curriculum, “home pages” for each case study follow a common structure (Figure 1). The home page provides a brief introduction to the case study and links to the various activities, including text-based pages for more in-depth background about the case study, links to download

¹ Go to <http://portal.naturnet.org/index.php?act=moodle>, log in and select “Learning using conceptual computer models” from the list of blocks in the center of the screen.

model files, and links to the various interactive lessons that guide the learner through the model. Activities are organised so learners progress from investigating simple scenarios that explore a narrow subset of processes to more complex scenarios involving multiple interacting processes and more complex model behaviour.

The next five subsections briefly describe the content and aims of each case study and models based on the MDG. The sixth subsection describes how these are being re-organized into a common *Integrated Library of Reusable QR Model Fragments* (project deliverable D6.7).

8.1.1. River Mesta case study (Bulgaria)²

The River Mesta region is recognized as economically under-developed, with high unemployment. Regional development plans focus on intensifying economic activities based mostly on natural features of the region. This includes further development and diversification of tourism; modernizing and intensifying agriculture and forestry; increasing energy production from hydropower; construction of new roads and streets, and enhancing infrastructure like sewage systems, wastewater treatment plants, and domestic waste landfills.

All of these activities need more water than the River Mesta watershed can supply, potentially leading to conflicts between users. State and local authorities are faced with difficult solutions how meet these competing demands. Reconciliation of these conflicts requires finding of sustainable solutions and appropriate environmental and/or ecosystem health indicators, in addition to the economic and/or social ones usually taken into account.

One of the indicative parameters of aquatic ecosystem health is the amount of dissolved oxygen (DO) in the water. Oxygen is an essential component for all living organisms in the aquatic ecosystem. All water bodies contain some amount of DO due to diffusion from the atmosphere. Normally there is a dynamic equilibrium between inputs and outputs of DO due to the biological processes of oxygen production and consumption. Water pollution, abstraction, erosion and other human activities can disrupt this balance, worsening ecosystem health and decreasing sustainable uses of ecosystem services.

Based on these factors, being able to discriminate between anthropogenic and natural fluctuations of DO is potentially of great importance for decision making about sustainable and integrated management of aquatic ecosystems. QR provides a modelling paradigm that allows explicit representation of the various processes that interact in a water body to affect DO. Furthermore, the ontology provided by QR facilitates education about these processes, which will be useful for explanation to decision makers and stakeholders—those people who have a vested interest in the outcome of sustainable decisions.

Main Model Goals

We have identified the following modelling goals to focus and narrow the scope of our model. The model should:

1. Describe the behaviour of DO under different conditions (hydro-morphological, physico-chemical and biological).
2. Examine mechanisms of change in ecological functions anthropogenic influences of organic pollution, erosion (due to agriculture and deforestation), and water abstraction.
3. Be useful for scientific and management purposes to explain cause and effect processes to decision makers and stakeholders.

² Refer to project deliverable D6.2.1 and D6.2.2 for full documentation.

Although the focus of the model is the River Mesta system, the processes should be generalisable to any riverine aquatic ecosystem.

8.1.2. Danube Delta Biosphere Reserve case study (Romania)³

The DDBR, located at the mouth of the Danube River before it reaches the Black Sea, has been designated as a World Heritage Site and Wetland of International Importance since 1990 (according to The Ramsar Convention on Wetlands, signed in Ramsar, Iran, in 1971). Its area of 5,800 sq. km, making it one of the greatest wetlands in the world, contains 30 types of terrestrial and aquatic ecosystems, of which 23 are natural or artificially modified and 7 are man-made ecosystems, including human settlements.

The DDBR's status as a biosphere reserve dictates that all social and economic actions must fall in line with biodiversity conservation and protection measures. Thus, the most appropriate concept of sustainable development for DDBR can be expressed by development through biodiversity, where most flora and fauna species are protected both to meet obligations of international conventions, but also to serve as natural resources for social and economic development of the region.

Stakeholder Issues

Scientists from DDBR met with local stakeholders to determine threats to conserve and develop these resources within the DDBR. The stakeholders involved in DDBR management include: nature conservation and protection bodies (DDBRA, NGOs), fishery and fishing companies, tourism companies, fluvial and marine transport companies, and recreational hunting groups.

Stakeholders identified the following threats:

- Decline in biodiversity (number of species) over the last several decades
- Contamination of water and fish from pollutants
- Concern about contamination in humans
- Reduction of fish diversity and abundance.

Decline in biodiversity is most likely a direct result of loss of wetlands through embankment works for different types of land use (agricultural polders, fish ponds, and forest plantations), summing 15% of the whole DDBR surface. This has reduced habitat for migratory waterfowl, an important draw for ecotourism. Contamination from water pollutants is also an important potential mechanism for threatening biodiversity in the DDBR.

Contamination of water and fish from pollutants also contributes to health problems in humans. Contaminants come in basically two forms: heavy nutrient loads from agricultural fertilizers and heavy metals from industry. In both cases, most of the pollutants originate from far upstream in the vast Danube River catchments. Heavy nutrient loads lead to algal blooms, which can result in toxic by-products from algae as well as depletion of oxygen in the water when algae die and are degraded by bacteria. This can cause die-offs in fish. Heavy metals in the DDBR waters threaten human populations in two ways, first from direct consumption because many people drink untreated water directly from the DDBR waterways, and second from consumption of fish which bioaccumulate heavy metals in their muscle tissues.

Fishing has been the main occupation of the Danube Delta inhabitants since ancient times and although nowadays the supply of fish has diminished and changed in quality, it continues to be

³ Refer to project deliverable D6.3.1 and D6.3.2 for full documentation.

basic trade. Contamination is one of the causes of reduced fish diversity and population sizes, but also over-fishing (even poaching) has been recorded especially within the last decades.

Main Model Goals

Contamination by pollutants is at the root of most of DDBR's threats to SD. Furthermore, in order to understand indirect as well as direct effects of pollutants on humans, their effects on other ecosystem components, like fish, must also be understood. Thus, the DDBR model will describe the aquatic ecosystems behaviour governed by water pollution rate and the ways it propagates to aquatic organisms and to humans living in or around the DDBR. The main goal of the DDBR model is:

- Understand and emphasize connections between water pollution in the Danube River catchment basin and health of human population living in and around the DDBR.

The model will be used to explain and educate the environment agency representatives, decision makers and stakeholders about the working of processes within the Danube River and their influence on these processes. The model will be used for argumentation purposes to convince decision makers what kind of actions they should take in order to improve (or stop) the Danube River water pollution process.

8.1.3. Riacho Fundo case study (Brazil)⁴

The Riacho Fundo basin has been one of the most disturbed areas under Brasilia's influence area since the beginning of the new capital construction, in the 1950s. It was progressively impacted by the transformation of natural areas into rural and urban areas. These changes eventually created a densely populated urban structure where few rural properties still keep an agricultural production of fruits and vegetables that supplies food processing industries. In these areas, springs, streams and natural vegetation patches are still protected and keep local biodiversity.

Main Model Goals

In 2000, a group of stakeholders prepared a list of relevant problems in the Riacho Fundo basin. The uncontrolled land occupation and changes in land use was identified as the most important. Deforestation, biodiversity loss, problems related to water resources and management and low community participation in the decision making process were also considered highly relevant. Accordingly, the following objectives were set for this modelling effort:

1. to improve understanding of environmental systems and problems that may affect sustainability in the basin;
2. to demonstrate the effects of human actions, both positively and negatively influencing different aspects of the Riacho Fundo basin system;
3. to mediate communication between stakeholders, policy makers, modellers and the public;
4. to provide support for stakeholders to learn about sustainability.

8.1.4. River Kamp (Austria)⁵

Catastrophic floods and inundations in August 2002, a nearly 2000-year event, set new conditions for life and economy in the in the Kamp valley (Austria) facing flood control management, landscape architecture and land use planning with essential and future challenges.

⁴ Refer to project deliverable D6.4.1 and D6.4.2 for full documentation.

⁵ Refer to project deliverable D6.5.1 and D6.5.2 for full documentation.

The high-water event represents a chance to develop the riverine landscape together with the local population as well as with the concerned scientific disciplines considering social, economic and ecological claims with regard to the EU Water Framework Directive. Within the whole valley there is a long tradition in water power use for grain and saw mills. Some power plants abstract water from the river for hydropower production and cause significant problems to fish by creation of residual flow stretches. The first river engineering measures besides local bank protection were carried out around 1900.

Main Model Goals

The goal of this lesson is to develop an understanding how the magnitude of natural disasters, such as the catastrophic flood in the Kamp valley in 2002, relate to fear in the community and government policy, in terms of sustainability.

8.1.5. River Trent (England)⁶

Prior to the industrial revolution, the River Trent had diverse and prolific fish stocks, and supported good fisheries. However, with the expansion of industry, the fishery began to decline, and water quality reached its lowest level in the 1950s. Long stretches of the Trent suffered from a lack of dissolved oxygen and were devoid of fish until the 1970s. Since the 1970's improvements in waste water treatment and management have led to great improvements in water quality to the point where these are no longer considered to be limiting factors to ecological recovery. In the past the River Trent was undoubtedly an important salmon river. The decline in catches from the 1880s onwards was almost certainly because of pollution and obstructions to the passage of migrating adult salmon (e.g., weirs used for water regulation). In recent times much consideration has been given to the potential to rehabilitate some of these semi-redundant weirs and to rehabilitate the salmon populations of the Trent). Much of the promotion of the potential rehabilitation of salmon populations lies around the fact that beyond their ecological and conservation value, salmon fisheries may have a high social and economic value. However, whilst there are potential socio-economic benefits of re-establishing salmon populations to the Trent catchment, alterations to the longitudinal barriers (i.e., weirs) on the Trent may detrimentally affect other user groups and impede continued development of other resources in the Trent catchment. If salmon are re-introduced, these conflicts between users will have to be resolved through negotiation with the various user groups. In addition, future proposals on the river will have to be evaluated to prevent degradation of the catchment and permit the sustained development of the salmon stocks.

Main Model Goals

A QR model for this case study could provide a tool that:

1. enables stakeholders, environmental managers, researchers and students to investigate factors limiting salmon stocks in the River Trent, to learn what activities are required to re-establish a salmon fishery in the River Trent, to describe the potential outcomes of rehabilitation activities and to identify potential stakeholder conflicts;
2. shows potential socio-economic benefits of re-establishing a salmon fishery, together with the socio-economic costs of rehabilitation both to the fishery and other river users.

⁶ Refer to project deliverable D6.6.1 and D6.6.2 for full documentation.

8.1.6. Models related to the Millennium Development Goals⁷

Rather than focusing on SD in a specific geographic area or ecosystem, these models address targeted SD issues in a broader, policy perspective. The Millennium Declaration, signed by some 190 heads of State in 2000 at the United Nations (UN) defines a set of 8 goals and 18 targets on poverty, hunger, education, gender, health, environment and cooperation to be achieved mostly until 2015. These goals are known as the Millennium Development Goals (MDG), and 48 indicators were selected to monitor the progress towards them. National governments are expected to periodically produce national reports and publicize the situation of the MDG. These national reports have to be clear, objective, and understandable for the “average citizen”. The idea was to create a feeling that “we can do something” about the goals.

Among the MDG, the seventh (ensure environmental sustainability) is the most difficult to be understood and to be achieved on time. Furthermore, each of the other seen MDG are directly or indirectly dependent on MDG7. Unfortunately, all the nearly 40 national reports published so far mentioned difficulties with MDG7 [16]. Reasons cited include conceptual problems in defining sustainability and problems to select (or create) indicators to monitor MDG7, other than those defined by the UN. Basically, for experts there are hypotheses and commonsense knowledge about environmental sustainability and for the public less than that. In developing countries, despite the efforts of UN agencies and local governments, data about indicators of environmental sustainability do not exist or are incomplete, based on poor-quality statistics, often expressed in qualitative terms. Finally, there are problems in communication with the public: environmental issues are poorly understood and indicators in general are presented as lists of data, unrelated to other indicators and without references to causal relations.

8.1.7. Integrated Library of Re-usable QR Model Fragments

The Integrated Library takes the content from each of the case studies and optimizes it for efficient interoperability, based on a shared ontology, common to all the case studies. Further details can be found in project deliverable D6.7. Currently, didactic materials for each of the case studies are based on individual model files, one for each case study. Future work will focus on implementing the didactic materials in the online curriculum based on scenarios implemented within the Integrated Library. The Integrated Library also facilitates the task of building your own QR model, so that future modellers don’t have to start from scratch.

9. The landscape of sustainability concepts

Each of the QR models described in section 8 addresses many concepts related to SD. These concepts are not isolated problems relevant only to each case study, but are related to similar issues in other systems. This section describes how we fit the case studies into the broader context of the many issues that relate to SD.

There is a truly monumental amount of information relevant for SD—so much that it becomes difficult to develop an overview of important concepts, especially for beginning learners [17]. Lack of tools to help organise, manage, and learn from this monument can lead to a sense of ‘well-informed futility’—the feeling that it is impossible to adequately process the available information to arrive at the best solution [18]. We adopt an analogy to support organisation of this information into a form that can be better approached for learning: this vast territory is a

⁷ For full documentation refer to reference 15. Nuttle, T., et al. *Navigating a landscape of sustainability concepts: towards progressive learning routes within and among qualitative reasoning models*. in *Proceedings of the 5th ECAI Workshop on Binding Environmental Sciences and Artificial Intelligence*, part of the 17th European Conference on Artificial Intelligence. 2006. Riva del Garda, Italy.

landscape of sustainability concepts and our task is to provide tools to facilitate exploration of that landscape.

Based on Cunningham and Cunningham's [2] definition of SD, tools to support understanding the sustainability landscape should support learning about the following *key concepts*:

1. increase in well-being and standard of life for the average person;
2. processes affecting environmental degradation;
3. long-term maintenance of this balance and keeping options open for the future.

Each of these three concepts requires further elaboration. What factors contribute to the increase in well-being and standard of life for the average person? How does one weigh the importance of well-being of not only the 'average person' but everyone? What is meant by 'environmental degradation' and how does it happen? What processes are important to consider? How do we evaluate long-term sustainability? How open should options be left for the future?

Some of these questions can be answered by experts and explained to learners—using expository text, presentations, or via more constructivist techniques such as interaction with computer simulations. Others are value judgements that each of us must consider in making our own decisions as citizens, stakeholders, and consumers. Furthermore, understanding SD involves a variety of scales – from local to global – and perspectives – from individual citizens to industry to government, in both developing and developed countries.

9.1.1. Mapping the sustainability landscape

Machado [19] viewed understanding as the process of capturing meaning. To capture meaning about something (an object, situation, concept, etc.) is to see it involved in relations with other things. Meaning is therefore constructed from a set of relations. Relations are themselves articulated webs or networks, built up by someone either via their own experience or in social interaction; these webs are continuously being updated. Hence, developing understanding can be seen as the learner becoming involved in this web of relations between objects, situations, and concepts [19].

The learning materials in our curriculum must support this process of individual involvement in the web of interconnected concepts; these concepts can be represented by a map of the sustainability landscape. Maps are representations of landscapes that facilitate their exploration. They provide a broad overview of the makeup of a landscape and show how features in landscapes are related—for example, cities may be connected by roads, located in different regions, etc. Such relations show how one might navigate through the landscape to more effectively explore it. Furthermore, maps can be used as tools to make plans for modifying features of the landscape. They point out what is in the landscape now, allow you to see where desirable connections are missing, and show how the future landscape will look if you create those connections.

Concept maps provide a useful means of organising ideas, such as those within the sustainability landscape. A concept map (sometimes also referred to as an entity-relation graph) is a graphical representation of ideas that a person believes to be true [20]. As such, a concept map is a web- or network-like representation of the internal landscape of concepts inside a person's head. A concept map consists of two primitives: nodes and arcs. Nodes reflect important concepts, while arcs show the relationships between those concepts. By making concept maps authors not only externalise information, but by doing so they also further specify and organise their own knowledge.

At a workshop in Sofia, Bulgaria, in March 2006, we organised a brainstorming session for project partners to create a concept map about sustainable development, based on our understanding of key issues as described above and contained in the content areas. Nodes were

to represent sustainability concepts and arcs were to represent how these concepts are related. Our goals in creating this concept map were to:

1. provide an overview of models being created by each of the project partners;
2. identify how concepts in models are interrelated;
3. identify how concepts in models are related to the SD key concepts;
4. provide a structure that facilitates integration of new content as it is developed;
5. identify areas of the landscape that need further elaboration and development; and
6. create a map of sustainability concepts that can be used by learners to navigate and explore the sustainability landscape, to develop a deep understanding of cause and effect in SD.

We broke into four groups of three people each to create concept maps reflecting the opinions and insights of different partners. Then the groups integrated their concept maps into one, common concept map. The goal was to stimulate thinking about how our work fit together to form the basis for a curriculum for learning about SD. The process led to productive discussion among model builders of the concepts captured in their models. As the map was successively adjusted by each group to accommodate and integrate alternative ideas, it ultimately reflected a shared understanding among model builders (see Figure 2).

We further organised the concept map developed during the brainstorming session with the help of the computer program Cmap-Tools [21]. The original paper concept map only contained nodes (sustainability concepts); relationships between concepts were represented using spatial proximity to indicate degree of relatedness. Using Cmap-Tools, we further specified the relationships between concepts using labelled arcs (Figure 3). The resulting concept map is a work in progress, and will be further developed as the landscape of SD concepts itself is developed based on the content areas.

Our goal is to transform the static representation of this map into one where concepts are linked to QR models and simulations (as well as to expository materials like text and graphics), and the arcs show how concepts are related to each other. Learners will follow the relations in the map to navigate from concept to concept in the landscape. In so doing, learners will internalise the knowledge contained in our external representations of expert knowledge about SD, and therefore gain a deeper understanding of processes and concepts of SD in contexts that meet their learning needs.

9.1.2. Defining relations to support development of progressive learning routes through the sustainability landscape

The sustainability concept map has limited means to represent all potential linkages between concepts in the sustainability landscape. Imagine a map of a country where all distances between all cities were explicitly represented with arcs and labels. The result would be an incomprehensible tangle of lines on the map. How can one hope to navigate through such a landscape?

Fortunately, in an online interactive map, different features can be displayed or hidden to show only information relevant to a particular use. For example, one might desire to display only distances corresponding to commercial passenger airline routes. The ability to control what types of data to display is made possible with the use of data tables (a familiar example occurs in road atlases as the distance table, showing distances in units of km or driving time between cities). In an interactive map, such tables provide means to query the map to display features of interest.

Following this analogy, we summarise all relationships between concepts in the sustainability landscape in a *relations table*. This will support querying and display of specific types of relations between different SD concepts. To facilitate future planning of specific learner

interactions that can be more easily transferred between topical areas, we adopted a more standardised ontology for representing relations between concepts to supplement the free, natural language relations used in developing our concept map. The relations used are adapted from those presented by Salles and Bredeweg [22], who categorised relations between ideas captured in QR models in a way that capitalised on their hierarchical and compositional organisation. Specifically, Salles and Bredeweg recognise the following types of relations between concepts in their QR models:

1. *Generalisation/specialisation*: one concept is a more general or specialised form of another. Air pollution *is a kind of* pollution.
2. *Analogy*: two concepts are related by analogy; they operate in similar ways. Immigration and births *are analogous* because they both add individuals to populations.
3. *Inverse*: two concepts are the opposite of each other. Immigration *is the inverse of* emigration.
4. *Order*: used to represent the relation between a static representation (zero order) and how complexity is added by allowing dynamic change (first order).
5. *Structural change*: used to show how new behaviour results from adding, removing, or replacing concepts.

These relations were used to construct progressive learning routes within a given QR model, specifically one built using a compositional modelling approach [22]. The idea is that complex, dynamical systems can be more easily understood by breaking them down into more manageable pieces. The relations help organise the presentation of material so that complex concepts build from simpler ones.

We adopt the first three relation types as relevant to our purposes of developing conceptual linkages between concepts and between different QR models; the second two are more relevant to understanding the causal nature of concepts, and can be employed within the specific context of a given QR model. For the purposes of organising the concepts in the SD landscape, we require additional relations to describe the non-causal content of our concept map. Thus, building from the first three relations described above, we recognize the following general relations types:

1. *Generalisation/specialisation*.
2. *Analogy*.
3. *Inverse*.
4. *Causal*: there is a causal dependency between the two concepts. For example, burning fossil fuels *causes* pollution. This combines the notions of *order* and *structural change*. This relation type is useful for identifying content elaborated in QR models, as opposed to purely text-based content. Within a given QR model, order is illustrated by running simulations and inspecting static and dynamic aspects of the simulation and structural change is illustrated by running simulations of different scenarios.
5. *Has property/belongs to*: one concept can be characterised by another concept or belongs to it. Targets for SD *belong to* the MDG. This is useful for more expository presentation of information about system structure (It can also be used to represent the relationship between quantities and entities inside a QR model).

By inspection of Figure 3, it is clear that most of the relations already represented can be easily translated into one of these more specific labels. Others might require further decomposition or combination of concepts to allow a clearer mapping using these relations. Furthermore, by creating a relations table, we can represent all relevant relations between concepts; how they are represented graphically can be optimised later. We provide an example of construction of a portion of the relations table in section 5.

Once all relations between concepts are identified, learning materials can be developed that follow these linkages in a structured manner to teach a body of related sustainability concepts. Alternatively, a learner may choose to explore the sustainability landscape on his or her own by

examining different types of relations or following different ‘relations chains’ explicitly represented on the map.

10. Themes and progressive learning routes

The NNR open curriculum must allow learners to access content from the concepts most relevant to their learning needs. In principle, a learner should be able to begin exploring the sustainability landscape starting from any concept in the concept map. They can look up these terms in the Glossary of Sustainability Concepts. The relations table can also be used to scan down and see all concepts that are directly related to a given concept. However, we envision that learners would interact mainly with the concept map, glossary, and lessons. Concepts and relations in the map will be linked to text, graphics, and models.

Many of the terms in the SD Concept map are developed as Themes in the Glossary of Sustainability Concepts. For example, the concept “deforestation” is a Theme: it provides a definition or overview of the concept, as well as suggests further steps in the overall curriculum that can be followed to learn more about the concept. Each of the case studies also develops a theme, and certain themes like ‘erosion’ and ‘water pollution’ can be explored in the context of multiple case studies.

Several Themes explored in a logical sequence form a progressive learning route. Several such learning routes are provided as activities in Moodle. Each of these learning routes is formatted to provide a set of learning goals and steps to follow. There are the following types of progressive learning routes provided in the Curriculum:

1. Lessons for exploring scenarios within case studies (see below).
2. Thematic learning routes:
 - a. Effects of human actions (e.g., water abstraction, pollution, fishing, etc.);
 - b. Biophysical processes (e.g., photosynthesis, aeration);
 - c. Population ecology (e.g., eutrophication, bioaccumulation, food chains);
 - d. Human well-being (e.g., health, economy, stakeholder involvement);
 - e. Policy (e.g., Targets and Indicators of Environmental Sustainability (MDG7)).

10.1.1. Implementation: indicators of environmental sustainability from MDG7

In this section, we discuss how ideas about curricula presented in previous sections can be implemented using a qualitative reasoning model involving indicators of MDG7, showing the consequences of deforestation [23]. After describing the content of the model, we then integrate it into the map of sustainability concepts, and show how the relations between concepts can be used to construct progressive learning routes through this portion of the sustainability landscape.

10.1.2. Deforestation model

This model includes three indicators of MDG7: reduction of the area covered by natural vegetation (indicator 25), loss of biodiversity (indicator 26) and proportion of population without access to safe water supply (indicator 30) (see Figure 4). The goals of this model are to educate about:

1. consequences of deforestation (direct and indirect);
2. the value of natural resources (vegetation and biodiversity; biodiversity and technological innovation; soil and uses of water; soil and agriculture)
3. relations between natural vegetation and wealth (measured as GDP)

The model (Figure 4) shows how deforestation can have negative consequences on different indicators of MDG7 and on quality of life. Deforestation causes a decrease (I-) of land with vegetation (forest), and this loss is associated (P+) with a loss of biodiversity. Loss of biodiversity results in less chances (P+) of developing technological products, such as food, medicines and raw materials. Furthermore, increases in the area without natural cover of vegetation speed up (P+) the erosion process, resulting in an increase (I+) in the amount of removed soil that can erode into water reserves. Hence, as removed soil increases, water reserves decrease (P-). Reduction of water reserves means there is less water to use (P-) and therefore is associated with (P-) increase in population without access to clean water. More removed soil also leads to less agricultural production (P-). Causality flows in the model towards a measure of wealth, so that technological innovation, water uses, and agriculture add to the gross domestic product (GDP). An example simulation with this model shows how the values of each of these quantities change due to deforestation: increasing rates of deforestation result in less wealth overall, whereas reduction in deforestation leads to more opportunities for exploiting technological products related to biodiversity (e.g., pharmaceuticals), water resources, and agricultural production [23]. This conveys the message of sustainability.

10.1.3. Integrating the model into the sustainability concept map and creating the relations table

We integrated the concepts captured in the deforestation model into the sustainability concept map from Figure 3. The resulting concept map (Figure 5) can be viewed as a region of the global sustainability landscape represented in Figure 3 ('zooming in' on the top left corner). We also represent some linkages with the Riacho Fundo case study to illustrate some possibilities of learning routes between specific pieces of content (in this case, between different QR models) within the SD landscape.

Starting with the concepts in Figure 5, we developed a relations table (Table 1) using the specific relations labels defined above (section 9.1.2). We also filled out the table with knowledge about how content of the five case studies relates to concepts in the deforestation model and MDG indicators.

We found the process of constructing both the concept map and relations table to be useful in stimulating ideas about interrelationships between models and concepts. Specifically, creating the concept map facilitated rapid generation of ideas, whereas completing the relations table helped identify potential relations that were missed when creating the concept map (perhaps because concepts were spatially separated and therefore not noticed). The concept map was then revised to include the previously omitted relations.

10.1.4. Themes and progressive learning routes related to deforestation

Here, we present some example learning routes starting from different thematic concepts in the SD landscape, reflecting varied learning interests of users. For example, a learner might be particularly interested in the MDG, the concept of deforestation, or the Riacho Fundo, Brazil. Each of these concepts is developed as a Theme in the Glossary of Sustainability Concepts. Additional examples of potential learner interactions with the curriculum (though not focusing on exploring the SD concept map) are described in [24] as use cases of different types of learners with different learning needs.

If the learner is interested in the MDG, following the relations table (Table 1), we see that the MDG *specialise* to MDG7 (that is, MDG7 is an instance of MDG), MDG7 *has the property* of Targets, and Targets *specialise* to a number of specific Targets (i.e., Targets 9, 10, and 11). Targets *have property* Indicators, which *specialise* to particular indicators (e.g., Indicator 25, 26, etc.). Each specific Target (e.g., Target 9: integrate principles of SD in policies to reverse loss of environmental resources) has specific Indicators as properties (e.g., Indicator 25: proportion of

land area covered by forest). So far, all of these kinds of relations can be depicted in a subtype hierarchy, with accompanying text to explain the relations. Once the learner reaches the specific indicators, say Indicator 26, QR models become useful in explaining the *causal relations* of Deforestation and Biodiversity and then between Biodiversity and Biotechnology Development and between Deforestation and Indicator 25. Indicator 25 has a *causal relation* with Erosion, and the learner could use the QR model to explore the nature of that causality. Additionally, we see from Table 1 that a number of case studies have Erosion as a *property* (in other words, Erosion is relevant to the case studies). The learner might then become interested in investigating the consequences of Erosion in the context of a specific case study, like the Riacho Fundo or River Mesta (note that relations to case studies also exist for Deforestation and Biodiversity). Or the learner's interests could lead to investigating the causal chain linking Erosion or the other concepts to GDP and Indicator 27.

If the learner is interested specifically in Deforestation, she can begin exploration of the landscape there. She will be able to see that deforestation is *analogous* to erosion and other environmental problems, and that Deforestation *belongs to* the Riacho Fundo and River Mesta case studies. Her interest might then lead to exploring the effects of *causal relations* of Deforestation in the context of one or both of those case studies, or how Deforestation is *causally related* to Indicators of MDG Targets. Within one of the case studies, the learner would have the opportunity to investigate how a balance in the amount of forest is struck by counteracting, or *inverse*, processes of Deforestation and Reforestation (not shown).

Finally, a number of potential learners, especially those who live or hold stake in the case study systems, will be particularly interested in exploring sustainability concepts relevant to a specific case study (that is, that *belong to* it). The relations table shows some of the environmental Problems that *are properties of* the Riacho Fundo case study, for example. Those learners can explore the *causal effects* of those problems on concepts of interest to them, for example, Biodiversity or GDP. It might also be of interest to compare and contrast the effects of these processes in *analogous* situations, by investigating the *causal relations* of the processes in other case studies.

10.1.5. Lessons for learning about Sustainable Development

Each lesson follows a common structure. The lesson begins with an introduction to the goals of the lesson and an overview of the main topics covered. Next, there is a series of ten questions that guide the learner's interaction with the model. These questions are organized as follows:

1. background about the case study;
2. introduction and learning goals for the scenario;
3. exploration of the system structure;
4. exploration of causality of the system;
5. exploration of the dynamics of the system;
6. application to real world situation and to sustainable development.

Hence, questions are organised to move from structure to causality to dynamics to evaluation, while also achieving the six levels of cognitive ability described in Bloom's Taxonomy (namely: knowledge, comprehension, application, analysis, synthesis, and evaluation). Each question is accompanied by a hint link, which instructs the learner how to interact with the model in Garp3 to discover the answer to the question. The Moodle tool collects learners' typed answers to the questions and reports them to the instructor (if desired). Before moving on to the next question, learners are able to compare their answer with an answer provided by the instructor. This allows

learners to assess whether they have understood the intended content before moving on to higher-level questions.

10.1.6. Questions in each lesson

The following list of questions is provided for each lesson. Hints refer to entries in the “Hint glossary” that help the user if they don’t know how to discover the answer using the QR modelling software (see Figure 6). Each question is tailored to each specific scenario being investigated. Questions are:

1. Explain in your own words the system being modeled by this scenario. Hint1
2. What processes and external influences are likely to be important in this system? Hint2
3. What are the state variables, the rates, and their starting magnitudes and derivatives for the initial state? What entities are the variables (quantities) associated to? Hint3
4. Inspect each quantity’s derivative (in state 1) and explain why it is increasing, decreasing or stable. Hint4.
5. What are the focal quantities in the system? How can you tell? Hint5
6. Predict what will happen to the focal quantities (your answer to question #5) and why. Will they stay the same, or will they reach another value, e.g., a maximum/minimum? Will a new equilibrium be reached, or might the system keep changing? Are multiple outcomes possible? Hint6
7. Describe what the model predicts to happen in the system over time. How many behaviors are possible? (one, two, three, many...?) Describe/Interpret what happens in each (at least three, if present) of these behaviors and explain why these behaviors happen. Hint7
8. Compare the model predictions (your answer to #7) with your predictions (your answer to #6). Do they match? What in your predictions is missing in the model predictions and vice versa?
9. Relate your description of the system, starting conditions, and model predictions to a real-life situation. Describe under what circumstances the system being modeled might arise and give examples of the entities, quantities, and agents (as relevant). Explain whether the scenario describes a sustainable or unsustainable situation and how you arrived at that conclusion. What factors in the scenario contribute to this outcome? What could be changed to reverse the outcome (make an unsustainable situation sustainable or vice versa)? What might get in the way of achieving a sustainable condition or prevent an unsustainable one from developing?
10. What do you think people can learn from studying this lesson and scenario, including new facts, ideas, or ways of thinking about things?

11. Glossaries

A useful feature of Moodle is the automatic linking of terms in glossaries to matching text in lessons, web pages, and other Moodle resources. We exploited glossaries to allow learners to quickly gain access to information related to specialized terms without bogging down each lesson with a lot of text. We developed four main categories of glossaries:

1. **Glossary of Sustainability Concepts** provide the structure for Landscape of SD Concepts, which can be navigated following Progressive Learning Routes, Themes, or the interest of the user.

2. **Glossary of Qualitative Reasoning Terms** provides an efficient means of looking up specialized terms that users encounter while exploring lessons related to QR models.
3. **Hint Glossary** cues users on what steps to follow in order to inspect QR models. This avoids having to provide detailed instructions at every step for users who are already familiar with the model-inspecting tools, yet provides ready access for beginners.
4. **Glossaries for Case Study-specific terms and ingredients** provide definitions for specialized terms that may appear only within the context of a particular case study. This includes explanations of the concepts that model ingredients such as entities, agents, and quantities are meant to capture.

12. Build your own QR model

This section is aimed at providing the advance user with guidance on how to build his or her own model to investigate a particular SD issue that interests him/her. Lessons are provided that guide the learner through the process of building a model either from scratch, or by developing individualized scenarios using the Integrated Library of Re-usable QR Model Fragments (see project deliverable 6.7).

13. Evaluation

There are two phases of evaluation: technical evaluation of model content by independent expert review and user evaluation of effectiveness for supporting learning about SD. Each of the models has undergone technical review both within the project in addition to being subjected to independent peer review as a part of being accepted for publication in a special section of the International Workshop on Qualitative Reasoning in 2007.

Aspects of the curriculum related to the Millennium Development Goals have been extensively evaluated and have been shown to facilitate learning of SD concepts, as well as provide a stimulating platform for learning (see project deliverable D7.2).

Additionally, we evaluated one of the lessons on the Curriculum page, as implemented in Moodle, with a university Botany class of 19 students. The class was composed of students ranging from second- to fourth-year Biology majors. None of the students had previously had a course in ecology or sustainable development. Some of the students had worked with concept maps, but none had experience with qualitative models. We asked the students to write down their answers to the questions as presented in the River Kamp Lesson 1. Because we didn't have access to separate computers for each student, however, we displayed the appropriate screen shots as if the students had run the model themselves, using a computer and video projector. Some students at first had difficulty grasping the meaning of some of the model diagrams during the first few questions. This may have been due to their inability to access the help tips that would ordinarily be available if they were working on their own computers. However, once they had the opportunity to hear responses of other students and the class went over the "correct" answer provided in the Lesson, most were able to catch up and were able to understand and appropriately respond to later questions. Students successfully used the diagrams to reason about a complex system involving causal feedback loops and multiple possible outcomes, including cyclic behaviour.

Students were also asked about their impressions of the lesson format and using QR models to learn about sustainability. Many students responded that they thought the simulation model provides useful support for learning about the behaviour of complex systems. Several students suggested more use of colour in the presentation, perhaps to hold their attention better or draw their attention to specific parts of the various diagrams. Again, when students interact with the models themselves on their own computers, this will probably be less of an issue because they

will be moving screens around, be able to view photographs from other pages if they want, and can access help tips to draw their attention to the focal points of each diagram. Overall, students responded positively to the experience and several expressed interest (orally or in their written evaluations) in participating in future activities using the online curriculum. We are currently planning additional evaluation of the curriculum using this and other groups of students, where each student will have the opportunity to complete lessons on individual computer work stations.

14. Conclusions

Developing tools to facilitate learning about SD requires innovative organisation and presentation of SD concepts. To support the goals of the SSD, this organisation and presentation must be open to exploration by a variety of different types of learners with a variety of learning needs and interests.

By mapping the sustainability landscape and developing a scheme for explicitly representing relations between concepts, we provide a means for navigation and exploration within this vast landscape. The relations we specify are also ones that exploit the hierarchical nature of knowledge, both expository (e.g., generalisation/specialisation, inverse, analogy, has property), and that subset of knowledge that represents causal relations. The scheme thus provides a framework for presenting both textual descriptions of relationships and explanation of cause and effect through exploration of QR models. By providing tools to facilitate active involvement in the web of knowledge making up the SD landscape, we hope to support development of deep understanding for citizens to become active partners in the process of making decisions that affect sustainability, thus contributing to the goals of the SSD.

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Topic outline

Curriculum to learn about Sustainable Development concepts using interactive conceptual modelling.

You can use this portal to learn about sustainable development via interaction with dynamic simulation models that show the conceptual linkages involved in sustainability in a variety of case studies. These models are supported by an encyclopedia containing definitions and discussion about concepts relevant to sustainable development.

[Click here for more](#)

[Introduction to the curriculum to learn about SD using interactive conceptual modelling](#)

If you click here, you will be provided with the plan for the organisation of the curriculum

1 Glossaries

- [Sustainability Concepts glossary](#)
- [List of case studies](#)
- [Qualitative Reasoning Terms](#)

Glossaries contain automatically linked definitions of terms.

2 The Riacho Fundo case study (Brazil)

This case study addresses the impacts of urbanisation and resulting deforestation, erosion, and flooding on biodiversity and human well-being in the Riacho Fundo, a river basin in the Brazilian capital of Brasília. There is something about stakeholders.

1. Read the Background on the Riacho Fundo case study information on the case study.
2. [Download model file.](#)
3. Complete lessons.
 1. [First lesson.](#)
 2. Second assignment.

[The Riacho Fundo case study](#)

[Background on the Riacho Fundo case study](#)

[Riacho Fundo urban semi-urban model file](#)

[Lesson 1: What happens if there is no drainage?](#)

[Lesson 1: complete list of questions](#)

[Assignment 1: What happens when there is no drainage in a city?](#)

Home pages for each case study follow a common structure.

3 The River Mesta case study (Bulgaria)

This case study investigates the impacts of changes in erosion, organic pollution, solar radiation, and water abstraction on the concentration of dissolved oxygen in the River Mesta.

1. Read background on the River Mesta system.
2. [Download the model file.](#)
3. Complete lessons:
 1. River Mesta Lesson 1: aeration and diffusion of dissolved oxygen.

[The River Mesta case study](#)

[Background on the River Mesta](#)

[River Mesta model file](#)

[River Mesta Lesson 1](#)

4 The Danube Delta Biosphere Reserve case study

This case study addresses the impacts of runoff from agriculture and industry in the Danube River catchment area on biodiversity and human well-being in the Danube Delta Biosphere Reserve (DDBR), Romania.

1. Read more background on the DDRB.
2. Download the model file.
3. Complete lessons:

Figure 1. The SD curriculum in Moodle (<http://portal.naturnet.org>).

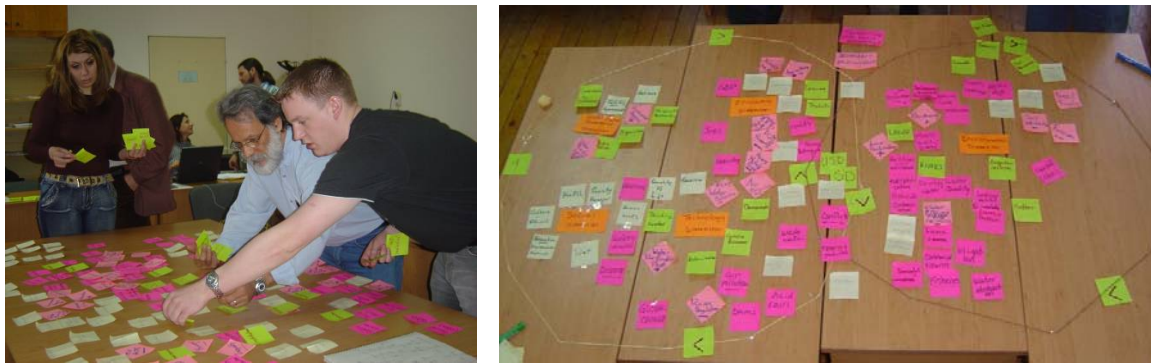


Figure 2. Left: The fourth group integrates their concepts into the evolving concept map laid out by the first three groups (pictured in foreground left to right: Elena Nakova, Paulo Salles, Richard Noble). Right: The final concept map resulting from all the participants. Concepts in the left circle represent issues most closely related the economic, social, industrial, and institutional dimensions of sustainability. Those in the right circle represent those most closely related to the environmental dimension. The arrow heads on the circumference of the circles represent the idea that society and the environment are dynamic entities, and this dynamism can be thought of as spinning in a cycle. Society can control the direction of the societal cycle, but not that of the environment. When the two circles cycle in concert with each other, sustainable development is achieved; when they cycle in opposite directions, there is conflict and unsustainable development.

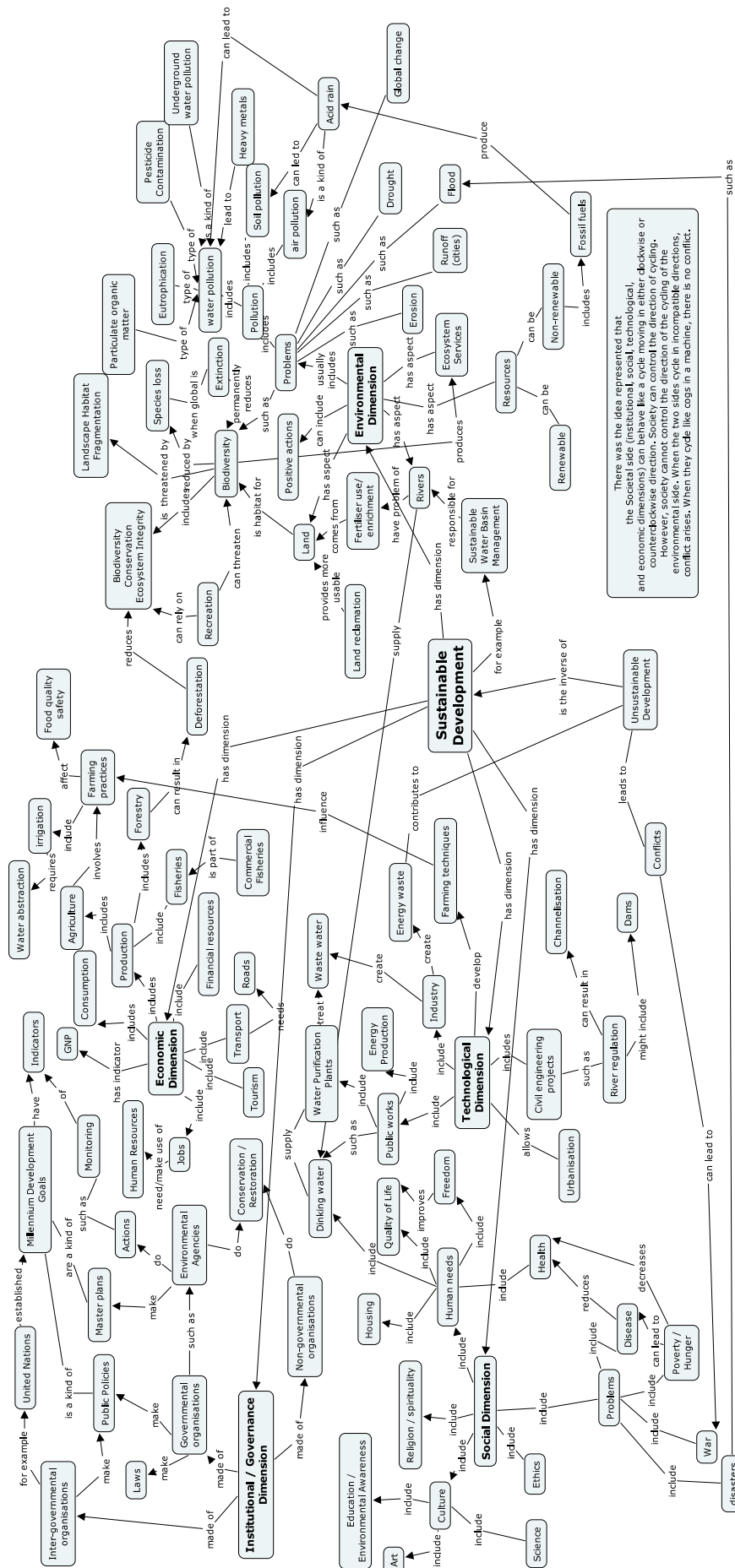


Figure 3. A map of the sustainability landscape to be developed with QR models from the three content areas and explored with the help of progressive learning routes.

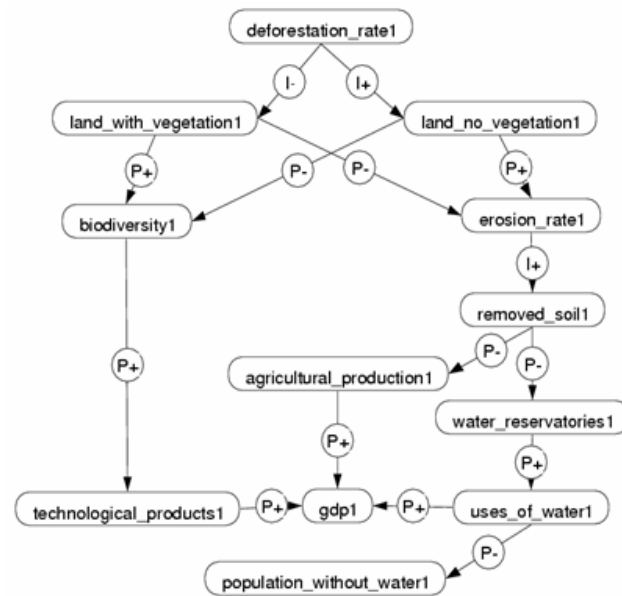


Fig 4. Causal model of the deforestation model. P+, P-, I+, and I- represent different types of causal dependency (see Salles et al. [20]).

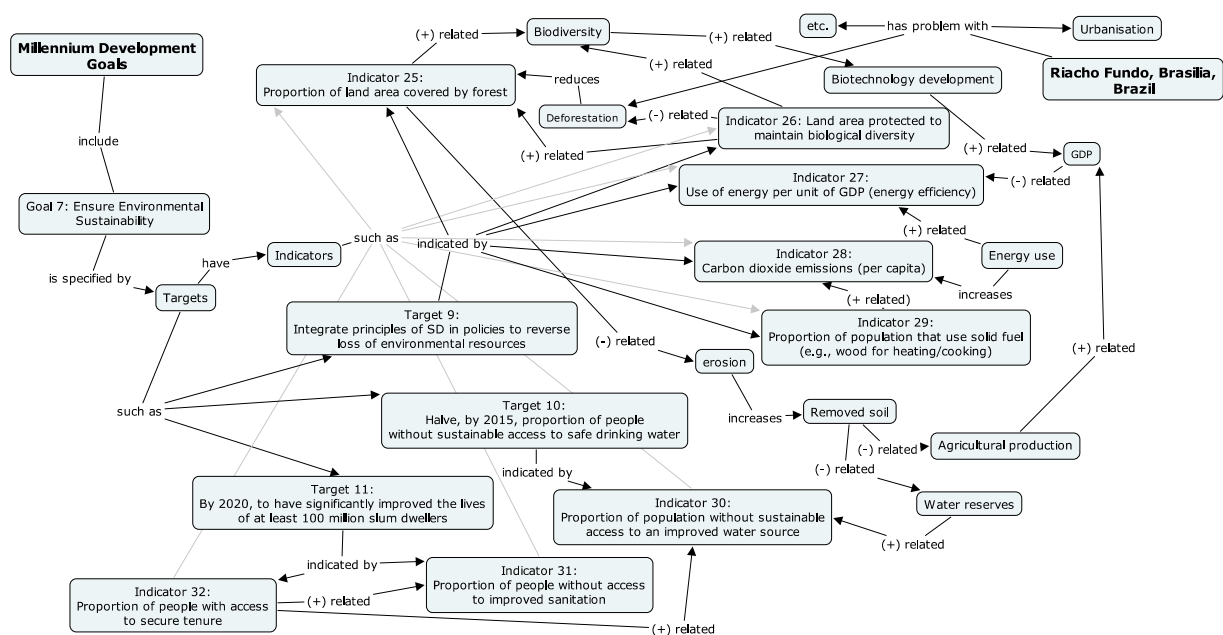


Figure 5. Concept map integrating the deforestation model into a portion of the map of sustainability concepts from the top left of Figure 2. The figure also shows how the Riacho Fundo case study relates to the concepts in the model.

Example lesson: River Mesta lesson 1

Goal
Show how physical aspects of the River Mesta system affect DO via their effects on *aeration* and *diffusion* rates.

Introduction
One of the indicative parameters of aquatic ecosystem health is the amount of dissolved oxygen (DO) in the water. Oxygen is an essential component for all living organisms in the aquatic ecosystem. All water bodies contain some amount of DO due to *diffusion* from the atmosphere. Normally there is a dynamic equilibrium between inputs and outputs of DO due to the biological *processes* of oxygen production and consumption. Water pollution, abstraction, erosion and other human activities can disrupt this balance, worsening ecosystem health and decreasing *sustainable* uses of ecosystem services.

Overview

- Definitions of *entities*
 - River
- Changeable properties of *entities* (*quantities*)
 - Heat
 - Temperature
 - Diffusion rate
 - Aeration rate
 - Dissolved oxygen
 - Flow velocity
 - Light
- What affects these changeable properties (*processes*)
 - Aeration
 - Diffusion
 - Water abstraction
 - Solar radiation

Before you begin

- Download the *River Mesta model file*.
- Run Garp3 and open the *model* file.
- Open *scenario* for 07 physical only (*water abstraction* increases and *sun heat* increases) and run the *simulation* (for the initial state's only).

You can view a list of all the questions *here*. However, please answer them using the forms in this lesson.

Start by clicking "Continue" below.

SD-related terms are linked to the Sustainability Concepts glossary.

QR-related terms are linked to the Qualitative Reasoning Terms glossary.

The introduction page for a lesson about the River Mesta, Bulgaria.

When you're done answering a question, you can compare it to a prepared answer.

Question pages within each lesson provide a space for learners to type their answers.

The Hint Glossary contains useful hints on how to interact with Garp3 to discover the answers to questions.

Interactive Conceptual Modelling

Hint 1: Select one of the initial states. Open the Entity Relations view. Arrange the contents so you can see everything clearly.

Compare your answer to the following

This is the entity relations view for state 1 in the simulation:

```

graph TD
    Sun -- Shines on --> River_mesta
    Irrigation -- Active in --> River_mesta
  
```

The Sun shines on the River Mesta. Also, there is irrigation active in the River Mesta. Sun and irrigation are *agents*, which means they are *external* influences on the system.

Figure 6. Example lesson from the River Mesta case study, showing the introduction page for the lesson (top left), a question and hint (bottom middle), and the “correct” answer provided by the course creator.

Table 1. Relations table for sustainability concepts, focusing on concepts related to MDG7 and the case studies. Relations are G = generalization; S = specialization; A = analogy; I = inverse; C = causality; P = has property; B = belongs to; 1 = identity. The table is read in this order: column heading, relation, row heading. Superheadings of columns condense S and P relations.

	Millennium Development Goals												Dimensions of sustainability*																	
	MDG7: Ensure environmental sustainability												EN	EC	TX															
	Targets	Indicators														Case studies	Problems													
	Target 9	Target 10	Target 11	Indicator 25	Indicator 26	Indicator 27	Indicator 28	Indicator 29	Indicator 30	Indicator 31	Indicator 32	Riacho Fundo, Brazil	Danube Delta Biosphere Reserve	River Mesta, Bulgaria	River restoration, Austria	River Ouse, England	Deforestation	Urbanisation	Pollution	Air pollution	Indoor air pollution	Water pollution	Erosion	Biodiversity	Removed soil	Water reserves	Agricultural production	Gross domestic product (GDP)	Energy use	Biotechnology development
Millennium Development Goals																														
MDG 7: Ensure environmental sustainability	B	B	B																											
Targets (of goals)	G	G	G																											
Target 9: Integrate principles of SD in policies to reverse loss of environmental resources	1	A	A	B	B	B	B	B																						
Target 10: Halve, by 2015, proportion of people without access to safe drinking water	A	1	A						B																					
Target 11: By 2020, to have significantly improved the lives of at least 100 million slum dwellers	A	A	1							B	B																			
Indicators (of targets)				G	G	G	G	G	G	G	G																			
Indicator 25: Proportion of land area covered by forest	P			1	C/A	A	A	A									C													
Indicator 26: Land area protected to maintain biological diversity	P			A	1	A	A	A																						
Indicator 27: Use of energy per unti of GDP (energy efficiency)	P			A	A	1	A	A																			C	C		
Indicator 28: Carbon dioxide emissions (per capita)	P			A	A	A	1	C/A																					C	
Indicator 29: Proportion of population that use solid fuel (e.g., wood for heating/cooking)	P			A	A	A	A	1																						
Indicator 30: Proportion of population without sustainable access to an improved water source																														
	P								1		C															C				
Indicator 31: Proportion of people without access to improved sanitation		P								1	C																			
Indicator 32: Proportion of people with access to secure tenure			P								1																			
Case studies												G	G	G	G	G	B	B	B											
Riacho Fundo, Brazil												1	A	A	A		B	B					B	B						
Danube Delta Biosphere Reserve												A	1	A	A								B							
River Mesta, Bulgaria												A	A	1	A		B					B	B							
River restoration, Austria												A	A	A	1															
River Ouse, England												A	A	A	A	1														
Problems																	G	G	G					S						
Deforestation					C			C				P		P			1	A	A											
Urbanisation												P					A	1	A											
Pollution																	A	A	1											
Air pollution																			G	1										
Indoor air pollution								C											S	1		G	A							
Water pollution																			S	1		A								
Erosion				C						C		P	P	P			S	A	A	1										
Environmental dimension																														
Biodiversity				C	C																			1						
Removed soil																							C		1					
Water reserves																								C		1				
Economic dimension																														
Agricultural production																									C		1			
Gross domestic product (GDP)																										C		1		C
Energy use																														