A new teaching tool in education for sustainable development: ontology-based knowledge networks for environmental training

Aristomenis M. Macris*, Dimitrios A. Georgakellos

Department of Business Administration, University of Piraeus, 80, Karaoli & Dimitriou Street, 18534 Pireaus, Greece

Received 1 August 2005; accepted 26 December 2005
Available online 6 March 2006

Abstract

This paper presents a prototype model for the design and development of environmental training materials, where both the multimedia objects used in training scenarios and the knowledge built into them are captured and fully reusable. Knowledge found in the logic, the structure and the ways of use of environmental literacy is represented as a knowledge network (a collection of educational scenarios), based on an ontology. A prototype environmental pollution ontology and three self-contained sample educational scenarios have been developed. The training approach helps students to understand the contemporary global environmental issues, how they are linked and interrelated and to consider the differing views of these issues, before reaching a decision or judgment.

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Keywords: Education for sustainable development; Ontology-based training; Educational knowledge networks; Environmental literacy; Global air quality

1. Introduction

Sustainability is a fluid and emergent concept that has attracted considerable discussion and criticism. However, internationally it has become the principal aim of environmental policy and for many environmental managers it has become an appropriate vision of the future. Various models of sustainability can be found in the literature but those that follow a three component or a multiple capital framework typically include elements relating to equity, empowerment, social cohesion and participation. One aspect of participation relevant to sustainability is public involvement in resource and environmental management. Public involvement is of fundamental importance because it is consistent with the principles of participatory democracy, improves planning and decision making, helps resolve conflicts and makes difficult political decisions more acceptable. If current patterns of resource use are unacceptable, and if sustainability is an appropriate vision of the future, by what means can society move from the present towards the vision? A detailed and comprehensive response to this question may be quite difficult and complex, but a reasonable survey of the alternatives would likely include environmental education and learning [1]. In other words, major ecological restoration will not be undertaken unless human society approves the goals and objectives of it and, in addition, has sufficient esteem for the restored ecosystems to protect their integrity. Linking ecological restoration to sustainable use of the planet seems a promising way to foster society’s interest in and acknowledgment of human dependence on natural systems. An increase in environmental and ecological literacy is essential to achieving this end, as is an awareness of the goals and conditions of sustainability [2]. Although few dispute the need for behavioural changes leading to more effective mitigation of environmental problems, popularization of the term “sustainable development” and speculation about its role in education continue to be problematic for many educators.

* Corresponding author. Tel.: +30 2106104918, mob: +30 6974435735; fax: +30 2104142339.
E-mail addresses: arism@unipi.gr (A.M. Macris), dgeorg@unipi.gr (D.A. Georgakellos).

1 Tel.: +30 2104142252; fax: +30 2104142339.
As a result, a number of experts claim that it is inappropriate to plan and implement academic curricula without adequate conceptualization of central concepts. In this case, “sustainable development” seems imprecise. Likewise, “sustainable development” has become, for many, a vague slogan, a bold platitude, susceptible to manipulation and deception. For some it is logically inconsistent. Others are concerned that efforts to implement sustainable development will obscure understanding of the economic, political, philosophical and epistemological roots of environmental issues, and adequate examinations of social alternatives [3]. This raises questions about the efficiency of traditional educational processes with regards to implementation of sustainable development.

In this context, this paper proposes a new teaching tool in education for sustainable development. Specifically, it examines the combination of a reusable ontology (made of concepts and their relations) that captures domain-specific knowledge, with reusable multimedia objects (MMOs) constructed specifically for teaching environmental literacy, in order to form a knowledge network (combination of educational scenarios).

All digitized educational aids for environmental training developed with the existing technology are essentially collections of multimedia files. These multimedia files are (a) grouped, (b) indexed and (c) combined in order to support various educational scenarios.

1. The grouping of these multimedia files follows a hierarchical structure organized in units and sub-units, etc. like the chapters of a book. So the user can select a unit or sub-unit and then the system guides the user to the multimedia that explains it.

2. Alternatively the user can use the index or the search feature, search for one or more words, locate the relevant units and when selecting them he is guided to the specific multimedia explaining them.

3. The multimedia can also be combined with the use of hyperlinks. Hyperlinks allow the user, while browsing the contents of a specific node (e.g. web-page), to move to another node or multimedia unit and when finished to return to the starting node.

But all this grouping, indexing and combining simply restructures the educational materials without representing the knowledge itself that is hidden within the material and that must be decoded by the trainee him/herself.

According to Sowa [4], perception is the process of building a working model that represents and interprets sensory inputs, a mosaic of percepts, into a more abstract part (conceptual graph). A conceptual graph is made of concepts that are composed of the simplest possible self-contained entities, and the relations between them. Therefore, when a trainee is asked to understand the training material accompanying a training process, the act of utilizing the material can be modeled as a two stage process: (i) the analysis process, where the material is broken down into concepts and (ii) the synthesis process, where concepts are linked to other concepts found in the training materials at hand and other related materials that the trainee has already analyzed, in order to form more complex structures or conceptual graphs. Therefore, meaning is not discovered but constructed and training materials have meaning only in relation to other materials that are interconnected to each other as codes and systems in the culture and in the minds of the trainees.

The proposed methodology is designed to represent the knowledge found interspersed within the educational material for environmental training in the form of knowledge networks (collections of educational scenarios serving specific educational needs) that simulate the approach of analysis and synthesis of knowledge discussed. This makes it easier to be decoded and comprehend by the trainee.

Each knowledge network consists of various educational scenarios. The building blocks of these knowledge networks are domain-specific (for environmental training) ontologies. The ontology captures all domain-specific knowledge in the form of concepts (the simplest possible self-contained entities), instances of concepts and the relations between them. Educational scenarios combine the concepts, instances and relations found in the ontology with supportive multimedia (text, image, video, animation, etc.), thus combining the knowledge built into the ontology with the collections of multimedia objects (MMOs) currently used for environmental training.

In this context, this paper examines the combination of a reusable ontology that captures domain-specific knowledge, with reusable MMOs constructed specifically for teaching environmental literacy in order to form knowledge networks that can help trainees understand (i) which are the building blocks of an environmental issue, (ii) how they relate with each other and (iii) how they can be used in order to analyze specific environmental problems. For the needs of this research, an upper environmental ontology was defined and three educational scenarios were built; the associated lower ontology concepts and relations were defined to support them, with the tools developed by the CULTOS² project. The developed educational scenarios were based on Ryan’s nine narrative structures [5].

2. Environmental literacy teaching in sustainable development

As is well known, sustainable development is economic development that meets the needs of the present without compromising the ability of future generations to meet their own needs [6,7]. Critical to consistent progress towards sustainable development is the advancement and application of appropriate technologies and management strategies across socioeconomic sectors throughout the world. These refer to strategies or production changes that benefit the environment even though that is not their primary intent. All of these advances and innovations are important for achieving economic growth while preserving and protecting the natural environment. This approach relies on a number of independent factors among them, research, physical capital investment, financial

resources, and most importantly education. It is critical that society be made aware of environmental risks and about the importance of responding to reduce or eliminate those risks. The objective is to attain environmental literacy throughout all economic sectors across all regions of the world. Without this awareness in place, society will not understand the need for change; it will tend not to support it, and may be unwilling to participate in the process. Thus, for many years, most people had neither the idea of the extent of environmental degradation nor did they have an accurate sense of how rapidly the problems were becoming worse. As a result, society unwittingly continued to contribute to the problem. Learning from our mistakes, we now understand that environmental literacy, achieved through environmental education, is part of an effective strategy to protect the earth’s resources [8].

However, it is apparent that it is a practical impossibility for citizens to be knowledgeable about all important scientific, economic, or political details (i.e. ‘content’) surrounding technically complex environmental science, technology and policy controversies. Good citizenship simply requires literacy about how the scientific and decision-making elements interact (i.e. ‘context’) – in short, familiarity with the social processes that accompany most environmental issues and some understanding about how the scientific method works [9]. Within this framework, the transition towards a sustainable society will be a long and complex process of collective learning. A process in which every social actor will need to play a role, assume new responsibilities and acquire appropriate new capabilities [10]. More precisely, in the coming decades, the entire production and consumption system will require a radical reorientation as we move towards a sustainable society [10]. New challenges and paradigmatic changes are as follows: from pollution control and waste handling technologies after generation to process integrated prevention (cleaner production and source reduction); from the environmental aspects of manufacturing processes to considering the entire life of products; and from a sole emphasis upon technology to broader perspectives which also encompass non-tech measures [11]. Recently, it has become clear that such interventions must be more radical and go beyond the redesigning of existing products in order to catalyze a transition towards sustainable society. This introduces a relatively new issue into the global debate on sustainable development—the need for sustainable consumption. This means that citizens need to be made aware of their new responsibilities and to become competent to make specific contributions in the transition towards a sustainable society [10].

Nevertheless, environmental literacy is not simply being well versed in the knowledge and methods of related environmental disciplines, but it also includes having familiarity with the interdisciplinary integration process, the policy-making process, knowledge- versus advocacy-based assessments and the various gradations of uncertainty that necessarily accompany environmental policy debates [9]. In this context, a new approach in environmental training and especially in teaching environmental literacy is necessary. The demand in this new approach is teaching tools that are more efficient and flexible than the traditional ones. This is the goal of the tool that has been developed and which is presented in the following sections.

3. Ontology-based knowledge networks

The proposed methodology deals both with the creation of educational materials and their utilization by trainees. Domain experts in the field of environmental training can record their knowledge using ontologies (knowledge repositories), which combine the concepts making up the field of knowledge and the relations between them. This recording process of each concept and interrelationship takes place only once in the ontology and it is afterwards available to every educational scenario using it.

Additionally, all existing, supportive material is collected in the form of multimedia (text, image, video, animation, etc.), or new multimedia material is created, in order to develop a collection of reusable multimedia [12] (content repository) relative to the knowledge domain under consideration.

The ontology is then used by the writers of the educational materials, who combine the knowledge contained in the ontology with the multimedia contained in the multimedia collection in order to create new educational scenarios. Knowledge-based multimedia authoring is then, the filling up of a database with instances that reference the ontology on the one hand, and designated segments of multimedia objects on the other (Fig. 1). Knowledge networks serving the same or similar purposes, although they might use different multimedia collections (content repositories), tend to use very similar knowledge-based structures, since they all deal with similar entities (e.g. environmental training).

The user of the educational scenarios, instead of being guided to the supportive multimedia through the existing methods of structuring and searching the multimedia material already discussed (units—sub-units, search, etc.), is now guided, either through a procedure of concept search, or through a navigation procedure, to the knowledge network that presents the requested concept or relation as it is found in each diagram. Then the user can request supportive material in the form of multimedia for each concept or relation under consideration and will be able to learn how this concept or relation is related to other relevant concepts or relations in each educational scenario.

A particularly positive contribution to the visualization of educational scenarios that can range from adventurous unguided tours to systematic representations of sources can be found in Ryan’s chapter on selective interactivity and narrativity, entitled “Can Coherence Be Saved?” [5]. Ryan offers nine narrative structures (Fig. 2) produced by different designs:

1. The complete graph, “in which every node is linked to every other node and the reader has total freedom of navigation”.

2. The network, “in which the reader’s movements are neither completely free nor limited to a single course”.

3. The tree, which controls the reader since “once a branch has been taken there is no possible return to the decision point and there is only one way to reach a given terminal node”.

3. Ontology-based knowledge networks
4. The vector with side branches, “where the main road is fixed, but the structure of links allows the reader to take short side trips to roadside attractions”.

5. The maze, characteristic of adventure games in which “the reader tries to find a path from a starting point to an end point”.

6. The directed network or flowchart, in which “horizontal progression corresponds to chronological sequences, while the branches superimposed on the vertical axis represent the choices offered to the user”.

7. The hidden story, in which there is, “at the bottom narrative level, a fixed, unilinear, temporally directed story of events (or arguments) to be reconstituted”; on the top level there is “a temporal network of choices that determines the reader’s investigation”.

8. The braided plot, which is “multi-stranded but determinate narrative where the same events are told from different perspectives”.

9. Action space, Epic Wandering, and story world, where “the system designs the general outline of the plot, and the user selects the details of its realization” (This is the opposite of #6).

All the educational scenarios undertaken by training designers can be modeled using one of these structures. With an accommodating and open ontology, and alternating representations of the different structures, the proposed approach might become the ideal approach for digitized educational environments.

3.1. Ontologies

An ontology [13,14] would furnish terms and definitions for concepts (entities, objects, events, processes, goals, and results) deemed to be important in characterizing the domain of knowledge under consideration at a desired level of detail; concepts and their relationships would be further characterized in terms of axioms and constraints that may be expressed more or less formally. Among those who adopt the ontology, its terms are used in asking and answering questions, making assertions, offering insights, describing practices, and performing investigations.

Ontologies are therefore, collections of concepts, instances of concepts (e.g. Aristotle was an instance of the concept ‘person’), and the relations between them. Concepts are general in nature and stand for a whole category of specific objects. These specific objects can be created as instances of the relevant concept.

The concepts and instances of a knowledge network are connected via various relations. The two basic relations are: the super/sub-concept relation and the instance of relation. But a more comprehensive listing aimed at linking concepts and instances thematically is sure to require additional relations. Attributes can be assigned to concepts, instances and relations. Using these attributes, the ontology editor can utilize other features of the knowledge network, from synonyms to URL-links. For example, the names, dates of birth, etc. of specific people can be stored with the concept “person”. The editor of the knowledge network can decide which attributes may be assigned to the instances.

At this point, it must be pointed out that the development of an ontology is not a one-step process, because it is almost impossible to foresee, in advance, all the concepts and the relations that will be needed for all educational scenarios. For this reason, the more general concepts are first recorded in the upper ontology. Depending on the size of the ontology, an intermediate stage might be needed, the development of the mid-ontology that includes more detailed concepts and relations than the upper ontology. Finally the lower ontology includes all the concepts, instances and relations necessary for the specific educational scenarios for environmental training.
1. **The complete graph** - Fully connected bi-directional paths

2. **The network** - A partially connected, cyclic graph with uni- and bi-directional paths

3. **The tree** - Unidirectional (from top to bottom), every traversal is a well-formed plot.

4. **The vector with side branches** - One main direction, with bi-directional subplots

5. **The maze** - Structure typical for adventure games

6. **Directed network** ("flow chart")

7. **The hidden story** - Plotting navigation on to time

8. **The braided plot** - Events and destiny lines

9. **Action space or Epic Wandering** - System defined plot with user choices for action

Fig. 2. Ryan’s narrative structures.
3.2. CULTOS tools

The tools used to implement the ontology and the knowledge network for environmental literacy teaching are the tools built by the European Commission CULTOS3 (Cultural Units of Learning — Tools and Services) Information Society Technologies project (IST-2000-28134) that developed knowledge-aware multimedia authoring and presentation tools for non-technical experts, for cross-media integration of cultural multimedia artifacts. The authoring tools used are: (i) K-Infinity4 knowledge-editing tool (ontology authoring), (ii) CULTOS Media Import Tool (in order to import the MMOs) and (iii) CULTOS Authoring Tool (in order to build the Ontology-based knowledge network).

The tools demonstrate how knowledge structures can be transformed into navigable, spatial structures as needed for use in Web based education and training. The knowledge networks built using the CULTOS project tools, are saved as Enhanced Multimedia Meta Objects (EMMOs), a novel type of structured multimedia meta-objects, containing expert knowledge. Therefore, each scenario is a self-contained entity that, on top of all local knowledge structures, includes a part of the ontology (knowledge repository) and a part of the MMOs collection (content repository).

4. The environmental literacy teaching ontology

The ontology built for the needs of this research is based on the ontological analysis of Sowa [13] and consists of two layers: (a) the upper ontology and (b) the lower ontology. The latter concerns the environmental issue of Global Air Quality in an introductory level, according to the relevant literature [8,15]. For this reason, the environmental concepts and models in the present application are basic, while a deeper analysis or exhaustive refinements in the form of the ontology are out of the scope of the present work, which is designed to illustrate how the ontology-based knowledge networks’ approach can be applied as a new tool for environmental training, as well as how this tool works.

4.1. The upper ontology

The upper ontology consists of the top concepts (Figs. 3 and 4). The concepts are organized in a subsumption hierarchy (specialization) and are linked with relations. The upper ontology consists of the six categorizations proposed by Sowa [13]: physical (consisting of matter or energy) and abstract (for pure information structures and concepts), broken down to ‘continuant’ (having stable attributes that enable its various appearances at different times to be recognized as the same individual), and ‘occurrent’ (a process or event that “is in a state of flux” and that “can only be identified by its location in some region of time-space”). These concepts are then further specialized (lower-level sub-concepts) in an object-oriented fashion.

The physical continuant concept is further specialized in the concepts: (a) agents, (b) resources, (c) sources of pollution and, (d) pollutants. The resources concept is further specialized to the environment and then to the three media: air, water, and soil.

The relation between the instances of the concepts sources of pollution and pollutants (appearing as dashed arrows in the diagram) is the relation ‘Emit’ (a source emits pollutants), with inverse relation ‘Are emitted by’.

The physical occurrence concept is further specialized in the concept, environmental impact, which is further specialized into the concept damages and then to more specific damages: ecosystem damages and human damages.

The abstract occurrence concept is further specialized in the sub-concepts: (a) quality of media, (b) environmental impact types and (c) pollutant types.

The environmental impact types are further specialized to the concepts: global, regional, and local.

The pollutant types are further specialized to the concepts and sub-concepts:

- Pollution sources further specialized to the sub-concepts: non-point-source pollutants and point-source pollutants
- Effect duration further specialized to the sub-concepts: cumulative pollutants and non-cumulative pollutants and
- Source operation further specialized to the sub-concepts: episodic pollutant source and continuous pollutant source

The abstract occurrence concept is further specialized to the concepts: (a) processes and (b) exposure. The processes concept is further specialized to the sub-concepts: hydrological, meteorological, chemical, and physical.

4.2. The lower ontology

The lower ontology deals mostly with local concepts and relations used by the various scenarios. Details about the lower ontology (concepts and relations) can be found in Fig. 5.

Sub-concepts, defined for the needs of the educational scenarios, built per upper ontology concept are:

- For the concept, sources of pollution the sub-concepts: sources of greenhouse gases and sources of ozone depletion pollutants;
- For the concept, pollutants the sub-concepts: greenhouse gases, and ozone depletion pollutants are used;
- For the concept, environmental impact, the sub-concepts: global warming and ozone depletion are used;
- For the concept, ecosystem damages, the sub-concept: ecosystem damages from global warming are used;
- The sub-concept, global air quality is under the concepts air and quality of media.

The relations defined for the needs of the educational scenarios (in addition to the default relations that include: ‘is instance of’, ‘is a sub-concept of’ and ‘is extended by’) are:
- The relation ‘enable’ (with inverse relation ‘is enabled by’) between the instances of the concepts processes and environmental impact, since various processes (hydrological, meteorological, chemical, and physical) enable various environmental impacts.

- The relation ‘result in’ (with inverse relation ‘is a result of’) between the instances of the concept physical concepts. This is a common practice to define a relation at an upper concept. That way the relation is also available, through inheritance, to the instances of all its sub-concepts and thus it is used in educational scenarios to show that a pollutant ‘result in’ an environmental impact, which ‘result in’ ecosystem damages. Therefore the relation defined for the (upper) concept physical concepts is also available to the three sub-concepts mentioned (pollutant, environmental impact, and ecosystem damages).

5. The educational scenarios

In order to avoid repetitions of terms that will make the text difficult to read, all concepts and sub-concepts will appear in italics and all relations will be enclosed in single quotes.
In the scenarios appear terms not defined in the ontology. Those terms are (a) local relations referencing ontology-defined relations (Table 1) and (b) instances of concepts.

The reason why local terms were used is in order to avoid over-loading the ontology with too many relations. But this is a decision the designer has to make, i.e. either define all possible relations in the ontology and use them in the scenarios, or define generic relations in the ontology and use local scenario-specific terms.

Finally instances of concepts appear in the various scenarios, which are defined locally and they are linked to MMOs.

5.1. The environmental pollution flow scenario

The environmental pollution flow scenario (Fig. 6) resembles the “directed network or flowchart” (6th Ryan’s structure), where two flows of environmental impacts are represented in the scenario, one on the left (resulting in ecosystem damages from global warming) and one on the right (resulting in ecosystem damages from ozone depletion).

The scenario starts with the sources of pollution, which ‘emit’ pollutants, whose emission ‘result in’ environmental impacts, which ‘result in’ ecosystem damages.

In more detail, the scenario shows on the left, the sources of greenhouse gases which ‘are’ sources of pollution. The sources of greenhouse gases ‘emit’ greenhouse gases, which ‘are’ pollutants. Greenhouse gases ‘result in’ global warming, which ‘is an’ environmental impact. Ecosystem damages from global warming, which ‘is a result of’ global warming, ‘are’ ecosystem damages. Global warming also ‘effects’ on global air quality. Finally the reduction of sea ice ‘is an’ instance of ecosystem damages from global warming and is associated with a multimedia object showing what is meant by reduction of sea ice.

Similarly the flow on the right shows the sources of ozone depletion pollutants which ‘are’ sources of pollution. The sources of ozone depletion pollutants ‘emit’ ozone depletion pollutants, which ‘are’ pollutants. Ozone depletion pollutants ‘result in’ ozone depletion, which ‘is an’ environmental impact.

Global warming and ozone depletion ‘result in’ large stratospheric cooling, which ‘is enabled by’ various (hydrological, meteorological, chemical, and physical) processes. Large stratospheric cooling ‘is an’ instance of ecosystem damages and is associated with a multimedia object (MMO) showing what is meant by large stratospheric cooling.

Finally CFCs ‘are’ both greenhouse gases and ozone depletion pollutants, meaning that they are emitted by both processes. The locally defined instance CFCs is also associated with a multimedia object.

After capturing the multimedia objects (MMOs), they were imported into the CULTOS media import tool, so they are available to the (knowledge network) authoring tool.

### Table 1

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Local term of relation</th>
<th>References the ontology-defined relation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>‘Are’</td>
<td>‘Is sub-concept of’</td>
</tr>
<tr>
<td>1</td>
<td>‘Is an’</td>
<td>‘Is sub-concept of’</td>
</tr>
<tr>
<td></td>
<td>(used for concepts)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>‘Is an’</td>
<td>‘Is instance of’</td>
</tr>
<tr>
<td></td>
<td>(used for instances)</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>‘Effects’</td>
<td>‘Result in’</td>
</tr>
<tr>
<td>2</td>
<td>‘Sources’</td>
<td>‘Has instances’</td>
</tr>
<tr>
<td>2</td>
<td>‘Pollution source type’</td>
<td>‘Extends instances’</td>
</tr>
<tr>
<td>2</td>
<td>‘Source operation’</td>
<td>‘Extends instances’</td>
</tr>
<tr>
<td>3</td>
<td>‘Explains’</td>
<td>‘Is instance of’</td>
</tr>
<tr>
<td>3</td>
<td>‘May occur from long’</td>
<td>‘Is extended by’</td>
</tr>
</tbody>
</table>
actual design of the scenario involved: (i) import all ontology concepts and relations, (ii) define all local entities (instances) and select associated concepts (from the ontology) and multimedia objects (and portions of them) associated with the entity and (iii) define the local relations between concepts and instances, based on ontology-defined relations, by either using the term defined in the ontology, or by using local scenario terminology.

5.2. The sources of pollution scenario

The second scenario is designed to show trainees the sources of greenhouse gases and ozone depletion pollutants and to characterize each source, based on source types already defined in the ontology (Fig. 7). The structure of the scenario is a unidirectional tree from top to bottom (the 3rd Ryan’s structure) where every traversal is the path that a user must traverse in order to arrive at the required source and be able to examine it.

The sources of greenhouse gases can be analyzed to the following ‘sources’ (which are instances associated with multimedia objects):

- Burning of fossil fuels and deforestation whose ‘pollution source type’ is point-source pollutants,
- agricultural and biological activities,
- aerosol propellants, refrigerants, and various industrial activities whose ‘source operation’ is continuous pollutant source,
- fertilizers whose ‘pollution source type’ is non-point-source pollutants and
- chemical reaction from combustion.

Similarly the sources of ozone depletion pollutants can be analyzed to the following ‘sources’ (which are instances associated with multimedia objects):

- aerosol, propellants, refrigerants,
- air-conditioning, packaging, and insulating gases,
- foaming agents,
- fire extinguishing agents whose ‘source operation’ is episodic pollutant source.

5.3. The ozone depletion scenario

The third scenario constructed is the detail ozone depletion process. The structure of the scenario resembles to “the vector with side branches” (4th Ryan’s structure), since each node of the main path on the left, is connected to side branches, showing each node’s relations with various concepts and instances (Fig. 8).

The concepts, instances, and relations on the left, including the global air quality sub-concept at the bottom were all used and explained in the environmental pollution flow scenario (Section 5.1). The instances of the sources of ozone depletion pollutants (sub-concept) appearing on the right top were used and explained in the sources of pollution scenario (Section 5.2).

The following instances (associated with multimedia objects) ‘are’ ozone depletion pollutants:

- CFCs
- Methyl chloroform
- Halons
- HCFCs
- Carbon tetrachloride
- Methyl bromide
In this scenario the following multimedia-associated instances are also introduced:

- What is ozone depletion that ‘explains’ ozone depletion?
- What is global air quality that ‘explains’ global air quality?
- Skin damage from UV radiation, which ‘is a result of’ ozone depletion, ‘is a’ human damage and ‘may occur from long’ exposure.

The current scenario uses the knowledge and the MMOs of previous scenarios and therefore, the design of most parts of the scenario are just a drag and drop exercise, showing the biggest advantage of the proposed methodology which is reusability of both knowledge structures and multimedia files already developed.

5.4. Other proposed types of scenario structures for further development of the model

Up to this point three scenario examples were constructed based on Ryan’s nine narrative structures, namely structure three, the tree for the sources of pollution scenario, structure four, the vector with side branches for the ozone depletion
scenario, and structure six of the directed network/flowchart for the environmental pollution flow scenario.

The remaining six structures are now examined and examples are provided for possible training scenarios based on those structures:

- Structure one (the complete graph). This structure is not applicable because there is not always a relation between each and every concept and instance found in the ontology.
- Structure two (the network). The ontology is a network structure since it shows all possible relations between concepts and instances.
- Structure five (the maze). This structure can be used for examining trainees’ understanding of various scenarios and the sequence of environmental processes. An ecosystem or human damage can be given (e.g. skin damage from UV radiation) and the full path must be identified by the trainee, including all intermediate sources, pollutants, and environmental impacts resulting in the requested damage.
- Structure seven (the hidden story). This structure can be used to show how a series of environmental processes take place over time. The environmental processes must be identified and put into the correct sequence on the time dimension.
- Structure eight (the braided plot). This structure tells the same story from different perspectives and can be used to examine a trainee’s understanding of the relations between sources, pollutants, environmental impacts, and damages. For example, ecosystem damage can occur either as an immediate result of one or more environmental impacts or as a result of various hydrological, meteorological, chemical, and physical processes taking place between one or more environmental impacts.
- Structure nine (the action space). With this structure, the system designs the general outline of the plot, and the user selects the details of its realization. For example, an outline of the global warming flow will be given to the trainee (the top concepts) and the user must analyze each detailed sub-concept, instance, and relation associated to the outline.

6. Discussion and concluding remarks

This paper presents a new prototype approach for the implementation of environmental training scenarios (that can also be used in any training scenario) which consists of the steps: (i) define and implement the upper ontology (concepts and relations between them) in a top down approach, (ii) design each educational scenario and identify: (a) a lower ontology (concepts and relations to support it), (b) the MMOs necessary for the scenario, and (c) the scenario structure, using one of the proposed eight structures that best fit the educational objectives, (iii) enhance the initial ontology by adding all concepts and relations required by local scenarios in a bottom up approach, (iv) reconstruct all existing material and construct all new MMOs necessary to support the various scenarios, and (v) construct each scenario by combining ontology-defined concepts and relations with local scenario entities (instances associated with MMOs). The paper further enhances the work of the CULTOS project that implemented hypertext based inter-textual studies about the European culture, by examining a different use of the tools built by the project, in the development of training scenarios. In addition, the paper presents:

a) The environmental literacy teaching ontology prototype that was developed in order to support educational scenarios’ prototypes. The ontology considers and solves application-specific problems and can be used for further research on the subject.

b) The eight proposed scenario structures for environmental pollution training are based on Ryan’s nine narrative structures that can be used to build other educational ontology-based scenarios.

c) The three scenarios built that demonstrate, through specific examples, possible uses of the approach.

The main findings are presented in the following paragraphs.

The methodology of the proposed prototype is about the representation of knowledge found in the logic, the structure, and the ways of use of environmental literacy as a knowledge network (a collection of educational scenarios serving a specific educational need), which is based on an ontology. The ontology contains all the relative concepts, instances of concepts (nodes), and the relations between them. The knowledge network relates the basic entities defined in the ontology with the various multimedia (text, image, video, animation, etc.), which are supportive for better understanding the entities of the ontology.

The user of this technology can search for a concept, examine it closely with the help of the supportive multimedia and navigate to other concepts that relate to the concept under consideration and to each relation, in order to understand, through this navigation and the support of the multimedia:

(a) Which are the building blocks of an environmental issue?
(b) How do they relate and interact between them?
(c) How can they be managed to better support the promotion of sustainability in society?

The proposed methodology does not abolish the existing methodologies for structuring educational material, but introduces an additional dimension, that of navigating into the knowledge itself, based on the knowledge domain under consideration. Therefore, the methodology co-exists with the existing technologies and combines the multimedia material already developed, with ontology entities, using knowledge-based multimedia authoring tools, in order to formulate educational scenarios and to satisfy specific educational needs. That way both the knowledge built within the ontology and the multimedia developed using various tools are fully reusable.

The proposed methodology deals with (a) the creation of the educational materials about sustainable development and (b) its exploitation by trainees. Specifically (a) the
contemporary technology allows the domain experts, in the environmental field, to record their knowledge using ontologies, which combine the concepts making up the field of knowledge, and the relations between them. This recording of each concept and relation takes place only once in the ontology and it is subsequently available to every educational scenario using it. Additionally all the existing supportive material is collected in the form of multimedia (text, image, video, animation, etc.), or new multimedia material is created, in order to develop a collection of multimedia relevant to the knowledge domain under consideration. The ontology is then used by the writers of the educational materials who combine the knowledge contained in the ontology with the multimedia contained in the multimedia collection in order to create new educational scenarios. (b) The user of the educational scenarios, instead of being guided to the supportive multimedia through the existing methods of structuring and searching the multimedia material already discussed (units—sub-units, search, etc.), is now guided, either through a procedure of concept search, or through a navigation procedure, to the knowledge network that presents the requested concept or relation as it is found in each diagram. Then the user can request supportive material in the form of multimedia for each concept or relation under consideration and can gain an understanding of how this concept or relation is related to other relevant concepts or relations in each educational scenario.

The importance of these features in the process of education, in general, may be significant. Although, the dissemination of knowledge is an important function of any kind of training, the accumulation of mere facts and disconnected information, in most cases, is not enough. Knowledge transfer that takes place during the educational process can only be achieved if the trainee digs up some basic understanding of the bits of information, the relationships between them, and why they exist, thus enabling him or her to make sense of the topic that he/she studies. In other words, the ability to think critically is a necessary criterion in order to say that knowledge has been developed. Obviously, this ability is much more important in education for sustainable development since this is more than just a knowledge-base related to environment, economy, and society but it also addresses learning skills, perspectives, and values that guide and motivate people to seek sustainable livelihoods, participate in democratic societies and live in a sustainable manner.

The proposed framework has numerous advantages for both the creator of the educational materials and for the user. More precisely, the creator, in addition to the multiple reuse of the multimedia, which is achieved through existing technologies, also achieves the multiple reuse of the knowledge recorded within the ontology, which is readily available to all the educational scenarios. They can also utilize the knowledge recorded within educational scenarios previously created. Additionally, each concept or relation is only recorded once into the ontology and can then be used wherever it is needed with the same name and the same features (synonyms, attributes, relations to other concepts, supportive multimedia related to it, etc.). Furthermore, the object-oriented approach used in creating ontologies and the hierarchical structure of the ontology, allows the lower-level sub-concepts to ‘inherit’ all the characteristics of the higher-level concepts (attributes, relations, etc.), therefore, it improves considerably, the productivity. At last, the expected deployment of the semantic web [16] will allow the multiple exploitation of the educational ontologies through the internet:

(i) from writers of educational materials, since both educational ontologies and educational scenarios will be available at various sites around the world;
(ii) from programs that will be able to process the knowledge built into ontologies for various purposes.

On the other hand, the user, in addition to having the browsing capabilities to the educational multimedia material provided by the existing technology, can navigate into the knowledge itself, since he/she can identify all the concepts composing this knowledge as well as the relations between them, as they are recorded within the ontology, and the educational scenarios, thus considerably improving knowledge development.

Regarding the weak points of the proposed prototype, the problems encountered were mainly due to limitations of the CULTOS prototype tools. The main limitations found were: (i) the lack of local languages support by the ontology authoring environment, (ii) the limited MMO import capabilities, the tools only support Apple Quick Time supported formats, (iii) the limited navigation into the ontology concepts and relations from the multimedia authoring environment and (iv) the knowledge network designer cannot easily format the HTML pages created by the HTML prototype transformer if a different end-user interface is requested than the one provided.

Those weak points can be limiting in some situations (e.g. develop ontologies in the Greek language, or use MMO formats not supported by Apple Quick Time), but still the environment can be fully utilized to develop educational scenarios, because the tools provided support the full development life-cycle i.e. define the ontology, import the MMOs, design the scenarios, and provide HTML pages that can be utilized by end-users.

Because of these weak points other similar environments are currently being investigated and tested in a real-life class situation, involving students and field experts. The findings of this research will be subject of a future work, as soon as adequate feedback is available.

Summarizing, it is well known that education for sustainable development carries with it perspectives that are important for understanding global issues as well as local issues in a global context. Every issue has a history and a future. Looking at the roots of an issue and forecasting possible futures based on different scenarios are parts of it, as is the understanding that many global issues are interlinked. The ability to consider an issue from the point of view of different stakeholders is essential to education for sustainable development. By considering an issue from another viewpoint besides one’s
own can lead to improved intra-national and international understanding. This understanding is essential for creating the mood of cooperation that must underpin societal sustainable development. This is why the training approach presented here could be very valuable in education for sustainable development because it can help students initially understand that contemporary global environmental issues are linked and interrelated between and among themselves and to help them consider the differing views of these issues before reaching a decision or judgment.

Moreover, the proposed training approach allows students to acquire, in a time-efficient and uncomplicated manner, knowledge in the formation and construction of environmental systems that serve as the basis for the analysis of environmental impacts and the management of natural resources. Thus, students would be able to better understand the complexity and multidisciplinary nature of the problems that have led to the unsustainable development of today, as well as be aware of the fact that these interconnected and systemic problems require a new approach based on different ways of thinking and acting. Therefore, the training framework presented here empowers the sustainable behaviour of students, improves their capacity to manage sustainable development, and motivates them to go further in searching for answers in questions such as:

- What are the main obstacles and difficulties to overcome, in order to get a sound complement between environment and development?
- Who are the main actors and how can they co-ordinate their efforts?
- How could the technological potential be used for a global human development?

In other words, this kind of education aims to help learners to be able to describe the components of a complex system, to diagnose the natural evolution of the system under analysis and to study possible scenarios, in order to predict the behaviour of the system. Through this, it is designed to be a tool that has the potential to teach students systematic ways of identifying problems faced on the path towards sustainable development, providing them the opportunity to solve or, even better, prevent them.

Acknowledgements

The authors would like to thank Professor D. Huisingh as well as the anonymous reviewers for their most valuable recommendations and comments.

References