Modelling Activities in Schools with a collaborative technology-based learning environment: Scenarios of use in secondary education

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Abstract: During the last years, modelling activities becomes an important aspect of the curricula in European secondary education. Technology based modelling environments have enhanced the available possibilities for learning activities in schools, while networking technologies have allowed to associate promising capabilities for collaborative learning in a wider learning community. The present paper presents briefly a modelling collaborative environment addressed to young students 11-16 years old, focusing on the presentation of some general scenarios of use in classroom, related to concept construction and modelling process.

Keywords: modelling, physics, mathematics, chemistry, biology, secondary education, technology-based learning environment, collaboration

Introduction

The multidisciplinary field of Information and Communication Technologies in Education, during the last thirty years has produced an important number of applications that could be inserted in the schools. They belongs to various categories, such as hypermedia encyclopaedias, educational games, open exploratory programming environments, systems supporting media based-laboratories, educational robotics systems, simulation systems, modelling systems, collaborative learning systems, but also various open tools that could be used for rich learning experiences under appropriate conditions [Dimitracopoulou, 2002,; Teodoro 2002]. Some of the systems were well developed from the previous decades, while the development of others categories were accentuated during just the last years. Examples of these systems are modelling systems and collaborative systems.

The scientific activity involves in great extend creation and testing of adequate models of phenomena, systems or situations under study. These models can be either formal (such as the mathematical models built in physics) or can constitute simple iconic representations. Models appear in most scientific areas (economics, history, biology, meteorology, archaeology etc.), as well as in our everyday life. The concept of 'scientific model' is a key one, common among many (if not all) the disciplines. Consciousness of this concept enables science exploration from an advantageous point of view. Additionally, detecting common, similar, or comparable models among different disciplines accelerate knowledge transfer and reusability [Bertalanffy, 1969]. Moreover, during the last years, modelling tools provided by computer science, considerably influenced some disciplines function. This kind of epistemological reasons could be one factor that has influenced the development of modeling systems for education [Hestenes, 1996]. But, there are also purely learning reasons for this: research in the field of science education and cognitive psychology [Bliss, 1994; Lemeignan & Weil-Barais, 1993] have indicated that the application of a modelling process could reinforce the learning process. Through the analysis of the situation, the initial design of the model, the comparison with the other students' models, its exploration, its testing/control and improvement, students express their intuitive ideas and *develop gradually mental models* closed to the scientific ones. Thus, school curricula have started to integrate in their planning modelling activities, as it is the case, in the curricula of secondary education in France, United Kingdom (specially the National Curriculum for England and Wales) or Portugal.

The present paper presents a technology based learning environment, named MODELLINGSPACE that defines a space for expression of ideas, modelling and collaboration. It allows students to express and test models of various situations, while communicating and collaborating with other students and teachers via the Internet.

The main objective for its development was to create an open modelling system, appropriate for a wide range of ages (from primary school to high school). The idea was to support effectively students and teachers during the learning/teaching process (in school class or by distance), and to offer a common environment used in the context of different curriculum subjects, in different European countries.

The MODELLINGSPACE environment is composed by: i) the technology based learning environment, ii) the accompanied educational material and iii) approaches for alternative implementation modes in currents educational systems (specially in Greece, France, Belgium and Portugal) and in the frame of various subject matters such as Mathematics, Physics, Biology, Chemistry, or as projects of interdisciplinary themes of study (e.g. integrated in Environmental Education, Science & Mathematics, etc).

The present paper presents in a brief way, firstly the main educational objectives, then the main tools and functionalities of the technological environment, and finally it focus on the presentation of some examples of use cases in class.

Main educational objectives

The main objective is the improvement of the quality of learning and teaching at secondary school level. Specifically, the object of models, the technological environment and the underlying pedagogical approach has the potential to develop:

- M*odelling process skills (*understand, develop and verify models) permitting work on the heart and the evolution of every science. The environment incites students to cope with various *problem-solving* situations (simple or complex one) of everyday and scientific life and support them through multiple “reasoning and representational tools”.
- Necessary *meta-cognitive skills* (realised with the help of specific tools, as well as appropriate pedagogical strategies). We focus on *learning how to learn* so that knowledge becomes less about facts themselves and more about how to be creative in new and challenging situations.
- *The students' creative and flexible thinking*: the possibilities of multiple representations (appropriate for young students), different reasoning modes and the open architecture of the system permits to students to express their ideas via simple manipulations of a wide and open range of entities & relations (from the concrete and empirical to abstract and scientific ones).
- *Communication* (modelling constitutes a means and a support of the expression of ideas and the communication) and *collaboration skills* (the environment implicates students to work on rich collaborative situations supporting them by appropriate tools).
- A wide range of fundamental *concepts*, *laws* and *reasoning* approaches of different subject matters (mathematics, physics, biology, chemistry, environmental education, computer science) thanks to the wide variety of situations that the environment permits to study.
- *‘New’ knowledge* required interconnecting knowledge and methods from different subject matter in order to cope with complex problems of every day and professional life, thanks of *interdisciplinary* approaches promoted by the environment. It could be characterised as a ‘new kind of knowledge’ given that actual educational systems constrain its development.

Additionally, the approach aims to the improvement of the quality of teaching supporting teachers and inciting them to have a greater organisation and professional effectiveness on school educational acts.

- To fulfil the teacher's role (on standard environment and on web-based) in order to efficiently manage pedagogical process, the environment *provides support to teacher*, by: a) A variety of tools designed to support diagnosis of students, and pedagogical process such as “student's activities historic”, “teaching dialogues tools”, etc. b) Research based teaching material, providing examples and alternatives approaches, information about students intuitive knowledge and difficulties.

- The project incites *teachers to collaborate between them* in the frame of the internal school community national or European community (via a web-based support) thanks of that modelling is a common topic to most of subject matters and in different countries.

Brief description of MODELLINGSPACE's main tools and functionalities

The existing modelling software can be classified into three wide categories, which support corresponding reasoning modes: *quantitative* (these models work on countable things and algebraic forms reflecting the connections between them), *qualitative* (these models represent the knowledge, that is not possible to be reflected in a countable way and involves usually categorical distinctions) and *semi-quantitative* modelling. The latter class of models, even if it depends on countable objects, it does not reflect their values. Scientists from science education and psychology fields [Bliss, 1994; Bliss et al. 1992] have conceived semi-quantitative modelling, offering an intermediary tool for the children and helping them to have progressively access to the quantitative reasoning.

During the last decade, the interest in modelling activities and the possibilities offered by technology have led to the development of a number of systems that concern different kinds of modelling. Some of them are dynamic modelling systems involving mainly quantitative reasoning, such as STELLA and the recent MODELLUS [Teodoro, 1997], which is appropriate for mathematical modelling in physics and other disciplines. There are four systems that support semi-quantitative reasoning: the prototypes IQON [Bliss et al. 1992] and WlinkIt (Sampaio et al., 1996) permitting the modelling of everyday situations, the system MODEL-IT [Soloway et al.1994] dealing with ecosystems, as well the system SimQuest and its successor Co-Lab. The modelling systems AXON and INSPIRATION permit the creation of concept maps. Finally, the system WORLDMAKER [Ogborn 1997] is a spatial distribution prototype that permits the creation of models on ecological systems, traffic flows and different kinds of chaotic behaviour. Actually, complete systems constitute the following MODELLUS, , STELLA, AXON and INSPIRATION.

Some of them are not appropriate for young children (e.g. STELLA & AXON). Most of these systems usually support only one type of modelling (dynamic, space distribution, logic, or qualitative), only some of them focus on special domains and only one of them supports collaborative learning or by distance teaching support: the Co-Lab that is actually under development.

The specificity of MODELLINGSPACE rises on the fact that incorporates multiple modeling modes and a wide range of entities and variables (from the most concrete to the most abstract ones), has specific tools to support not only students and but also teachers during learning activities in both stand alone or networking collaborative mode. Moreover, it supports various representational forms, and allows the expression through the greatest visualization, combining the modelling tools with real world simulations (not only abstract ones).

The MODELLINGSPACE consists of some main tools and underlying functionalities. Concerning the modeling process, the most important are the following ones:

1. The *"Study Themes Creation Tool"* contains a number of situations that are proposed for modelling, while it allows for the creation of new problems by teachers and students (using a special multimedia editor).
2. The "Models Design-Testing" area invites students to design, test and validate models. It consists of the area where the models can be designed. It contains the design tools, the representation tools, the control tools (necessary to run the model). In order to design a model, students have to determine the model' s entities, their properties and the relations between them.

   Entities: A library provides two main kinds of entities: the concrete ones (that correspond to objects) and the abstract ones (that may correspond directly to concepts). The designation of each entity requires both the iconic and the textual determination, which are able to specify the concept, or the property referring to this entity or only the textual determination, which directly refers to a concept. For each entity, one or more properties have to be determined as well as the estimation of their values (if necessary). The effect of these values appears directly in a visual mode. For instance, in the semi-quantitative reasoning mode, the fact that the value of the volume (property) of the water in a barrel (entity) is high or low, can be seen from the water level at the barrel's icon.

Relations: The students can choose and determine the desirable relation between two properties of two entities, among the available relations of the four categories:

- *Qualitative semantic relations*: they are used to produce concept maps, which are particularly useful to present and study the relations between concepts coming from various subject matters (environmental education, physics, history, etc).
- *Semi-quantitative relations*: these relations are in terms of variation of properties' values and direction of this variation. In the current version, the student can use simple relations that correspond to simple algebraic relations, which are common in mathematics and physics as well. Each relation is represented by a symbol. For instance, the relations of analogy or inverse analogy are expressed through the reasoning "If the one entity increases, the other one might increase, decrease, or remain unchanged" and are represented by special graphic symbols (↑↑,↑↓,↑↔,↑↑, or ↑↓).
- *Quantitative simple algebraic relations*: these relations are defined by arithmetic operators (+, -, *, /, =). In a direct manner, a dialogue box permits to relate some of the entities' properties - previously defined in a model- with arithmetic operations in order to determine a quantitative algebraic relation.

Additionally, students dispose two other means to explore relations between properties of entities or abstract concepts:

- *Graph based indication of co-variation:* students have the possibility to draw (through the mouse) a graph showing the co-variation between two properties, and when running it, they can see the simulation of the phenomenon. It is very useful (a) for complex models that cannot be expressed by a known mathematical relation, (b) to enhance the flexibility of students thinking on representations.
- *Table of values based indication of co-variation:* Students can insert the values of two variables that disposes (for instance from an experiment), so as to simulate the phenomenon, and then to try to explore the appropriate underlying model. This characteristic enables the user to represent data from external real experiments, and compare them with the data coming from the model, -a possible necessary step in the phase of model's validation.

3. *Representation Tools:* Before or after model running, the student can activate the "Representation Tools", including: tables of data, graphs, and bar charts. The system can also count the variation of a variable between two successive instances (e.g. ΔV).

4. Annotation tools: There are three kinds of annotation tools: a) *the sticky notes*: that can be posted in the models-design area. They consist of flexible resizable notes linked to specific positions of the space, to specific objects or to other notes. (b) *the "structured notebook"* that stimulates students to take notes during the modelling process. The specially designed notebook contains three folders: "determination of situation", " model designing", and "model validation'. Its aim is to encourage students to put their thoughts down during the different successive modelling phases. It gives to students the possibility to recall these notes later, working on the model, in order to think about the evolution of their ideas. (c) *The Report*: that is a modelling support tool, aimed to promote reflexive modelling activity, inviting students to prepare during and/or at the end of the modelling process a whole report synthesizing the previous activity. Into the report students insert 'icons' from intermediary or final models as well as data (images of graphs, of data or of simulations) that support the validation or the reject of a given model.

5.The "*Management tools for teachers*: They are three different functionalities' categories that permit teachers correspondingly to add or delete users, to observe in details the student's activities historic and to allow him/her to create and insert new entities. The existing entities editor allows the creation of new entities of various kinds, extending the range of the already available phenomena or situations to model.

Concerning the effective communication, cooperation or Collaboration, via local network or via Internet, a number of tools are actually under development. In order to allow and support teaching and collaborative learning through the Web-Based MODELLINGSPACE, we need two categories of tools and services addressed to students and teachers: (a) tools and functionalities that are needed for the synchronous collaborative problem solving on modeling (by two or three students), and (b) tools that are devoted to the needs and the functions of a wide community of learners around common activities.

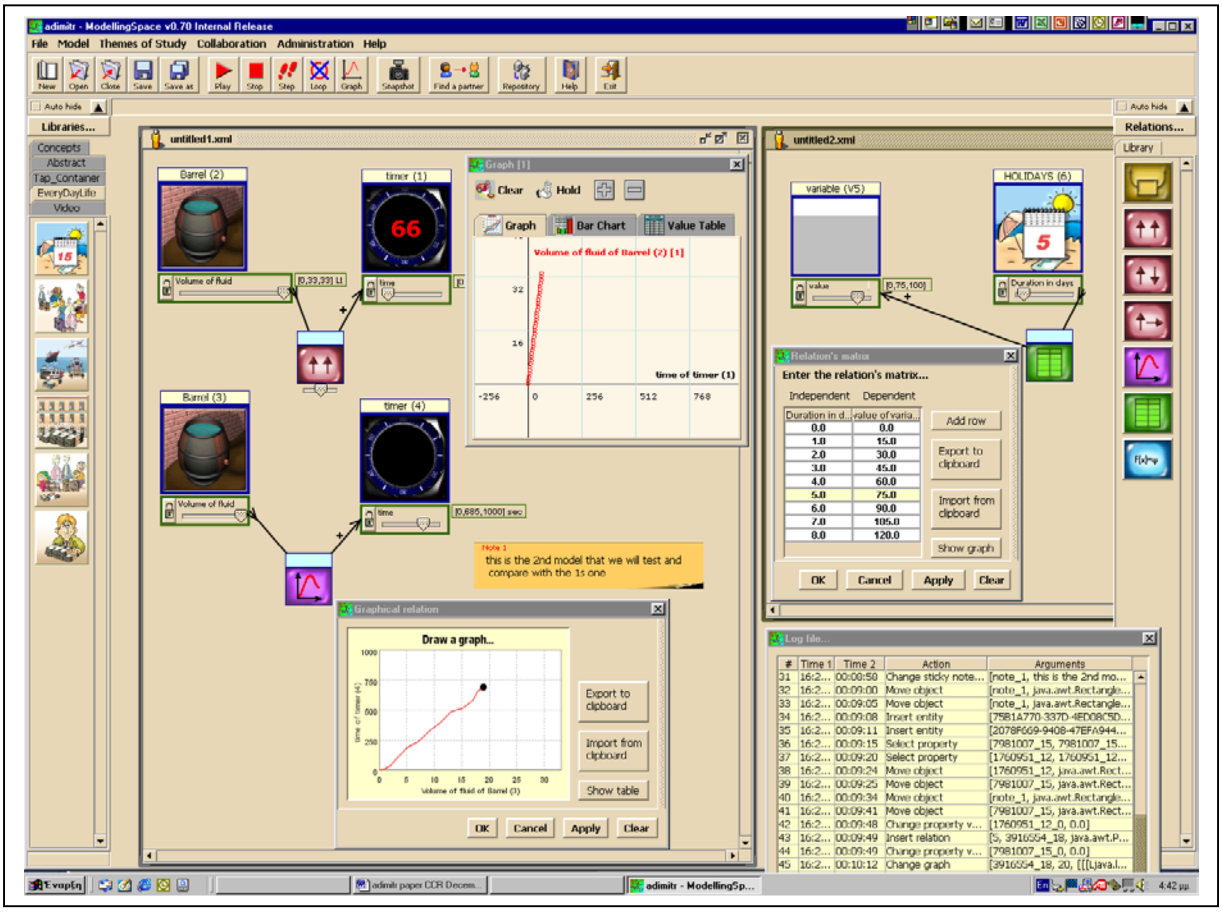

Figure 1: The model-design area MODELLINGSPACE with some significant tools

Various tools will be provided to students so as to allow or to support the synchronous collaborative activities:

6. *Communication, Collaboration-dialogue based tools*: Three different kinds of dialogue modes are available: a free dialogue through chat, a structured chat dialogue, and sticky notes for immediate annotation in the shared models creation area. One or more of these available modes could be appropriate depending the collaborative settings, or the phases of modeling.
7. *Co-ordination tool of the shared workspace:* A specific protocol permits to manage the users and the actions taken place in the shared workspace during synchronous collaborative model's creation. It allows partners to coordinate their actions, through an *Action Key* protocol of coordination, according to which: one takes the control, then others need to ask for it via dialogue tools, or via a request button, in order to get it.
8. *Awareness of others activity support:* provides information on others' activity, for instance, if they are in process to move an object, to insert a new one or to write a message. In the same time the system, inform which member of a group are on line.
9. *Students' activity meta-analysis tool:* permits to present an elaborated historic of the learning activity in an appropriate visual mode, aiming to promote the development of meta-conceptual awareness of students. There are two tools: (a) Visual Historic of modeling process. This tool permit to students to see a playback of the modeling process, thus providing a memory aid. (b) Advanced analysis of students based on functional roles of students actions and utterances, that constitute indicators on the quality of modeling and collaboration. (such as: the extend of use of 'models test tools' by one students or by a students group, the degree of participation, the density of interactions, etc.)

The tools that aims to support teachers are the following ones:

10. *Supervision:* the tool is a viewer that allow teacher to supervise students screens when they work for instance in a local framework, and support also a simultaneous view of a number of students finals productions.
11. *Litteral and visual history of modeling process:* it presents the logfiles, which have been produced during the whole modeling activity, in a readable way. The inspection of the logfiles by teachers is a valuable activity specially during collaborative activities, when the interaction is based both on written dialogue and action. The *Visual history of modeling process* permits teachers to select one instance of the logfile and make reconstruct the corresponding state of the models design area.
12. *Modelling and collaboration activities' analysis tool:* the analysis of students' modeling process is based on a specific framework (Avouris, et all, 2002 Dimitracopoulou et all, 2002). A model of the collaborative modeling process is produced based on the notion of ownership of the components of the solution provided by students, and presenting indicators related to the content of the modeling process as well as on the collaboration quality.

Additionally, there are actually under preparation tools and functions that concerns the *Community level* of interaction. We can distinguish: a) the website general level information and tools, b) the groups management tool, c) the session management tool, d) the repository of material with a database allowing different kinds of materials (primary entities, models (problem solutions), problems (themes of study), reports on modelling process, as well as logfiles. Finally, a *General activity Record Database*: permits global recording of the whole on-line actions/interactions/collaborations of teachers and students.

Appropriate and sufficient accompanied educational material is currently developed, necessary for large scale use of MODELLINGSPACE environment, comprising:

- *Situations for modelling* (learning activities), studied by mathematics, physics, chemistry, biology, environmental education related to some existing national curricula (in France, Belgium, Portugal, Greece) and other situations enriching these curricula, and addressed to different ages 11-12 (primary school), 14-15 and 16-17 (secondary school). The learning activities results from an extensive, analysis of the European Curricula and the national teaching conditions and approaches.
- Detailed *material for teachers* is developed, concerning appropriate pedagogical and teaching approaches, students' difficulties, modelling and models in sciences and in educational curricula, etc.

Some Scenarios of uses

Our viewpoint aims to render pupils capable to: understand and appreciate the nature of sciences and their concepts, laws and theories; use the process of modelling to deal with situations – everyday life problems; analyse critically the results of constructing and using models.

Research studies in the areas of science education and cognitive psychology have demonstrated that modelling activity entails a learning process for the pupil who carries it out. This learning process consists in general of the following stages: the formulation of the problem – situation to be modelled; the initial design of the model; the comparison with other models of the same situation; the exploration of the model; the evaluation of the model and its modification.

It is expected and hoped for that as a result of this process pupils will reconstruct their representations, build concepts and understand theories, that is will progressively construct for themselves models similar to the scientific ones.

The MODELLINGSPACE environment, taking into account the population that it concerns, can be used in *a school context in the following general cases:*

1. In a typical class setting, exploiting or not local network facilities. Students will work by collaborating face to face (in small groups of 2 or 3 students) on a simple or more complex problem to model
2. In class but with global network facilities and exchanges: The network of schools, and a server supporting activities, and provide to students and teachers a wider spectrum of possibilities: Exchange ideas on problems, exchange ideas on solutions and reports, find peers for a specific problem, or classes that work on the same or similar kind of problems, etc.
3. In class with collaboration through networks in a school, national, or European level: it concerns not exchanges but collaborations with a specific aim to investigate one or more specific study themes.

4. From users home (students or teachers), as supplementary of the work started in school class: Given the technological advancement, in networks and bandwidths, as well in services and costs that will be seriously decreased, we consider that in the few next years it should be possible for students to work via network from their home, in order to continue a study theme started at school. Additionally, they could have the time and the opportunity to research the material and the experiences of other students or group in other classes, other schools or other countries.

Lets take an example of the first case, where students work in small groups in the school computer laboratory with the assistance of their teacher. In this case, students can:

- Study a problem and Create a model
- Explore verify and modify a given – created model
- Conceive a situation and propose to other groups to solve it, (eventual use of one entities editor with the help of their teacher)
- Study a detailed example of modeling process from the report presented by another student.

Lets examine an example of the first case, so an example of a complete modeling process, concerning a simple kind of problems. A possible sequence of events (described in a high level of abstraction) could be the following one:

A group of students collaborate face to face on a PC in the class or school laboratory. Students have to open a study theme that exists, or to create another one. Students have to analyse the situation described in the problem statement, and creating an initial mental representation to decide on what are the main factors that influence on the phenomenon.

They have to choose the kind of variables to represent these factors (entities such as real objects, indicating the properties that they play a role (e.g. not the color of moving car, but eventually its mass) or directly abstract variables, as scientific concepts, considering the studied system as a material point). The entities or the abstract variables have to be found from the library of entities (opening one or more of the available folders).

They have to indicate relations between two variables. In order to define the relations they have try to find an expression mode for this relation that is the most closed to the existing in the library of relations. So, if they can immediately use an exact algebraic relation, they will try to define it, otherwise, they will choose, one of the semi-quantitative relations. If they can infer only a literal relation so they will choose a qualitative one.

During this process, students are invited to take notes of these initial analysis and assumptions, in the structured notebook.

Completing the relations indication or before finish it, they could execute the model, in order to examine the simulation that the system produce giving the provided relations, by a run functionality (when it is an executable model, and not a concept map). In order to interpret the simulations and the appropriateness of this partial model, it must be useful either to see the values of the variables, or to run and examine the representations of the data that the model produce. So they can indicate the variables whose the values they wish to examine the co-variation, asking for the table of values, the typical x-y graph, or other kind of alternative representations of data such as, barcharts and pies.

This execution of the model and the graphs observation, could lead them to re-examine and modify the model, changing the relations or the variables or indicating different initial values of variables, or finally adding new relations.

Eventually, they will note their new ‘hypotheses’ into the structured notebook, or they will add just a note, by posting a sticky note in the area of the model editor, so as to remember the reason why they have put this specific relation.

In the investigation phase student could be helped by special questions or prompts written in the paper worksheet for students, related to this specific study theme.

Teacher that supervises the work of students via the group supervising utility, or via direct contact with the group, could support them by appropriate hints or questions.

The students will predict the modified model behavior, and will execute it. In order to interpret what happen and to validate the appropriateness of the model students will eventually again run the model, and ask to see the graphs.

They may think to take pictures/images of this data representation (e.g. an image of the x-y graph, an image of the table of values) in order to be able to explain later why they have validated or rejected this model. These images could be copied in the Report, in order to comment it later. They can take also images from the model in order to comment or explain, if later it appears that it is a non-appropriate model.

If the available time is over, students they have to save the model (and automatically, notes will be saved also).

At the end of this session, teacher could see the models and the notes of each group of students, as well as their history of their process as it developed by the analysis tools. These products will eventually lead he/her to give appropriate advices addressed to the whole class or to specific groups.

In the beginning of the next session, students can open the model (and directly the study themes, as well as all their notes must be automatically opened). They will have to continue the process of modeling until to reach to a sufficient for them solution or model.

The modeling process could not be considered as finished until to prepare and draw up a written report on the proposed model as well as on the modeling process, with eventually comments on their intermediary essays. For this last purpose, students could use the appropriate for them analysis tools in order to have a support on their memory related to their process.

Teacher, that know the final models of students (via monitoring) as well as their history (via the structured analysis of their process history) could orchestrate the presentation of the reports of some group of students. These presentations could result to a more general discussion on the process as well as on their conceptual implications of the specific problem, and or to invite some of the groups to improve their models.

It is useful to mention that students could analyse a study theme, and produce a model that could considered as:

1. A simple model: For instance, they could study an object moving on a inclined plan, that will need one or two sessions for young students of 13 years old, using only semiquantitative relations.
2. A complex model:
   - A complex model that incorporates many variables (e.g. in environmental education: where a group of the class will model only a part of the problem while another group will model another part. At the end, they will collaborate in order to produce a common model.
   - Eventually simple models that will need two or more sessions, if they have to support the transition from semiquantitative models to quantitative ones (e.g. models of simple standard types of motion).
3. A complex model with different levels of sub-models: For instance, problems in physics incorporating different “languages”: (e.g. a model in terms of energy, with a model in terms of cinematic equations, interconnected between them).

The problems can be more traditional ones focused on concepts and representations, while others more open, focusing on modeling process, or they may be interdisciplinary ones (innovative related to the current curricula).

Students can be implicated to work on various kinds of models, such as the following:

- Qualitative models of concept maps so as to structure concepts relations during final synthesis at the end of a long session or during initial brainstorming in order to analyse a complex problem and write down the whole number of factors that influence and their relations
- Semiquantitative models with ‘what influence’ relations
- Simple semiquantitative models for young students.
- Semiquantitative models that guide to use and identify appropriate quantitative models
- Quantitative models.

Some sessions must be longs: For instance, the sessions that support the transitions from semiquantitative to quantitative reasoning, may need:

- Study two or three different but internally similar problems,
- Create two or three models of this kind
- Think on similarities between these models
- Work on to find out a common entity (more abstract one) and more general variables that could express all of these models/situations.
- Continue and conceive models with more generic entities and so variables
- Work on, new relations, quantitatives ones, trying different typical mathematical equations and find the more appropriate one for a specific case

It is to be noticed that teachers' main roles during learning activities management involves:

- To propose and readjust with students the main study theme
- To support students in their questions, and to go around the groups during group working in order to give advice according to their questions
- To have an easy look-overview of all their group progress (supervise models state)
- To incite students to present their work in class, and to manage discussion during work group presentations (in all the cases, students present the whole work in the whole class)
- To institutionalise during next session or to readjust the set of problems
- To invite them to find relevant material in the public repository

Collaborative scenarios of use will not presented in the frame of the paper. In every case, different collaborative modes are actually under experimentation: "cooperative modelling", "negotiation of differences", collaborative common modelling", "peer tutoring", and "apprenticeship collaborative learning mode".

Discussion

The presenting learning environment is based in a previous technology based modeling environment (non collaborative one), named ModelsCreator that was tested in Greece during the previous years. MODELLINGSPACE is actually tested, for its integration in schools through:

- Case studies of use in primary and secondary schools implicating at least three validation sites in four different European countries: i) at Primary school level (e.g. 11 years old), ii) at Secondary school level for students 14-15 years old and iii) for students 16-17 years old, High School level.
- National experimental applications, on collaborative learning in the language of each country: i) In Greek schools, ii) in Portuguese schools.
- Multinational experimental applications on distance collaborative learning, between: i) French school - Belgian school (in French), ii) Greek school – Portugal school (in English).

Alternative modes of integration and use are implemented: (a) for initial introduction of concepts, according to the current analytical program of specific subject matters, (b) at the end of a unit as a kind of learning activities that help the synthesis, (c) as activities outside of the official curricula, specially concerning interdisciplinary approaches.

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