DESIGN PRINCIPLES FOR AN OPEN AND WIDE MODELLINGSPACE OF MODELLING, COLLABORATION AND LEARNING

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ABSTRACT
The aim of the paper is to present and discuss the main design concepts and principles, for a collaborative modeling environment for sciences and mathematics (MODELLINGSPACE). It incorporates various representational formalisms, allows synchronous and asynchronous collaboration among students and supports teachers. The main design principles and related issues under discussion concern certain central design questions such as: what must be the main modeling primitives when addressed to young students 11-16 years old, in a wide range of cognitive possibilities? In what specific ways support students reasoning applying rich visualizations and multiple representations? How to assure flexible main collaborative actions and communications and how to support related learning community needs? The paper approaches equally important questions such as how to support self-regulation and metacognitive development for students and how to assure teachers needs accomplishment when working in typical real schools conditions?

KEYWORDS
Modelling environment, collaborative learning, mathematics, sciences, secondary education, teachers' support, students' support, real school context

INTRODUCTION

Over the past ten years, there has been an increasing interest in computer based learning environments for modeling that could be used by individual students or pairs of students working in face to-face-settings in class (Soloway et al., 1994; Sampaio et al., 1996; Teodoro, 1997; van Joolingen, King & de Jong, 1997). Even if, most of the modeling environments usually offer only one representation formalism for modeling or they are not really appropriate for young students, there is at the present an acknowledgement of the necessity for more open and flexible learning environments and a better support of students' various reasoning modes and needs.

During the same period, research results regarding collaborative learning indicate the rich learning possibilities that collaborative inquiry and problem solving via networks could offer under appropriate conditions (Pea, 1993; Baker et al., 1999; Dillenbourg, 1999; Lipponen et al., 2001).

MODELLINGSPACE's main concept is to empower a modelling environment that supports young students reasoning, with the learning possibilities of synchronous and asynchronous collaboration, appropriate for various scenarios of use. It appears that modeling environments are not only of interest for face-to-face interaction in classrooms, but also for the expansion of learning opportunities. There it allows a flexible continuation of the work from school to home (and vice-versa), with either a small group of students or with a

larger one, exchanging ideas and collaborating with other students from other classes of the same school, in the same or other town, in the same or in another country.
The paper presents and discusses the main design principles and concepts for a modeling environment for students aged 11 to 16 years. It focuses on the rationale underlying the central design options that are grounded on issues related to science and mathematics education as well as cognitive psychology. Thus, issues that preoccupy researchers on both the fields of modeling environments and collaborative learning environments are discussed:

- What are the appropriate basic modeling primitives (implicated basic entities, variables and modeling formalisms) for young students and how to support the students' evolution?
- What should the appropriate visualization modes and representations be? What kind of simulations should be adopted, how to handle the representations?
- What could be the means of dialogue and the protocols of action during collaborative problem solving, so as to facilitate students' synchronous collaboration and incite interactions with rich learning potential? What multipurpose structuring tools for discussion and work presentation could be offered?
- How to facilitate more global exchanges and interactions in the context of the learning community that could emerge?
- How to support students for self-regulation and metacognitive activities, for both face-to-face modeling and collaborative problem solving?
- How to support teachers on analyzing students' interactions and collaboration features? How to assure the adaptability of the learning environment to their students' needs and context conditions?

The paper presents firstly the main considerations that have led to the environment design. Then, it discusses the main design principles related to some complementary and crucial aspects concerning collaborative modeling as well as students' and teacher's support. Finally, it comments on the main research activities that accompany the design and the development process.

MAIN CONSIDERATIONS AND OBJECTIVES

There are three main reasons that have led us to propose and conceive a new technology-based learning environment that promotes and support modeling and collaborative modeling activities.
Epistemological order reasons: Scientific activity involves to a great extend creation, validation and application of appropriate models of the phenomena, systems or situations under study. Models appear in most scientific areas (economics, history, biology, meteorology, archaeology etc.), as well as in our everyday life. Moreover, during the last years, modelling tools, provided by computer science, have considerably influenced the work of some disciplines. Computers have amplified the power of traditional models, but have also provided new representational systems and conceptual frameworks for modelling. Efficient employment and management of modelling tools appear to be key capabilities for the future citizen. Modelling and modelling with computers is what scientists do all the time, so modelling offers a more authentic view of doing science.
Learning order reasons: Teachers and students of all levels often conceive science education as a process of information transfer in which students accumulate whatever fact is conveyed to them by an instructor or by a textbook. Furthermore, when we present directly to students already conceived laws, formulas and models (e.g. algebraic ones), they don't appreciate the value of the model, they are not able to appreciate the

significance of variables, and thus they often use models outside the conditions of their validity, or cannot evaluate the appropriateness of the results of the application of a model. During the last decade, research in the field of science education and cognitive psychology [among others Clement 1989, Martinand, 1992; Lemeignan & Weil-Barais, 1993; Bliss, 1994; Halloun, 1996] has indicated that the application of a modelling process could reinforce the learning process for a number of reasons:

- Through a model construction process, learners express their own ideas and mental models [Bliss, 1994] of which, in most cases, they are not aware. This expression is the first step towards the process of cognitive awareness of ideas and reasoning modes, which are often necessary for conceptual change [Vosniadou, et al. 1994].
- The graphical and iconic representations that the models can obtain enable the abstract ideas to acquire a concrete form. These representations play the role of thinking support, a role that accompanies thought and reasoning [Laborde & Vergnaud, 1994].
- The expression of thoughts through model construction can help the learning process, since the ideas become an object of communication and discussion.

Furthermore, one of the worldwide problems of the current curriculum is the fragmentation of knowledge among different subject areas. The use of models and modelling processes constitutes a common point among different disciplines. So, modelling activities could contribute to the unification of common points between different subject areas, and could promote *interdisciplinary* teaching approaches.

Social order reasons and the dimension of a wide learning and teaching community: Learn to communicate and collaborate is an important skill of actual life. Collaboration is integral to today's organisations, which require individuals who can work together to solve complex problems and share their own knowledge and expertise with others. Collaborative skills can be learned, and it is therefore essential to provide individuals with appropriate learning opportunities (Abrami, 1996).

If learn to collaborate, must become an explicit objective of the actual education, at the same time, learning seen in a social context offers new possibilities for learning sciences, developing inquiry skills and contributing to the necessary conceptual change.

Social interaction (and interaction with the tools of technological culture) provides new cognitive resources for human cognitive accomplishment (Miyake, 1986; Slavin, 1995; 1997; Hutchins, 1995; Pea, 1993). A fundamental assumption is that interaction among children around appropriate tasks increases their mastery of critical concepts. In general, in cases of knowledge seeking inquiry, technologically sophisticated collaborative learning environments designed to follow cognitive principles could provide advanced support of social process of inquiry, facilitating advancement of a learning community's knowledge as well as transformation of the participants epistemic states (Pea, 1993).

Finally, lessons learned from a number of research studies suggest that we need to consider the school (and their members teachers and students) as a community of practice. Schooling can be improved by understanding the practices of its participants, by creating systems to help the school be a learning organization, by expanding the single local school community to a wider one, that through rich interactions could mutually support teachers, so as to extend their work to new or additional outcomes (Brown & Duguid, 2000).

DESIGN PRINCIPLES CONCERNING MODELLING

PRINCIPLES RELATED TO MAIN MODELLING PRIMITIVES

(a) Scientific concepts and variables vs properties of real objects

How to encourage students to express their ideas and proceed by their own conceptualisation of the situation under study? The latest approaches to learning suggest

that we must render children able to express their intuitive ideas and test their validity in order to change and/or gradually develop them.
For scientists, the initial analysis and description phase in a problem solving or modelling process is severely constraint by their choice of theory to be applied (for instance, mechanics); this specifies what kind of objects and properties can be modelled by specific concepts.
However, reality can be viewed without any kind of 'scientific' concepts. Students, and specially those who are in the process of constructing scientific concepts, can interpret reality, simply as constituted by objects (such as inclined plan, ball, person) (Chi, Feltovich and Glaser, 1981). Most people's everyday thinking is about real entities and events (Bliss, 1992), even if scientific models are more abstract than reality, and a lot has to be left out. Young students' thinking is 'concrete object oriented' and not 'concept oriented'.
Most modelling or simulation systems impose directly abstract thinking and particularly the use of variables. Moreover, in order to allow students to explore a phenomenon by manipulating the relevant factors, they present them directly with the whole list of the implicated variables (not less not more). For instance, they present in an explicit way in the menu the variables of time, distance, velocity, mass, etc. This situation reduces the possibility of the students to reflect on their own cognitive resources.

⇨ In order to *encourage students to express their ideas* and proceed by their own conceptualisation of the situation under study, it is important to keep away from the eventually technical restrictions, and *offer them a wide range of basic modelling primitives as 'variables'* (and not just the scientific ones), so as to make it possible to them express their ideas.

Thus, concerning the 'entity' that could constitute one of the basic primitives for models creation, MODELLINGSPACE provide a wide spectrum, from the more 'object-oriented' to the most 'abstract' ones (see Figure 1).

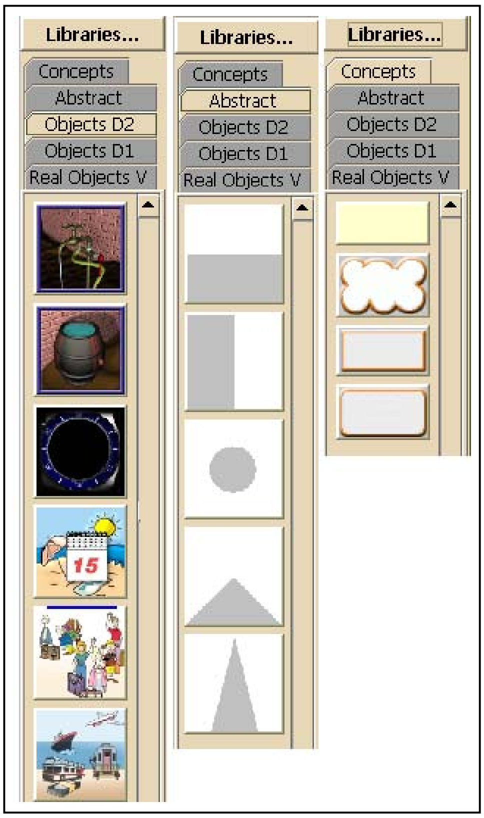

Fig. 1: Entities categories

(a)The system allows children to express their ideas, if they want, with 'entities' that are centred on objects, corresponding to their phenomenological status. These properties that concern real objects could be considered as a kind of *"proto-variables*", able to evolve to more abstract ones. The *'object-centred entities'*, which represent specific objects, may have various properties, both those that could play a role in the object's behaviour, and others that do not play any role (for instance the colour of a moving object, in a problem studying the motion of the object). The manipulation (change) of each attribute/property of this kind of 'entity' is better to have a visual consequence.
(b) A more abstract entity could be considered as a 'construct' depicting an object from a group of uniform real or imaginary objects, that take meaning in the context of a phenomenon, system, process or speculation. This more *abstract entity* represents in general an *abstract conceptualised object* that describes the common characteristics of a set of uniform objects. The properties of these entities have a general value that could characterise all the similar objects. For instance, a

small circle or a point could represent and model any object that is moving. This more abstract entity is characterised by abstract variables that are closer to many scientific ones.
(c) A third category is the abstract entities that directly correspond to abstract *scientific variables* in symbolic form, and that do not have any unique link to a specific object of the real world, which they may occasionally represent and describe. For instance, staying in the area of mechanics, such an abstract entity, could be the concept and variable of acceleration (expressed with its literal name or symbol *a*).
Except the considerations on the entities, it remains to examine the status of the implicated symbols. Scientific symbols correspond to socially accepted meanings. Given that young students have not yet constructed the scientific concepts, symbols presented in the books, or in the educational software, cannot be expected to represent for them the social accepted meanings as the scientists defined them decades or centuries ago.
Thus, one approach to follow for a learning environment design is to be open and flexible allowing students to define and use the names and symbols that they want, both for entities (concrete or abstract ones) and properties or variables.

- ⇨*A learning system should not be rigid in the implicated symbols. It should be open and flexible,* allowing students to designate variables in accordance with the symbols that are currently socially constructed or accepted. This becomes possible if the environment allows *naming and re-naming* the properties of the entities or the concepts by a literal and/or a symbolic mode, from the users themselves.

(b) What relations?

In order to apply appropriate modelling to different problem categories and scientific fields, different modelling formalisms have been developed (Ogborn 1994): difference equations, algebraic structures, finite elements, statistical models, geometric models, graph theory, Monte Carlo methods, cell automata, production systems, discrete event models, logical formalisms, etc. But among the different modelling formalisms, what are these that appear the most appropriate in order to be used (a) by young students, (b) for the modeling of a wide range of phenomena and problems and (c) in different subject matters of the school curricula? There are two basic principles, derived from science education that guide our choice:

- ⇨For a technological environment to be really appropriate for young students it is important to gradually support learning progress, as well as knowledge and skills development starting from the existing ones.
- ⇨The structural elements of modelling, the ontology and the structure of the models have to correspond and be adaptable to the cognitive level of the students (different ages, cognitive resources and demands). They also have to be compatible with the epistemology of the different disciplines.

To fulfil these principles, it is important to adopt not only one but a range of modelling formalisms, including those that are the most appropriate for children. Thus, first of tall, the environment focus *in allowing and supporting qualitative and semi-quantitative reasoning*, which is closer to the existing cognitive resources of young students (Bliss, 1994), comparing to quantitative one. Semi-quantitative thinking is ubiquitous in natural everyday reasoning (Ogborn and Mellar 2004). It recognises ordering of quantity but not magnitude, and it is one of the three main ways in which pupils approaches relations. It offers an intermediary tool for the children, helping them to have progressive access to the quantitative reasoning.
It is to be noted that examining the existing systems for modelling addressed to young students, we consider that they belong to three main categories. There are systems that support semi-quantitative reasoning: the WlinkIt (Sampaio et al., 1996) and its previous prototypes IQON [Bliss et al. 1992] 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. Systems that impose algebraic reasoning is among others STELLA and the MODELLUS [Teodoro, 1997]. The modelling systems AXON and INSPIRATION permit the creation of concept maps.

All the above mentioned systems, partially in the exception of SimQuest, support only one reasoning mode, while others are restrained on specific domains (such as Model-It). Given the objective to conceive a learning environment addressed to a wide range of pupils and be applied in various subject matters, it is essential to support a range of reasoning modes that could allow pupils to gain flexibility in their activation, depending on their cognitive possibilities and the situations to be modelled. Consequently,

⇨ The system should incorporate a simplified as well as a synthetic form of different independent modelling system categories: *dynamic quantitative* (algebraic) modelling systems; *semi-quantitative* modelling systems; *qualitative modelling;* so that it may allows the study and the creation of models for a wide spectrum of problems and phenomena. These categories of models are able to support procedures and modelling mechanisms that derive from *different subject matters* (physics, mathematics, biology, chemistry, environmental education) and thus permit working *in an interdisciplinary mode*.

Three main categories of modelling formalisms (see Figure 2) are perceived by MODELLINGSPACE as the most appropriate for young children in order to work in the frame of their existing school curricula:

(a) *Quantitative models or mathematical algebraic modelling formalism*: This formalism is used in various disciplines. Specifically, in mathematics and in sciences quantitative models are central throughout senior high school. Quantitative models make use of quantifiable variables and algebraic relations. In all quantitative models, the initial conditions are specified by giving values to independent variables. The model uses algebraic relationships to calculate the values of depended variables.

(b)*Semi-quantitative modelling formalisms:* Semi-quantitative models involve quantifiable variables, whose change however is not defined by algebraic relationships, but by the kind of influence that one exerts on the other. In other words these models are based on a formalism that indicates qualitative relationships.

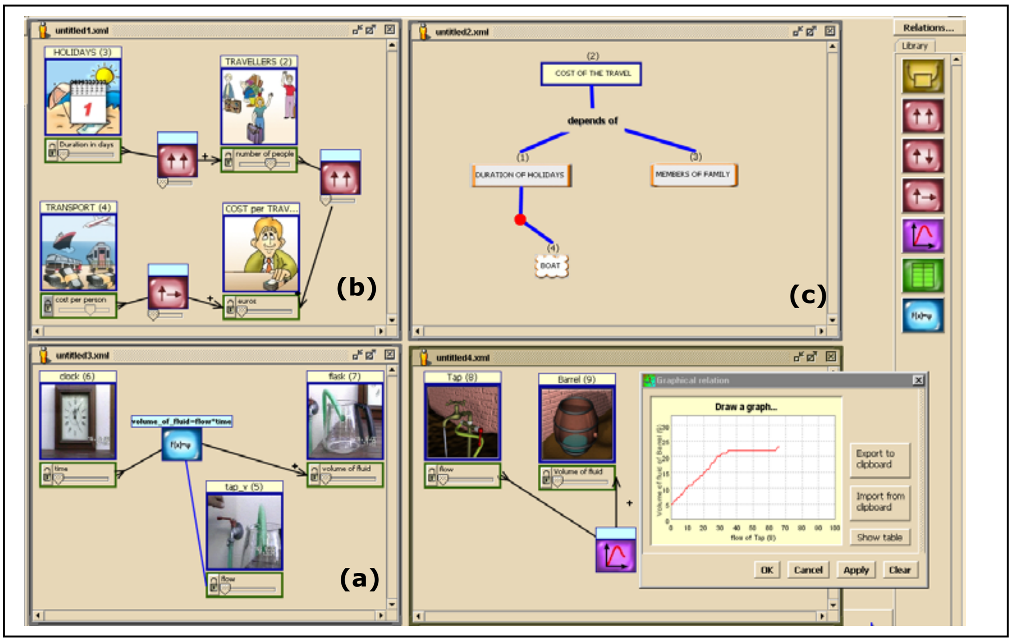

Fig.2. Modelling Formalisms

(c)*Semantic qualitative modelling formalisms constituting concept maps*: They form static, non executable models, like concept maps. Qualitative models express relationships which cannot be expressed in a quantifiable way, and of which the criteria of validity are not strictly defined. Such relationships appear in all the subject matters of school curricula. For instance, the creation of a concept map to present the concepts (and their relations) of a specific domain, is always a valuable learning activity either for purposes of diagnosis of alternative conceptions (e.g. at the beginning of a unit) or of synthesis of acquired concepts (e.g. at the end of a unit). Additionally, there are situations in which using concept map-like diagrams for a qualitative analysis of the implicated factors is very important (such as diagrams of analysis of interactions among objects in mechanics: Dumas-Carré & Caillot, 1989, Dimitracopoulou & Dumas-Carré, 1996, or energy chains diagrams: Lemeignan & Weil-Barais, 1993).

Apart from these three modeling formalisms, the environment provides an additional important possibility to express relation between two variables: by *"drawing the co-variation diagram"* of these variables. This possibility is necessary so as to express complex quantitative relations, where the exact algebraic relation is not known by the user (see Figure 2, the lower right part).

(c) Which visualization?

Appropriate visualization constitutes a crucial point for the support of the development of reasoning in children and more specifically the support of the transition from reasoning with objects, to reasoning with abstract concepts.

⇨The expression through the *greatest and most appropriate visualization* must be supported, concerning first of all the modelling primitives that support reasoning: the entities as well as their properties or variables and the relations that govern them or impinge upon them.

The simulations that are being produced from most of the existing modelling but also simulation systems are merely abstract, representing for instance, an already model object in motion (usually, a small circle, or a small rectangle). For young students who have not the required conceptualisation, it is important to have the possibility to test and validate models through simulations that represent the phenomenon itself in an obvious visual way.

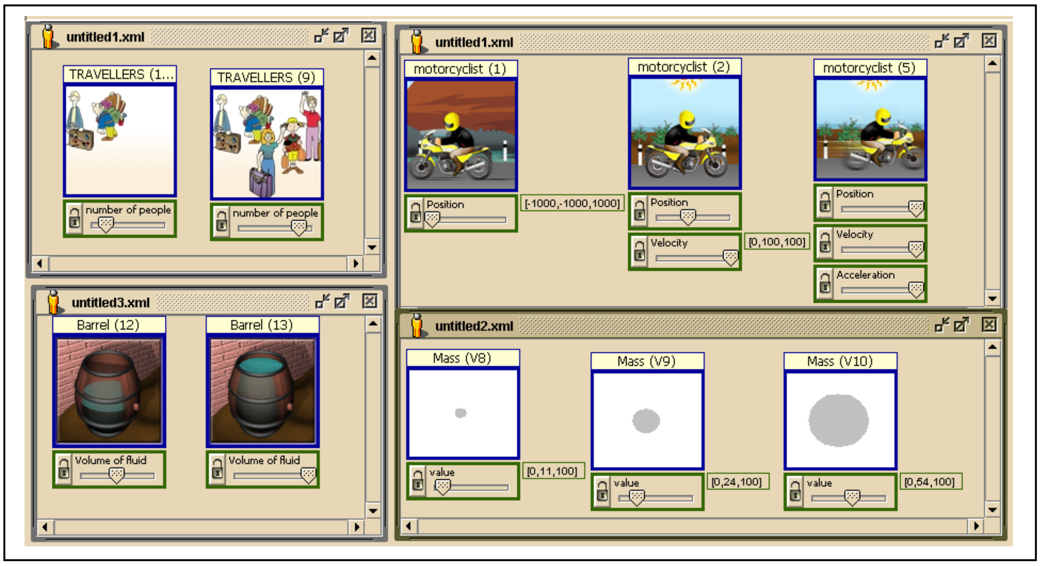

Fig.3. Instances of Simulations of various Variables

Thus, the environment visualises the entities as real objects where the variation of properties change the appearance of the object, based on two kinds of images: (a) drawn images (b) Images based on video captures. In the case of drawn images, specific codifications are explored and adopted, in order to visualize the modifications of the values of the variables (see Figure 3). This necessity of visualisation, in relation to the possibility to work on the entities as real objects, lead to the necessity to support simultaneous combination of multiple variables change visualisation; a need that often requires an important or even huge number or images that must be prepared to support the generation of the simulation. However the design and development effort of such entities appears to have interesting learning effects in the conceptualisation of given concepts, (Orfanos & Dimitracopoulou, in press), promoting the distinction of the nature and status of these variables as well as their conceptualisation as vectorial magnitude.

(d) Which representation modes?

⇨ The students' ability to conceive and use models depends on the representational tools, which are disposable to their command. Given the appropriate and multiple representations cognitive assistance for reasoning and consequently for learning (Ainsworth *et al.*, 1996) is provided. Thus, *the incorporation of alternative and multiple forms of representations* of the different kind of data produced by models is necessary.

⇨ Offering multiple representations is not sufficient, it is also important to support students to *develop cognitive flexibility* in their use (de Jong et al. 1998).

When the model is running, students during the simulation can see only the current value of the variables comparing to their maximum and minimum values. In parallel, in order to fulfil the first related principle, a relatively broad spectrum of representations is available to students and can be activated after demand, such as bar charts, graphs, and table of variables' values. Bar charts seem to be one appropriate representation for young students that explore or express relations in the beginning and have to study the co variation of variables, before having acquiring an experience on use and create typical graphs (x→y).

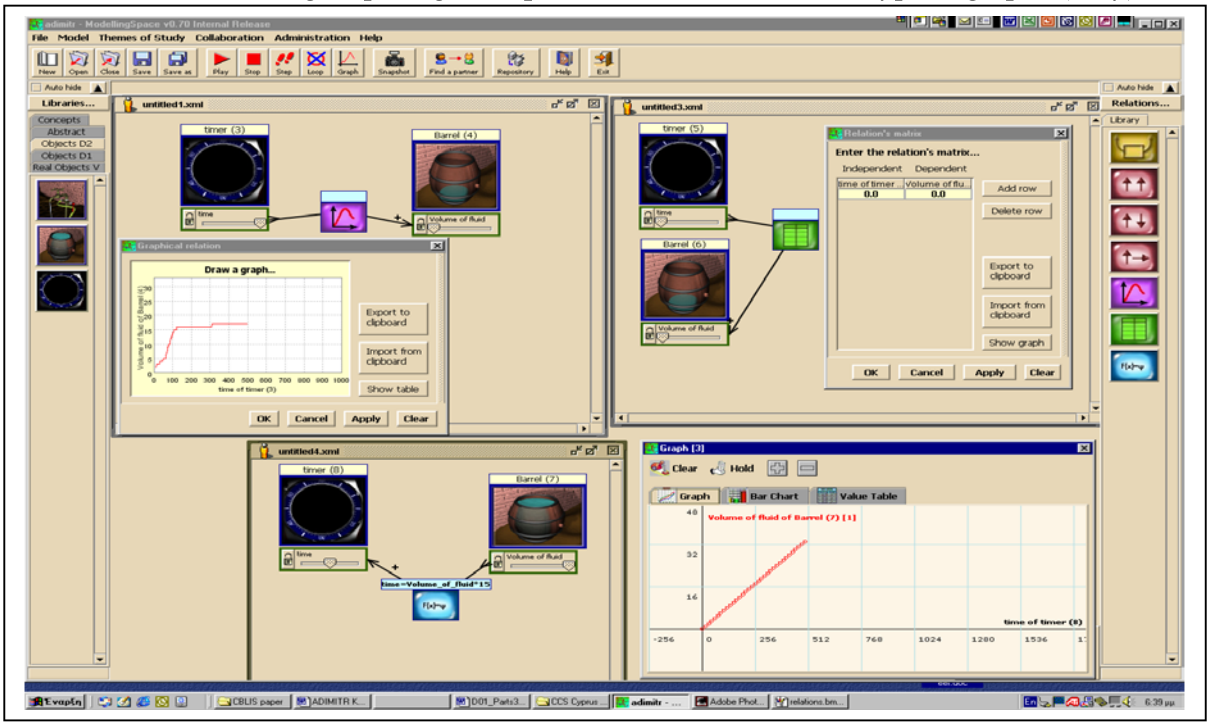

Fig.4. The Models' Design Area of MODELLINGSPACE including some representation modes

Given the above, the question that remains is how to enhance flexibility among the various representations? One minimum requirement is to design the system in such a way that students could observe one or more representations in parallel while executing model, or the one after the other, so as to avoid cognitive load phenomena (Gruber 1995). Another, eventually most important requirement that examines the representations in conjunction with the relations among the variables that students have indicated is: give students the possibility to start from the representations themselves and then explore the phenomenon, think and indicate on exact algebraic or semi-quantitative relation. For this purpose, two functions is supported by the system:

- *Draw and indicate graphs*, as a designation mode of the co-variation between two variables. It is possible for a student to draw a graph with a 'pencil', via direct manipulation interface. After this drawing, when running the model, the student could observe the simulation that corresponds to the specified co-variation.
- *Insert values of variables in an open table of values:* Student can insert the list of successive values of specific variables into an open table of value and then ask to produce simulation that derives from these given data. This possibility offers a powerful link with the real experiments (that could be conducted in class, or they are reported in their textbook).

DESIGN PRINCIPLES CONCERNING COLLABORATION

PRINCIPLES RELATED TO COLLABORATION SUPPORT

Collaborative learning is assumed to be effective because it requires participants to elaborate their cognitive structures in a social context. Moreover in cases of problem solving in rich and critical conceptual domains it appears that collaboration through a network could be more effective than face-to-face collaboration, specially due to potential cognitive effects. It seems that for purposes of a communication aiming to conceptual change, written communication, combined with face-to-face communication, is more effective than face to face alone because it requires more extensive thinking process (Cohen, 1994). During collaboration through networks, the need to externalize one's own thoughts, in a written way, could have significant effects, specially, when the learning activity implicates rich conceptual knowledge that is under development. Special attention is given to collaborative settings and the learning scenarios (Dillenbourg, 2002) according to the learning objectives and the context conditions so as to have the most appropriate conditions to receive the maximum of collaborative gains.

Various systems have developed allowing synchronous collaborative problem solving (such as: 'C-CHENE'; Baker et all. 1999; 'COLER', Constantino-Conzalez 2000; 'Algebra-Jam', Wu et al. 2002, of the under development 'Co-Lab'). In all the systems the significant aspects in order to allow collaboration are: the appropriate dialogue tools, action coordination protocols, awareness tools of collaborators activities. In MODELLINGSPACE, we would like to stress the importance of the following:

⇨ Take advantage from the positive learning potential of all kinds of collaborative settings, related to time and space dimensions: *face to face collaboration, synchronous and asynchronous collaboration and cooperation*, through local and wide networks.

⇨ Special attention is given to provide appropriate means during synchronous interaction, in order to *coordinate action* in a flexible way and learning significant way, through the eventual application of specific protocols of interaction on the shared space, providing functions able to support the *workspace awareness of collaborators*.

⇨ *Multiple, flexible and linked modes of dialogue* during interaction are of great importance in collaborative modelling and problem solving in rich conceptual domains: Chats, structured interfaces with sentence openers as well as sticky notes are provided during synchronous interaction, while during asynchronous interaction the tools for text annotation will be mainly used, enriched with functions of 'keep track' of each participant contributions. The linked mode of dialogue tools is important to be assured in a way that students and teachers could have access to an unified history of dialogue (Suthers, 2002).

PRINCIPLES RELATED TO THE LEARNING COMMUNITY SUPPORT

What it is needed in order to facilitate more global exchanges and interactions in the frame of the Technology based Learning Community on modelling that could emerge? There are specific systems based on the idea of knowledge building, one of the most characteristic of them is “Knowledge Forum” (Lehtinen et al. 1998) In the under development version of MODELLINGSPACE,, basic principles has initially to be fulfilled waiting to specify more, after the real activation and emergence of this community .

- ⇨ Apart from some typical tools such as threaded discussions and whiteboards for announces, the attention is focused on appropriate *open and interoperable repositories*, provided not only for storing and accessing intermediary or final products but also to store histories and analysis elements, as well as other additional external materials in various common formats. The whole approach tries to support sustainability and reusability of the work done.
- ⇨ *Awareness of new actions and events* from the community, as well as awareness of new materials added or any changes related to the repository must be supported.
- ⇨ *Flexibility of use from different places* at different times must be supported, while group and *community memory* must be assured concerning *the global community level* actions.

DESIGN PRINCIPLES ON SELF-REGULATION AND METACOGNITION SUPPORT

Inquiry learning is labor intensive in any age and class, but especially so in young students and large classrooms. If students do not understand how to do inquiry and if they do not take the time to be more reflective and think about what they are doing and why, then their self-regulation and learning will suffer. We can distinguish two approaches that have been applied to support students in technology learning environments (even if they are interconnections between them): (A) The first approach focuses on scaffolding, providing guidelines, prompts and hints, where students receive helpful guidance. (B) The second approach focuses on metacognition, providing tools that help students reflect on and analyse their own activity, where students need support to keep track of what they have been doing, so as to reflect on it later.

Supportive scaffolding is often provided through messages or indicators in a menu which appears to students when appropriate (active scaffold) or after demand by the student (passive scaffold), guiding them through subtasks of the process, (plan before building, test periodically) or providing examples if needed. The scaffolded activities are aimed at helping them learn about the characteristics of scientific laws and models, the process of modelling and data analysis the nature of scientific argumentation and proof (Kyza *et al.*, 2002). This approach is applied on the systems, ‘Inquiry Island’, White & Frederisken 1999; ‘Theory Builder’ (Soloway, 1999) as well as on SimQuest (van Joolinger & de Jong, in press).

Other researches consider that it is through *Reflective self-assessment* of the inquiry activities that their functional significance becomes apparent to the students (Schon 1983). Metacognition has to do with awareness and explication, with judgment of one’s own mental activity, as well as with decision making regarding continuation and self regulation (Noel, 1997). In order to promote the development of meta-conceptual awareness and help them in the exploration process, we could invite them in a systematic way to express clearly their initial predictions, their observations during ‘running’ and their explanations for each experiment. This could be done, by inciting children to express themselves in an electronic notebook (‘CoVis’, PEA, 1998; Dimitracopoulou et all, 1999). The advantage of an electronic notebook is that it gives the sense of a unified and indispensable process between the operation of modelling and investigation with the operation to take notes on these actions, assumptions, interpretations and changes. However, given the difficulty of a metacognitive analysis conducted by the students, we consider that in order to really support the process of returning to memory, and analysing one's own activity, specific tools of presentation or even better analysis of history of their process must be available to students.

⇨In order to promote *metaconceptual awareness*, we need to provide students with multiple and flexible tools, so as to facilitate the written expression of their thoughts during the different instances of a modelling process, and to give them the possibility to return and think upon their thoughts and the evolution of their ideas. These tools could be: *Sticky notes*, a free form to note down something (a short paragraph) in the working area, in order to specify or remind oneself of something; *Structured notebook*, that could invite students to note their thoughts during each initial analysis, expectation, or observation, and the *Final Report*, that concerns the whole modelling process, with arguments and data that will accompany the final model.

⇨In order to promote *metacognitive mental* activities we need to support students to return and reflect on their own process and evolution *providing a support to their group memory*. In other words there is need for appropriate tools that offer traces of the group's previous activity.

⇨In order to support *reflective inquiry by scaffolding,* it is important to create and customize templates that address the specific goals and sub-goals during a modelling process. The final report as well as the notebook could provide to students appropriate *prompts* (depending on their age and the task category) that may scaffold their activity. The scaffolds will be explicitly conceived to guide students to acquire general inquiry skills.

An additional question is how to support students when working in a inquiry modeling process and selfregulation in a collaborative mode?. Actually, some systems have been developed that incorporate tools that reflect interactions, collecting raw data in log files and displaying it to the collaborators. The hypothesis is that visualization structures of students' discussion and actions with the aid of a suitable representation can assist students' awareness of other's actions and opinions (Jermann 2001; Zumbach et al. 2002). But a main difference rests on the fact that the researches have tested these approaches with low-level conceptualization problems. The above methods eventually have a low potential to contribute to students awareness, metacognition and self-regulation of their activity, when working on rich conceptual domains. In every case, specification of different indicators for various collaborative settings and different ages is needed. The question must be further investigated after the first experimentations with students, in order to propose tools that are significant for the task and do not add an additional high cognitive demanding task.

DESIGN PRINCIPLES CONCERNING TEACHERS'SUPPORT

What is the role of the teacher during collaborative learning? What kind of collaborative problem solving activity analysis tools do we need, in order to support teachers?

Little research has yet been carried out on the possibility that teachers could have a significant role during synchronous collaborative problem solving through network, in class conditions and that they can derive useful knowledge from observing or participating with their students in CSCL environments (Lund and Baker, 1999).

A preliminary study aiming to explore the teachers' needs during tutoring or coaching of collaborating students, in class (Petrou & Dimitracopoulou, submitted) revealed that the most important requirements, of teachers were: (a) a way to supervise multiple groups of students that collaborate in a synchronous mode; (b) an appropriate and easier mode to take profit from the detailed logfiles of students' interactions, so as to be possible a diagnosis of group and individual difficulties; (c) if possible, an elaborated mode of analysis in order to examine in a very short time the whole history of interaction.

It appears that the most difficult requirement to accomplish is the third one. In order to develop effective analysis frameworks and tools for collaborative problem solving analysis, we need to investigate some key questions: How to coordinate the analysis of actions and dialogues? What are the most significant data to be logged and coded? How to inter-relate collaboration features with problem solving content and process? How to provide a rich variety of analysis output, to assist facilitators or experienced learners?

In order to answer these questions, a framework of analysis was developed that could support the development of appropriate analysis tools for students' interactions. The 'Object-oriented Collaboration Analysis Framework' (OCAF), identifies patterns of interaction and relates them to objects of the shared solution Avouris *et al.* (2002) Dimitracopoulou *et al.*, (2002). The corresponding model provides a new way of representing collaborative problem solving activity, taking into account both actions and dialogues of partners (in case of use of structured chat) and supporting qualitative and quantitative representations that can be used as meta-analysis and evaluation tools.

Consequently, the main design principles concerning teachers' support are the following :

- ⇨ Difficulties in applying collaborative learning environments in real school conditions are due in a great degree to the lack of *appropriate tools supporting teachers*. In parallel, when a learning environment is addressed in a wide range of students, it is crucial to be *adaptable by teachers*, leading to the requirement to design a system *open* (in new modelling primitives such as entities), *flexible and optional* (activated or deactivated functions).
- ⇨ It is considered as a minimum requirement to provide *tools* that allow *supervision* of students' screens. Important for teachers that want to diagnose students' process and their conceptual or strategic difficulties, are tools that based on the *logfiles* make them more easy *readable*, providing additionally link between the dialogues history and the state of the common workspace, *reconstructing the state of the shared working space*, in a chronological order.
- ⇨ Significant support should be provided by an *automated analysis of students' interaction*, presented in a diagrammatic form based on an object oriented collaborative problem solving analysis framework. This analysis, being more detailed and essential when a student uses the structured dialogue interface, is based on a unified analysis of actions and dialogues.

DISCUSSION

The environment is based in a "Grounded Design" process" of development (Hannafin, Land & Oliver 1999), working on a systematic implementation of processes and procedures that are rooted in established theory and research in human learning.

Thus, the design, assumptions, processes and methods have to be continuously informed, tested, validated or contradicted through successive experimentations in laboratory and in the real school contexts, in the various possible cultural contexts in a number of European countries, and with different scenarios in use. A part from a number of experimentations that have already been conducted concerning the effect of expression with the modelling primitives, or aspects of synchronous collaboration, other aspects have to be investigated, such as: analysis of interactions students-teachers with tools of supervision and meta-analysis for the teacher, systematic analysis of students actions and discourse during various modes of collaborative problem solving. In parallel, the actual implementation of a prototype in real school context, allows as to study the learning effects related to the scientific concepts implicated and of the modelling process itself in a variety of learning activities.

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