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Design principles for the support of modelling and collaboration in a technology-based learning environment

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Abstract: The aim of the paper is to present and discuss the main design concepts and principles, for a collaborative modelling environment for sciences addressed to young students 11–16 years old. The main issues under discussion concern central design questions such as: what must the main modelling primitives be when addressing young students, belonging to a wide range of cognitive possibilities? In what specific ways can we support students' reasoning offering multiple representations? How can we ensure flexible collaboration and how can we support related needs in a community level? Furthermore, how can we support self-regulation and metacognitive development for students and how can we support teachers when working in typical school conditions? This paper, which focuses on the design principles, briefly presents the derived developed tools and functionalities of a collaborative modelling environment (MODELLINGSPACE), while citing the main research results found during the design-development process.

Keywords: modelling environment; collaborative learning; sciences; secondary education; teachers' support; students' support; school context.

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1 Introduction

Over the past ten years, there has been an increased interest in computer-based learning environments for modelling 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; Joolingen et al., 1997; Penner, 2001). Although most of the modelling environments usually offer only one representational formalism for modelling or are not particularly appropriate for young students, there is, at 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 et al., 1994; Baker et al., 1999; Dillenbourg, 1999; Lipponen, et al., 2001).

Thus, a recent concept is to empower a modelling environment that supports students' reasoning, with the learning possibilities of synchronous and asynchronous collaboration. It appears that modelling environments are not only of interest for face-to-face interaction in classrooms, but also for the expansion of learning opportunities. There, we could allow 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 another country.

Based on this concept, a collaborative modelling environment called MODELLINGSPACE was developed, essentially aimed at supporting all learning process participants: students as well as teachers. In a genuine educational context, students and teachers must be supported during activities that incite model situations studied as part of the national curricula in Mathematics, Physics, Chemistry, Biology, Environmental Education, etc. as well as other interdisciplinary areas (Joolingen et al., 1997; Baker, et al., 1999).

In order to design such a system, issues that interest researchers in both the fields of modelling environments and collaborative learning environments are discussed:

- What are the appropriate basic modelling primitives (implicated basic entities, variables and modelling formalisms) for young students and how can we support the students' evolution?
- What should the appropriate visualisation modes and representations be? What kind of simulations should be adopted, how can we 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?
- How can we facilitate more global exchanges (e.g. exchanges of models, problems, modelling reports) and interactions in the context of the learning community that may emerge?
- How can we support students to self-regulate their activity and activate metacognitive reasoning, during both face-to-face modelling and collaborative modelling through a technological environment?
- How can we support teachers in analysing students' interactions and collaboration features? How can we ensure the adaptability of the learning environment to their students' needs and context conditions?

The paper focuses on the rationale underlying the central design options that are grounded on issues related mainly to physics and mathematics education as well as cognitive psychology. It discusses the main design principles related to some complementary and crucial aspects concerning modelling, collaborative modelling as well as students' and teachers' support. Finally, it briefly presents the main research activities that accompany the design and the development process.

2 Design principles concerning modelling

The main design principles concerning modelling influence the primitives for models' creation and testing, such as the variables, the relations, or the representation modes. The general structure of next sessions is as follows: the background knowledge from research issues in science education, cognitive psychology and previous technology-based environments, which are related, are discussed. These issues lead us to formulate design principles. Regarding these principles, the corresponding main features of the environment MODELLINGSPACE are presented.

2.1 Scientific concepts and variables vs. properties of real objects

How do we 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 constrained by their choice of theory 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 especially 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 et al., 1981; Mellar et al., 1994). Young students' thinking is 'concrete object oriented' and not 'concept oriented'.

Most modelling or simulation systems directly impose 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 (neither less nor more). This situation restricts, in an artificial way, students' reasoning, or even guides it, imposing them to use expressive means that do not correspond to students' cognitive possibilities. The above considerations lead us to formulate the first central design principle:

> *'Wide range of variables as modelling primitives' design principle* (M1a). 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 eventual 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 for them to express their ideas.

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

- 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 when having a visual consequence (see Figure 1(a), first column).

Figure 1(a) General entities' categories

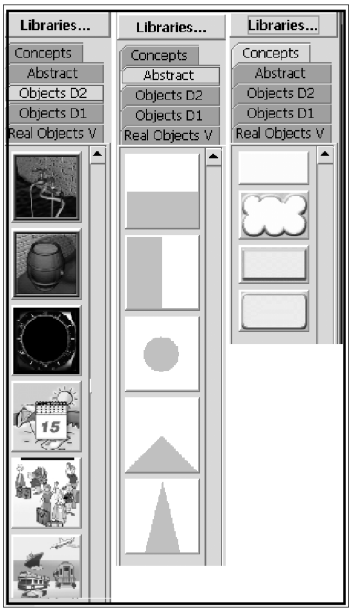
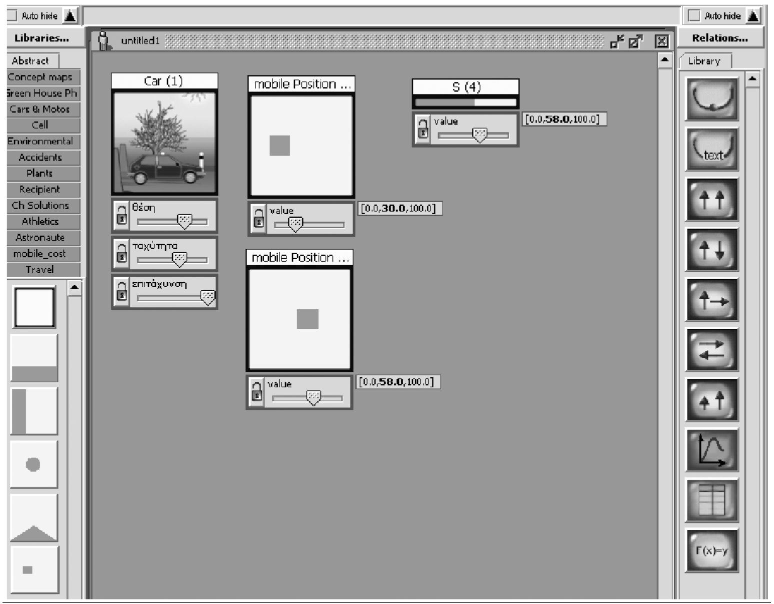


Figure 1(b) Three possible expressions of the same variable



- A more abstract entity could be considered as a ‘construct’, depicting an object from a group of uniform objects (real or imaginary), 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 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 (see Figure 1(a) second column).
- A third category is the abstract entities that directly correspond to abstract *scientific variables* in symbolic form, and that do not have any singular 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 position (expressed with its literal name or symbol *S*). Finally, a user could represent a concept with one of the three available modes, as it is seen in Figure 1(b), that present as an example the possible representations of the concept ‘position of a mobile object’.

Apart from the considerations of the entities, the status of the implicated symbols remains to be examined. 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, it cannot be expected to represent to them the socially accepted meanings as scientists defined them decades or centuries ago.

Thus, in order to conceive environments that really permit students to *express their ideas*, we need a second related design principle:

> *'Flexible naming of modelling primitives' design principle* (M1b). A learning environment 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.

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.

2.2 What relations?

In order to apply appropriate modelling to different problem categories and scientific fields, different modelling formalisms have been developed (Mellar et al., 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, which of these appear the most appropriate to be used

- by young students
- for the modelling of a wide range of phenomena and problems
- in different subject matters of the school curricula?

There are two basic principles, derived from science education, that guide our choice:

> *'Appropriate relations as modelling primitives' design principle* (M2a). For a technological environment to be thoroughly appropriate for young students, it is important to support gradually 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 all, the environment focuses *on allowing and supporting qualitative and semi-quantitative reasoning*, which is closer to the existing cognitive resources of young students (Mellar et al., 1994), compared to quantitative ones. Semi-quantitative thinking is ubiquitous in natural everyday reasoning (Bliss et al., 1992). It recognises the ordering of quantity but not magnitude, and it is one of the three main ways in which pupils approach relations. It offers an intermediary cognitive tool for the children, helping them to have progressive access to the quantitative reasoning.

It is to be noted that to examine 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, 1994) dealing with ecosystems, as well the system SimQuest (Joolingen, 1997) and its successor co-lab (2003). Systems that impose algebraic reasoning are among others: STELLA (Doerr, 1996) and MODELLUS (Teodoro, 1997). The modelling system INSPIRATION (2003) permits the creation of concept maps.

All the above-mentioned systems, possibly with 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 their application to various subject matters, it is essential to support a range of reasoning modes that may be used flexibly by pupils, depending on their cognitive ability and the situations to be modelled.

Consequently, we can formulate the following principle:

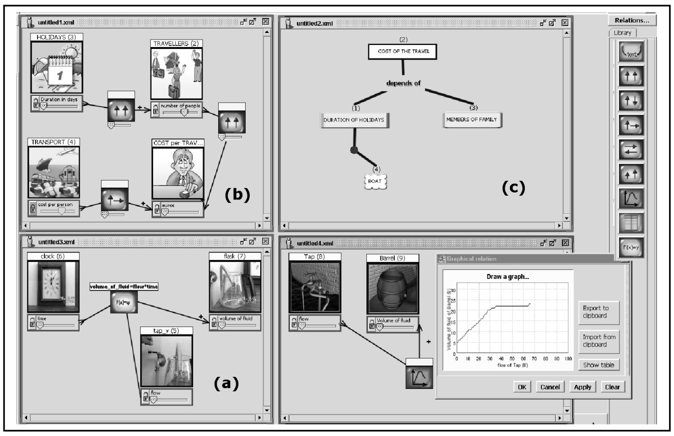
> *'Rich range of relations as modelling primitives' design principle* (M2b). The learning environment should incorporate a simplified as well as a combined form of different independent modelling system categories: *dynamic quantitative* (algebraic) modelling systems; *semi-quantitative* modelling systems; *qualitative modelling;* so that it may allow 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 within the frame of their existing school curricula:

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 dependent variables (see Figure 2(a)).

Semi-quantitative modelling formalisms. Semi-quantitative models (see Figure 2(b)) 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, such as "*when the one 'variable' increases the other increases too, or decreases or remain constant, etc*". In MODELLINGSPACE, five different semi-quantitative relations are specified, that are 'represented' by an arrow-based symbolism (see at the right of Figure 2). Each semi-quantitative relation corresponds to a specific algebraic relation, according to which the model calculates the values of the dependent variable ($y \sim ax$, $y \sim a/x$, $y \sim a$, $y \sim -ax$, $y \sim ax^2$).

Figure 2 Modelling formalisms



Semantic qualitative modelling formalisms constituting concept maps. They form static, non-executable models, like concept maps (See Figure 2(c)). 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, within mechanics (Dimitracopoulou and Dumas-Carré, 1996; Lemeignan, and Weil-Barais, 1997)).

Apart from these three modelling formalisms, the environment provides an important additional possibility to express a relation between two variables: by '*drawing the covariation 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). The ModellingSpace system can simulate entities behaviour, based on this diagrammatic representation.

It should be mentioned that two main ways were predicted for the students' transitions among the main formalisms and corresponding models:

- *A transitional mode, from one modelling formalism to the other.* Initially, young students reason on the basis of semi-quantitative relations, and then, when and if it is possible to them, they are incited to create quantitative relations: In this case, the relations, the models, and the representations of semi-quantitative models are usually used as reference models in order to compare the appropriateness of the new under-construction quantitative one.
- *A complementary mode among representations.* Initially a qualitative model may be created in order to analyse the problem, then a semi-quantitative one in order to explore some particular aspects of the phenomenon, and finally a new qualitative model or the improvement of the previous one, conclude the study of a phenomenon.

2.3 Which visualisation?

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

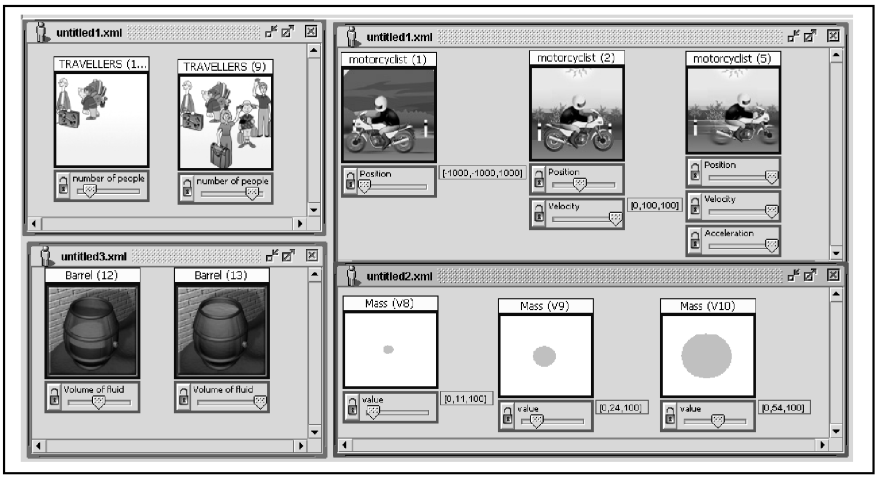
The simulations produced by most of the existing modelling and simulation systems use merely abstract representations, for instance, an object in motion is usually represented by a small circle, or a small rectangle. For young students who do not have the required conceptualisation, it is important to assure the possibility to test and validate models through simulations that represent the phenomenon itself in an obvious visual way.

The learning potential of 'visualisations' has been the object of researches during the last few years, researches that were accentuated also by the possibilities offered by 2D or 3D dynamic graphics as well as virtual reality technology (Lowe, 1999; Narayanan and Hegarty, 2000; Hedberg et al., 2002). While the initial discussion of researchers was focused on the importance of visualisations, it was then moved to the essentials of realistic visualisations, and finally only recently was the accent put on the appropriateness of these visualisations (Lowe, 2003). In particular, researchers acknowledge that current development practices typically reflect a simplistic approach to the design of animations that has not progressed beyond the goal of providing dynamic realism. Questions concern whether the most important aspect about realistic representations concerns the appearance or the behaviour; the full realistic visualisations (photo or video-based) are really better for learning purposes than the dynamic animations, especially for complex phenomena and students, etc.

For the design of a modelling environment that is addressed to young students, we formulate the following general principle related to visualisation:

> *'Visualisation' design principle* [M3]. The expression of all the modelling primitives that support reasoning (i.e. the entities as well as their properties or variables and the relations that govern them or impinge upon them) through the *greatest and most appropriate visualisation* must be supported.

Figure 3 Instances of simulations of various variables



Thus, MODELLINGSPACE visualises the entities as real objects where the variation of properties changes the appearance of the object, based on two kinds of images:

- drawn images
- video-taped images.

In the case of drawn images, specific codifications are explored and adopted, in order to visualise 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 a big or even huge number of 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 and Dimitracopoulou, 2004), promoting the distinction of the nature and status of these variables as well as their conceptualisation as vectorial quantities.

From the above, one can conclude that MODELLINGSPACE does not offer a full realistic visualisation. The kind of visualisation to be adopted, depends on the kind and status of the main object-oriented entity and of each variable (abstract variable with no phenomenological correspondence or concrete one, variable that changes at a macrolevel or a microlevel, etc.), as well as on the nature of the values of the variable (integers, ratio, boolean, ordered set, etc).

2.4 Which data representations?

During the last decade, many researchers have argued that multiple representations may have important benefits to the learning process. Given the appropriate and multiple representations, cognitive assistance for reasoning and consequently for learning (Ainsworth, 1999) is provided. The students' ability to conceive and use models depends on the representational tools, which are disposable to them. Multiple representations may serve at least two main aims:

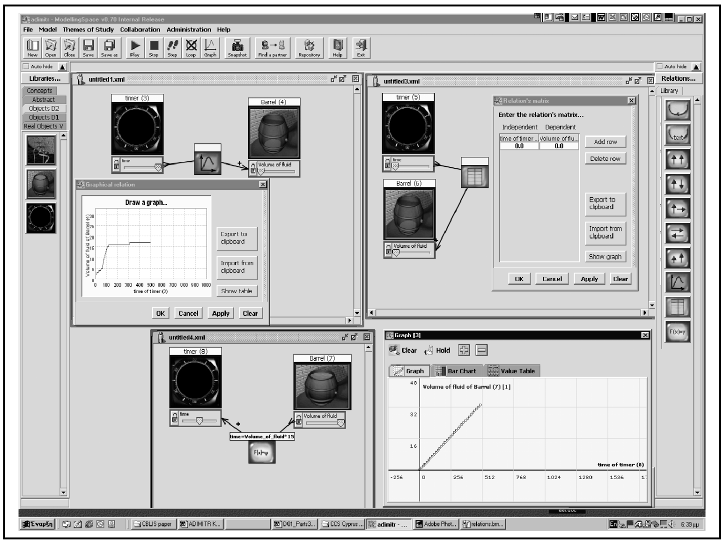
- each student can be adequately conveyed by a specific representation when the 'information' to be learned has multiple characteristics
- constraining interpretation that can be made of other representations and the domain to be learnt, supporting students on a better understanding of the domain (van Someren, 1998).

Additionally, it is also important to support students to *develop cognitive flexibility* in their use (van Someren, 1998). Consequently, concerning the representations of data produced by models, the following design principle can be formulated:

> '*Multiple data representations' design principle* (M4a). The incorporation of alternative and multiple forms of representations of the different kind of data produced by models is necessary.
>
> '*Transitions and links among data representations and models' design principle* (M4b). Offering multiple representations is not sufficient, it is also important to support students to *develop cognitive flexibility* in their use.

In MODELLINGSPACE, when the model is running, students during the simulation can see only the current value of the variables compared 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 for exploring or expressing relations, especially if they have to study the covariation of variables, but have not acquired experience in using and creating typical graphs (*x* → *y*).

Figure 4 The models' design area of MODELLINGSPACE including some representation modes



Given the above, the question that remains is: How do we 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 a model, or one after the other, so as to avoid cognitive load (Gruber et al., 1995). Another substantially important requirement that examines the representations in conjunction with the relations among the variables that students have indicated is to give students the possibility to start from the representations themselves and then explore the phenomenon, think and indicate an exact algebraic or semi-quantitative relation. For this purpose, two functions are supported by MODELLINGSPACE:

- *Draw and indicate graphs*, as a designation mode of the covariation 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 covariation.
- *Insert values of variables in an open table of values.* The 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 to the real experiments (that could be conducted in class, or are reported in their textbook).

A final point concerns when an environment must present the data from the execution of a model. When a scientist or the students in the science laboratory have to do an experiment, they have to prepare the necessary instruments in order to take measures, and then to use them to create the corresponding representation. In the simulation systems, scientists know how the numerical data are produced during simulation and how graphs are created. But children without sufficient experience of real experiments, can create a false mental representation of what happens, considering that these kind of data collections and data representations are given by automatically; subsequently producing inappropriate, unintentional phenomena of 'computational transposition' (Balacheff, 1994).

> *Users' conscious activation of data representations' design principle* (M4c). The environment must provide measures and data representations only on demand, after conscious actions of students and not in an automated way, so as to avoid creation of new misconceptions by the students.

In MODELLINGSPACE, the representations of data created by the internal system during each model execution are not presented to the user, other than being indicated by them before the execution of their model.

3 Design principles concerning collaboration

3.1 Principles related to collaboration support

In cases of problem solving in rich and critical conceptual domains, it appears that collaboration by distance through networks could be significantly effective: For purposes of communication aiming at conceptual change, written communication, combined with face-to-face communication, seems to be more effective than face to face alone because it requires a more extensive thinking process (Cohen, 1994). The need to externalise one's own thoughts, in a written way, could have significant effects, especially when the learning activity implicates rich conceptual knowledge that is under development (Baker et al., 1999).

Various systems have developed allowing synchronous collaborative problem solving (such as: 'C-CHENE'; (Baker et al., 1999; Dimitracopoulou, 1999); 'COLER', (Constantino-Gonzalez and Suthers, 2001); or the recently developed 'colab' (SimQuest and CoLab, 2003)). In all the systems, the significant aspects for supporting collaboration and collaborative learning 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:

> *Collaborative modelling for a wide range of contexts' design principle* (C1). It is essential to take advantage of 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.

This principle is important for a learning environment that is intended to be integrated in real school contexts; thus demanding a flexibility necessary for a wide range of scenarios of use. The principle has consequences firstly on scenarios of use and collaborative settings and activities predicted by designers, and then on available tools allowing different collaboration modes. Concerning the latter, the system must support

- not only synchronous collaboration, but also asynchronous one (e.g. allowing to send/exchange models that can be completed or pursued by another student, without losing his/her modelling process history)
- collaborative modelling, but also cooperative modelling (e.g. groups of students creating well-distinguished parts of concept maps)
- allowing to work in global networks via a central server but also in local networks via a local one.

> *Multiple dialogue modes for synchronous collaboration' design principle* (C2). Multiple and flexible dialogue modes during interaction are of great importance in collaborative modelling in rich conceptual domains.

In MODELLINGSPACE when students work in a synchronous collaborative mode, they work in a modelling creation shared space, while they can communicate by written dialogue modes. Two main *dialogue modes* are available during synchronous collaborative activity, in MODELLINGSPACE: a free chat dialogue, and a structured one, the latter using a structured chat interface, based on sentence openers. A third mode is supported by an annotation tool: the sticky notes (flexible resizable post-it notes), that can be posted in the models-design area. During asynchronous interaction, the tools for text annotation can be used, enriched with 'keep track' functions of each participant contributions.

> *'Coordination and awareness of synchronous collaborative actions' design principle* (C3). Special attention must be given to provide appropriate means during synchronous interaction, in order to *coordinate action* in a flexible way and a learning-significant way. The need or not for the collaborators to explicitly coordinate their actions, is directly related to the means that are offered to support the awareness of other collaborative partners' activity.

Users can choose to work under a specific synchronous collaboration protocol, coordinating their actions via an 'action-key exchange' metaphor, or in free mode (without a coordination protocol). In addition, the environment supports *the Awareness of others' activity*, providing information related to other collaborators' actions (e.g. that the partner is in the process of writing a message, or in the process of moving an object), and/or indicating the *ownership* of each contribution (by the name of the partner or a coded colour indication). We consider that when *actions' awareness*, and *ownership indication* are supported in a sufficient manner, there will be less need for an explicit and strict coordination protocol.

3.2 Principles related to the learning community support

What is needed in order to facilitate the more global exchanges and interactions in the frame of a technology-based learning community that could emerge? There are specific systems based on the idea of knowledge building; one of the most characteristic of them is 'knowledge forum' (Scardamalia and Bereiter, 1994). Until the present, collaborative problem solving or modelling environments (Baker 1999; SimQuest and CoLab, 2003; Constantino-Gonzalez and Suthers, 2001) supporting mainly a small group of students working synchronously, did not have any of the functionalities offered by wide-community knowledge building systems. On the contrary, we consider that collaborative modelling environments must incorporate some main tools and functions able to support actions and exchanges of an important number of students and schools that may create a wide community of learners. The implications of previous principles in this case are mainly the following:

- At the level of a wide community, in order to fulfil the principle related to collaboration in a wide range of contexts (C1), it is necessary to assure the *flexibility of use from different places* at different times; that refers mainly to asynchronous collaborative interactions and exchanges.

  For this purpose, apart from some typical tools such as threaded discussions and whiteboards for announcements, attention must be focused on appropriate *open and interoperable repositories*, provided for storing and accessing a variety of materials (e.g. primary entities, models, problems, reports on modelling process, etc.), in order to support sustainability and reusability of the work done, and assure group and *community memory*.
- *In correspondence with the actions' awareness principle* (C3) for synchronous collaboration, in the case of mainly asynchronous interactions in a community, it is also needed to support *Awareness of new actions and events* in the frame of a wide community (*social awareness of actions*), as well as awareness of new materials added or any changes related to the repository.

  Specifically, in MODELLINGSPACE, community level services support the exchanges and the actions of a wide community of learners around common activities. We can distinguish
  - the website general level information and tools
  - the collaboration groups' management tool (permanent or temporary groups, small or larger groups)
  - the session management tool
  - the repository of various materials, etc.

4 Design principles on reflective scaffolding and metacognition support

Modelling process is labour intensive at any age and school class conditions, but especially so in young students and large classrooms. If students do not understand how to process and if they do not take the time to be more reflective and think about what they are doing and why, then learning will suffer. We can distinguish two approaches that have been applied to support students during modelling or inquiry in general:

- The first approach focuses on scaffolding, providing guidelines, prompts and hints, where students receive helpful guidance. *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 in the systems, 'inquiry island', (White et al., 1999); 'theory builder' (Soloway, 1994) as well as on SimQuest (Joolingen, 1997).
- The second approach *focuses on metacognition*, keeping track of what students have been doing, providing tools that help students reflect on and analyse their own activity. It is considered that through *reflective self-assessment* of the modelling activities that their functional significance becomes apparent to the students. Metacognition has to do with awareness and explanation, with judgement of one's own mental activity, as well as with decision making regarding continuation and self-regulation (Noel, 1997). The implicated self-regulated skills such as setting goals, planning, monitoring and evaluating one's performance are critical in modelling process (Boekaerts and Pintrich, 1999). In order to promote metacognitive activity, at the first level, we could invite them in a systematic way to clearly express their thoughts during each 'phase' of modelling process. This could be done, by inciting children to express themselves in an electronic notebook (Pea et al., 1994; Dimitracopoulou, 1999).

In MODELLINGSPACE, we have tried to apply a combined approach, according to the following general principle:

> *'Scaffolding and metacognition support' design principle* (S). Given that modelling process as well as collaborative modelling process is a cognitive demanding activity, at any age and for any subject matter, it is necessary to help students with both supportive scaffolding and any kind of tools that promote metacognitive mental activities.

More concretely, this principle is further specified as follows:

> *'Promoting metaconceptual awareness' design principle* (Sa). 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.

Such tools can be

- *structured notebook*, that invite students to note their thoughts during each initial analysis, expectation, or observation
- a *final report*, that concerns the whole modelling process, with arguments and data that may accompany the final validated model, as well as arguments that reject intermediary tested models.

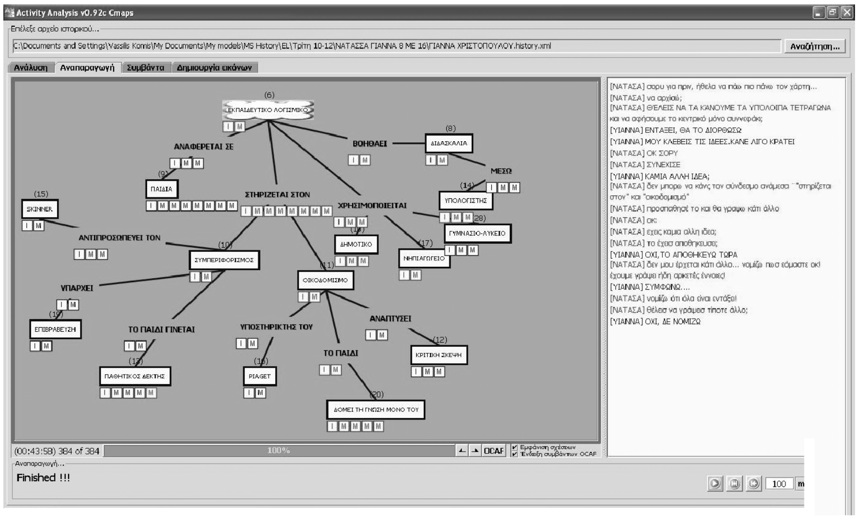
These kinds of tools can be well linked to the learning environment or independent to it (an appropriate template of word processor).

> ‘*Promoting reflective modelling by scaffolding’ design principle* (Sb). In order to support *reflective modelling by scaffolding,* it is important to create and customise templates that address the specific goals and sub-goals during a modelling process.

The final report as well as the notebook provides to students appropriate *prompts* (depending on their age and the task category) that may scaffold their activity. The scaffolds are explicitly conceived to guide students to acquire general modelling and inquiry skills.

> *‘Promoting metacognitive activity’ design principle* (Sc). In order to promote *metacognitive mental* activities, we need to support students to return and reflect on their own process and evolution, *offering tools to retain their individual and/or group memory*.

Figure 5 Students’ activity analysis tool in MODELLINGSPACE (snapshot from playback tool)



C:\Documents and Settings\Vassilis Komis\My Documents\My models\MS History\EL\Τρίτη 10-12\ΝΑΤΑΣΣΑ ΓΙΑΝΝΑ 8 ΜΕ 16\ΓΙΑΝΝΑ ΧΡΙΣΤΟΠΟΥΛΟΥ.history.xml

[ΝΑΤΑΣΑ] σορυ για πριν, ήθελα να πάω πιο πάνω τον χάρτη...
[ΝΑΤΑΣΑ] να αρχίσω;
[ΝΑΤΑΣΑ] ΘΈΛΕΙΣ ΝΑ ΤΑ ΚΆΝΟΥΜΕ ΤΑ ΥΠΌΛΟΙΠΑ ΤΕΤΡΑΓΩΝΑ και να αφήσουμε το κεντρικό μόνο συννεφάκι;
[ΥΙΑΝΝΑ] ΕΝΤΑΞΕΙ, ΘΑ ΤΟ ΔΙΟΡΘΩΣΩ
[ΥΙΑΝΝΑ] ΜΟΥ ΚΛΕΒΕΙΣ ΤΙΣ ΙΔΕΕΣ.ΚΑΝΕ ΛΙΓΟ ΚΡΑΤΕΙ
[ΝΑΤΑΣΑ] ΟΚ ΣΟΡΥ
[ΝΑΤΑΣΑ] ΣΥΝΕΧΙΣΕ
[ΥΙΑΝΝΑ] ΚΑΜΙΑ ΑΛΛΗ ΙΔΕΑ;
[ΝΑΤΑΣΑ] δεν μπορω να κάνς τον σύνδεσμο ανάμεσα ¨"στηρίζεται στον" και "οικοδομισμό"
[ΝΑΤΑΣΑ] προσπαθησέ το και θα γραψω κάτι άλλο
[ΝΑΤΑΣΑ] οκ:
[ΝΑΤΑΣΑ] εχεις καμια αλλη ιδεα;
[ΝΑΤΑΣΑ] το έχεισ αποθηκευσει;
[ΥΙΑΝΝΑ] ΟΧΙ,ΤΟ ΑΠΟΘΗΚΕΥΩ ΤΩΡΑ
[ΝΑΤΑΣΑ] δεν μου έρχεται κάτι άλλο... νομίζω πωσ είμαστε οκ! έχουμε γράψει ήδη αρκετές έννοιες!
[ΥΙΑΝΝΑ] ΣΥΜΦΩΝΩ....
[ΝΑΤΑΣΑ] νομίζω ότι όλα είναι εντάξει!
[ΝΑΤΑΣΑ] θέλεισ να γράψεισ τίποτε άλλο;
[ΥΙΑΝΝΑ] ΟΧΙ, ΔΕ ΝΟΜΙΖΩ

(00:43:58) 384 of 384

Finished !!!

In other words, there is need for appropriate tools that offer traces of the group’s previous activity. MODELLINGSPACE incorporates a ‘playback tool’ presenting all successive changes of workspace, in a video-taped like version (with pause and rewind functions) accompanied by codifications of partners ownership of actions (e.g. insert, delete or modify an entity, per partner), and dialogues’ extracts seem to contribute in this direction. Figure 5 shows a snapshot of the playback tool, while it was activated after a session of a synchronous collaborative creation of a concept map among two students, one of them is represented in red, while the other in blue (e.g. see chat messages in red and blue). Under each item of the concept map, the codifications of each partner ownership of actions (e.g. item inserted, modified, etc.) are presented using the respective colour coding.

5 Design principles concerning teachers' support

What is the role of the teacher during collaborative learning? What kind of analysis tools of collaborative problem solving activities or even more collaborative modelling activities 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 classroom conditions and that they can derive useful knowledge from observing or participating with their students in CSCL environments (Lund and Baker, 1999). Furthermore, there is a lack of research on teachers' needs in order to supervise or support collaborative modelling.

A preliminary study aimed at exploring teachers' needs during tutoring or coaching collaborating students, in classroom (Petrou and Dimitracopoulou, 2003) revealed that the most important requirements of teachers were:

- a way to supervise multiple groups of students that collaborate in a synchronous mode
- an appropriate and easier mode to profit from the detailed logfiles of students' interactions, so as to make possible a diagnosis of group and individual difficulties
- if possible, to provide an elaborate mode of analysis in order to examine the whole history of interaction in the shortest possible time.

We consider that teachers could be more amenable in applying modelling environments and collaborative learning environments in their everyday real school conditions, if there were not such a lack of *appropriate tools supporting their own role.*

Subsequently, the central design principle concerning teachers' support is the following:

> '*Teachers' support during modelling and collaborative modelling' design principle* (T). Teachers, especially in real everyday class contexts, need flexible environments and some valuable and structured information on what happens during students' interactions, that could allow them to have more appropriate synchronous or post-interventions, related to the learning process, the quality of the activity outcome and/or the quality of the collaboration itself.

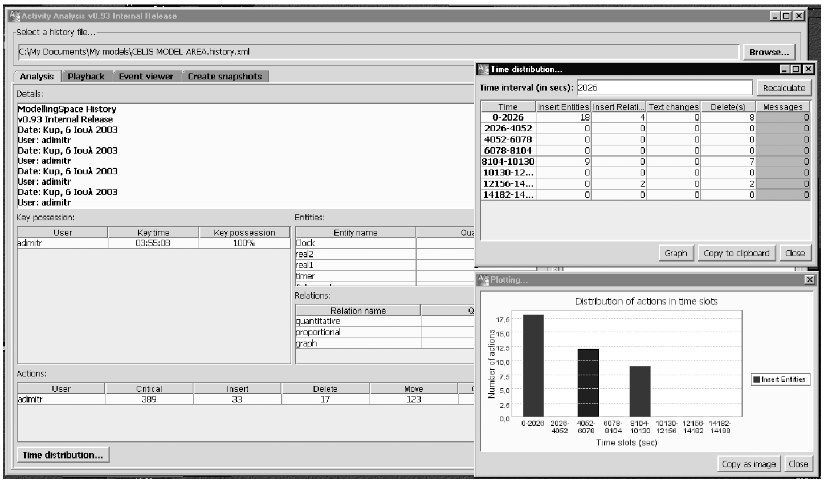
This general principle, leads to a number of more specific sub-principles, and subsequently to a number of environment specifications:

- When a learning environment is addressed to a wide range of students, it is crucial that it is adaptable for teachers (Ta).
  This leads to the requirement of designing a system open (e.g. in new modelling primitives such as entities), flexible and optional (e.g. with activated or deactivated functions).
- It is necessary to provide *tools* that allow *supervision* of students' screens (Tb).
  A system must allow simultaneous supervision of a number of student groups (that share a common working space with the teacher).
- It is important for teachers who want to diagnose students' process and their conceptual or strategic difficulties, to have at their disposal *students' interactions analysis tools* (Tc).

These tools can

- provide an *automated analysis of students' interaction*, presented in appropriate forms
- *reconstruct the state of the shared working space*, during the whole collaborative process, in chronological order.

Figure 6 Students' activity analysis environment for teachers' in MODELLINGSPACE (snapshot from statistics' window)



C:\My Documents\My models\CBLIS MODEL AREA.history.xml

ModellingSpace History
v0.93 Internal Release
Date: Kup, 6 Iouλ 2003
User: adimitr
Date: Kup, 6 Iouλ 2003
User: adimitr
Date: Kup, 6 Iouλ 2003
User: adimitr
Date: Kup, 6 Iouλ 2003
User: adimitr

User	Key time	Key possession
adimitr	03:55:08	100%

Entity name	Qua
Clock	
real2	
real1	
timer	

Relation name	Q
quantitative	
proportional	
graph	

User	Critical	Insert	Delete	Move
adimitr	389	33	17	123

Time interval (in secs): 2026

Time	Insert Entities	Insert Relati...	Text changes	Delete(s)	Messages
0-2026	18	4	0	8	0
2026-4052	0	0	0	0	0
4052-6078	0	0	0	0	0
6078-8104	0	0	0	0	0
8104-10130	9	0	0	7	0
10130-12...	0	0	0	0	0
12156-14...	0	2	0	2	0
14182-14...	0	0	0	0	0

MODELLINGSPACE, in order to support teachers in their effort to analyse students' actions and interactions, uses an interaction analysis tool, which produces

- the list of significant actions of one or another user (how many significant actions, and of what kind)
- some statistics (e.g. related to action key possession per partner)
- graphs of variables (e.g. distribution of actions' categories in time slots, or collaborative activity function) (see Figure 6).

Additionally, teachers can benefit from the playback function, which presents the whole collaborative modelling process in a video-like mode. Finally, it has to be noted that a teacher or a researcher can intervene into the analysis process, in order to further analyse, common students' actions and messages applying a specific object-oriented collaborative analysis framework (OCAF) (Avouris et al., 2003; Dimitracopoulou, 2002).

6 Overview of research results during design-development process

The environment is based on a 'grounded design process' of development (Jonassen and Land, 2000), working on a systematic implementation of design-development procedures that are rooted in established theory and research in human learning. Thus, the design principles, processes and methods applied in the case of MODELLINGSPACE had to be continuously informed, tested, validated or modified through successive experimentations:

- cognitive evaluation of the environment with students in a laboratory, conducted by a researcher, without the presence of the ‘natural’ teacher
- in real school contexts, taking into account the various cultural contexts in different European countries, and different scenarios of use.

Actual research has validated, helped refine or even concretised some of the main design principles of MODELLINGSPACE learning environment, and subsequently the corresponding main features of the environment. The presentation of all these studies with the corresponding research questions and results is out of the scope and possibilities of the present paper. Thus, only a brief overview of the main research results that are directly related with the main design principles mentioned into the previous sections will be presented.

6.1 About the design principles concerning modelling

The design principles concerning modelling and in particular those related to modelling primitives [M1a, M1b, M2a, M2b, M3] are of central importance to MODELLINGSPACE main purpose. In particular, principles affecting the range of entities, and also those related to the need of semi-quantitative relations, have been explored through four different researches in laboratory using groups of two students working in front of their PC.

- A study was conducted with students 14–15 years old, doing tasks in physics with reference to kinematics concepts (Orfanos and Dimitracopoulou, 2003). The study involved just two sessions of learning activities and was based on a pre-post test approach, as well as on detailed analysis of students’ face-to-face dialogues. It was shown that ‘object-oriented’ entities (such as those in Figure 3), and their animations seem to play significant roles in learning: in the first place, they help emerge the students’ alternative ideas (e.g. related to position, velocity) and they further contribute to structure the content of vector concepts. This result validates partially the design principle M1a (concerning students’ possibilities of reasoning using these entities), as well as the principle M3 (concerning the visualisation of variables that constitute vectorial concepts).
- Another study took place with ten year old students, doing tasks in mathematics (proportionality). The pupil through the presence of a researcher is brought to handle various entities and variables, which are time-independent (like the budget of the holidays, the number of travellers, etc.) (Weil-Barais and Dimitracopoulou, 2004). The study was focused on the way pupils interpret the modifications of variables (figurative and numerical modifications). It was shown that the entities of this category are correctly interpreted by the pupils. However, the interpretation of simulations by such young students reveals some obstacles, for example, the interpretation of the modifications in terms of sequential or topological relations.

- Two comparative studies also took place. The first one explored the relation between a real practical activity and the interaction with MODELLINGSPACE, while the other compared the learning effects of two modelling environments: MODELLINGSPACE and 'physics by image' an environment that is based on scientific formalisms and abstracts simulations. From the analysis of students' answers to the researcher during the interview, it was shown that the use of the MODELLINGSPACE environment facilitates the comparisons between aspects of reality, their conceptualisation and their symbolic notations. The results obtained consolidate the hypothesis that MODELLINGSPACE constitutes a good tool for helping pupils understand the transformations of the situations into relational terms. The results point out that the use of object-oriented entities with semi-quantitative relations is precursor to quantitative reasoning and modelling (Smyrnaioy and Weil-Barais, 2004; Smyrnaiou, 2003).

  Furthermore, a number of longer-term studies took place. These are respected ecological validity, given that they were conducted in class with normal teachers and all the students of the class. In this context, students worked in pairs side by side in front of their PC station.
- One of the studies in schools, with students of 15 years old, concerned the transition from semi-quantitative models to quantitative ones. This case study showed how students used one of their previously validated semi-quantitative models in order to compare the under-construction quantitative one, as well as identified interesting difficulties that students face during the construction of algebraic relations (e.g. to express a variable with constant value). Additionally, this case study led to the improvement of the expression of quantitative relations/formulas, at the level of human computer interface (Weil-Barais and Dimitracopoulou, 2004).
- Another study, with students 11–12 years old, related to activities in chemistry, have pointed out the rich conceptual gains that students can have when they combine qualitative concept maps, with semi-quantitative models (Weil-Barais and Dimitracopoulou, 2004).

A number of supplementary studies have produced partial results on:

- the effective data representation modes for different age levels of students (e.g. young students prefer bar charts and the study of tables of value, whereas older reason mainly with graphs)
- the features and content of students' worksheets and modelling report (two of the means for applying reflective scaffolding).

It is to be noticed that in all the cases (short or long sessions of learning activities with MODELLINGSPACE), students have shown motivation to work with this environment that appeared attractive to them. In all the experimental sessions, the most perceptible and appreciated gains, according to students and also teachers, were associated with the learning of particular scientific concepts. On the other hand, gains related to the acquisition of modelling skills were explicit and mentioned by students themselves only after long sessions of modelling activities (more than five hours).

6.2 About the design principles concerning collaboration

A number of initial studies have focused on the functions of synchronous collaboration.

- Concerning the *means of dialogue and the management of the shared working space*, an initial study with university students showed that management of the shared working space did not produce difficulties to students, while the dialogue-based interaction was rich enough and sufficient to conclude the modelling activity. The analysis of the content of messages revealed that 68% had to do with the task of modelling, 29% with the control of the shared space, while very few messages (3% and 2%) were characteristic of social interaction out of task, and related to the management of the shared space. (Komis et al., 2002). Subsequent studies in school class contexts (see below) have also confirmed that only a low percentage of dialogue was devoted to discussions related to the environment itself. It appeared that in all the cases, students use the free chat more than the structured one, and only in some cases the sticky notes (Weil-Barais and Dimitracopoulou, 2004). Additionally, the study showed that students might have interesting learning experiences when they dispose of different libraries of entities (Fidas et al., 2005).
- Concerning the *coordination protocol*, in a usability study with 12 groups of University students working on modelling tasks with concept maps, two coordination modes were applied: six groups with a strict coordination protocol (exchange of a 'key of action'), and six groups in a free mode of synchronous collaboration. The models produced by the two groups (A and B) were of similar quality, but the discussions of the group A, due to the roles established by the action control mechanism, were of better quality (more profound expression of arguments and justifications showing elaborate reflective activity) (Komis et al., 2002; Margaritis, 2003). Another study with ten students working during a number of sessions (3–4) revealed that strict coordination protocols were needed only when the students had not had enough collaborating experience with each other. In the cases where they knew each other and/or they had already collaborated once, they clearly prefer a free mode of synchronous collaboration (Weil-Barais and Dimitracopoulou, 2004).
- Concerning *actions awareness*, a case study with students has shown that collaboration seems more effective when the environment offers representations of partners' actions at a distance. For instance, collaboration is more natural when it is indicated that the partner is going to write a message or to move an object. The same study has validated the positive effect of the indication of ownership and allowed us to validate the need for this feature (Margaritis et al., 2003).

Synchronous collaborative modelling activity with MODELLINGSPACE, has also been investigated in real school class context, during short or long collaborative activities. It is to be highlighted that the research was focused on students and teachers working on different computers, with typical modelling activities using MODELLINGSPACE, in one classroom. The interest of teachers and students for this context of synchronous collaborative activities was proven in a previous study (Petrou and Dimitracopoulou, 2003). In a case study, four classes of students with their teachers participated from three public schools, using the same learning activities (duration among five to eight hours). Students' ages varied (15–17 years old). Four teachers participated in the implementation of learning activities. They supervised most groups of students, and also guided one or two of them (Orfanos and Dimitracopoulou, 2003). Analysis of data showed that the percentage of out of task interactions and management of the shared workspace by the students was less than 10%. Furthermore, it was shown that the environment is transparent, allowing the expression of different modes of collaborative patterns or even teachers' guidance patterns. According to the research data, students were highly motivated to use MODELLINGSPACE in collaborative settings, since they were engaged for long time periods in productive modelling. The same case study provided us information on student collaborative patterns, as well as on appropriate teachers' strategies during or after collaborative learning activities (Weil-Barais and Dimitracopoulou, 2004).

Finally, it is to be noted that design principles related to the 'wide community', even if they were basic ones, and they were not yet sufficiently validated due to lack of sufficient activities at this level.

6.3 About the design principles concerning reflective scaffolding and metacognition support

Concerning the effectiveness of reflective scaffolding, the support of metacognitive activity as well as the way that students self-regulate their actions, collected data are actually under analysis. The context of research concerned students' functioning in normal classroom conditions, while the approach applied was the following: reflected scaffolding was provided via flexible activity students' sheets, while the need to use the playback tool was part of the task of preparing a written report at the end of each modelling process.

6.4 About the design principles concerning teachers' support

The investigation of the validity of the corresponding design principle was done during the case study that took place simultaneously in four school classes (mentioned in a previous paragraph), involving synchronous collaboration through the environment among collocated students. The research aimed at investigating the usability and the utility of the available students' interaction and collaboration analysis tools, during synchronous computer mediated collaborative modelling, on-the-fly and afterwards (a posteriori). The main research questions were: what is the information that teachers decode in order to regulate their strategies, or in order to apply new ones? How valuable does each tool appear to schoolteachers? Research results validated the main related design principle T, as well as Ta, Tb, Tc, and also allowed us to specify them better. Collaboration analysis tools for teachers have to be:

- not only easy to use, but
- able to provide them easily decodable and meaningful information
- giving them essential information without using up their time. Teachers need to have an overview at a glance.

Furthermore, well-complementary and combined tools are needed, for use on-the-fly (during collaborative session), as well as for afterwards use (during a debriefing session).

Teachers used the tools in order to diagnose the students' individual or collaborative problem solving. This allowed them to diagnose students' conceptual or strategic difficulties, as well as discrepancies of collaboration. Additionally, they have used them in order to observe and become aware of their guidance strategies (Weil-Barais and Dimitracopoulou, 2004; Fessakis et al., 2004).

Additional research is currently being carried out focusing on the aspects of collaboration by young students of primary school, teachers' strategies during collaboration and available tools used to their advantage (according to different collaboration modes and settings), as well as for young students' metacognitive development. As was expected, an important number of researches and case studies are needed in order to validate design principles, to examine the appropriateness of each feature of the technology-based learning environment, as well as to investigate appropriate contexts and strategies of implementation in real school contexts in conjunction with the appropriate accompanied learning materials (for students and teachers). If this situation is true for every learning environment, it is much more so for MODELLINGSPACE which is meant to address a wide range of pupils.

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