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# Design principles of a new modelling environment for young students, supporting various types of reasoning and interdisciplinary approaches

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Epistemological and learning order reasons have led us to design and develop an open learning environment permitting modelling activities to young students, named MODELSCREATOR. The design of this system obeys a range of basic educational, cognitive and technological considerations and has been developed in such a way so as to satisfy a number of design requirements and principles. The main technological requirement was to apply a component object oriented programming approach. Concerning modelling, two main principles were specified: to support expression through different kinds of reasoning in a simplified and synthetic mode and model mechanisms that derive from different subject matters, which permit interdisciplinary approaches. The system supports the greatest visualisation, combines the modelling tools with real world simulations, not abstract ones and incorporates alternative and multiple forms of representations. Concerning interface design and human–computer interaction, a direct manipulation interface and ergonomics suitable for young students were determined, satisfying the criteria of minimisation of the distance of execution and the distance of meaning. The MODELSCREATOR consists of seven components: *"Study Themes"*, “*Modelling Space*”, *"Notebook*”, *"Models' Encyclopaedia"* “*Communication system”*, “*Files' management system”* and “*Help system”*. Most of the above components have been developed in Microsoft Visual C++ using the Win32 API.

## 1. Introduction

The scientific activity consists mainly of model creation of different phenomena or situations. These models are either very formalised (such as in physics with mathematical models) or constitute simple iconic representations. Models appear in various scientific areas such as economics, history, biology, meteorology and archaeology, as well as in our everyday life. Moreover, during the last decade, the way that some disciplines function has been modified because of modelling tools that computer science has provided.

Since scientific practice involves construction, validation and application of scientific models, the instruction should engage students in making and using models as well [7]. This epistemological reason could be sufficient enough a reason to consider modelling activities an important factor in the school curriculum and can lead to the decision to design appropriate educational software. Furthermore, educational reasons urge us to develop modelling tools for students. Research in the field of science education and cognitive psychology [2] have 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 [2] about which, in most cases, they are not aware of. This expression is the first step towards the process of cognitive awareness of ideas and reasoning modes, which are often necessary for conceptual change [17].
- 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 [8].
- The expression of thoughts through model construction can help the learning process, since the ideas become an object of communication and discussion.

Having accepted that there is an educational interest in designing and producing educational software for modelling, we need to give answers to some central questions referring to design, technological solutions and appropriate pedagogical approaches of use:

- ♦ What are the design requirements that concern human computer interaction in order to produce a modelling system appropriate for young students?
- ♦ By surpassing the drawbacks of existing modelling systems, how can modelling tools be conceived in order to be appropriate for young students?
- ♦ Which type of reasoning modes and what kind of models should be promoted?
- ♦ What are the needs of classroom management that could be taken into account in the system design?
- ♦ How can the new technological possibilities of communication through networks be exploited in order to promote collaboration?
- ♦ Concerning the modelling software use in the current school settings, how can one cope with a new learning environment and the associated innovative pedagogical strategies?

We have tried to answer these initial questions, in order to develop a new modelling environment, geared to young students (11-15 years old) and designed to be used in the actual educational settings.

In this paper, the actual state of the current modelling learning environments will be briefly explored, and some of the central points that have guided us to design it will be specified. Then the design principles will be presented as well as the description of the architecture and the main components of this environment, named MODELSCREATOR. Finally, the first indications from the environment experimentation in real school classes will be outlined.

## 2. The need to develop a new modelling system

Recent considerations over curriculum, which mostly support exploratory learning, problem solving situations and decision-making procedures, have contributed to the development of computer-based modelling, especially in subjects like sciences and mathematics [18]. The existing modelling software can be classified into three wide categories [3, 1] which support the corresponding reasoning modes: quantitative, semi-quantitative and qualitative modelling:

i. The quantitative models work on countable things and algebraic forms and reflect the connections between them. The majority of software-based modelling is enlisted into this category.
ii. The qualitative models represent the knowledge, which is not possible to be reflected in a countable way, and involves categorical distinctions and decision-making. This category includes nearly all of the remainder modelling products (expert systems, concept maps, etc).
iii. The semi-quantitative models even if they depend on countable things, they don' t reflect their values. The implicated kind of reasoning involves seeing how, in a complex system, the rough and ready size of something has an effect on something else, which may in turn, affect other things. The fact of the matter is that these models also work in a qualitative way. This kind of modelling software which has been conceived by scientists from science education and psychology fields [3], offers an intermediary tool for the children, by helping them to have progressively access to the quantitative reasoning.

During the last decade, the interest in modelling activities and the possibilities offered by technology have led to the development of a number of systems that concern different kinds of modelling. Some of them are intended for use in research and higher education, such as STELLA or AXON. Others are dynamic models asking mainly for a quantitative reasoning, such as the "Dynamical Modelling System- DMS" [11], and the recent MODELLUS [15] which is appropriate for mathematical modelling in physics and other disciplines. There are two systems that support semi-quantitative reasoning: IQON [3] which permits the modelling of everyday situations, and 'Model-It' which deals with ecosystems. 'ExpertBuilder' [18] supports qualitative models of logical reasoning, whereas AXON and INSPIRATION permit the creation of concept maps. Finally, WorldMaker [12] is a new spatial distribution system that permits the creation of models on ecological systems, traffic flows and different kinds of chaotic behaviour.

Some of them are not appropriate for young children (for instance STELLA and DMS), while others mainly support quantitative reasoning (MODELLUS). All of these systems usually support only one type of modelling (dynamic, space distribution, logic, or qualitative) and finally some of them focus on special domains.

Our endeavour to design and develop the MODELSCREATOR is due to three main considerations which have not -so far- been accomplished by other existing systems:

- The models and the modelling processes constitute a common point among different disciplines. One of the world-wide problems of the current curriculum is the fragmentation of knowledge in different subject areas. Modelling activities could contribute to the unification of common points between different subject areas, and could promote interdisciplinary teaching approaches. Consequently, we are interested in a combined environment that offers different kinds of models that support a large range of activities through different subject areas.
- It is significant to emphasise qualitative and semi-quantitative reasoning, given that research in the field of cognitive psychology has proved their importance in the learning process and development [2, 6]. Nevertheless, in order to support these kinds of reasoning it is essential to create environments appropriate for young children that will not be based on abstract modelling and representation tools.
- It is fruitful to exploit recent technological possibilities such as multimedia, communication via Internet and window-based environments.

## 3. Design principles of MODELSCREATOR

The design of MODELSCREATOR obeys to a range of basic educational, cognitive and technological considerations and has been developed in such a way so as to satisfy the following design requirements and principles:

The main technological requirements are the following:

- Implementation and functionality based on a *component object oriented* programming approach [13]. This requirement accomplishes reusability needs and allows for the evolution and extension of the components.
- Window-based components permitting, a synergy between the application in question and other window based applications (for instance, Microsoft Office applications).

Concerning modelling, four main principles were specified:

- Modelling based on analysis of situations, phenomena or problems to *entities* (objects or abstract notions such as concepts), *properties of entities* (concepts or simples properties) and *relations* between properties.
- Expression through *qualitative*, *semi-quantitative* and *quantitative reasoning.* Students can either work with the above modes independently or can proceed from the one to the other.
- Incorporation of *different categories of models* (semantic models as concept maps and logic formalism, semi-quantitative modelling, algebraic formalism) in a simplified and synthetic mode.
- Inserting categories of models able to support the procedures and the modelling mechanisms that derive from *different subject matters* and permit working in an interdisciplinary mode.

Concerning visualisation, the following principles were determined:

- The expression through the *greatest visualisation*: the application of this principle concerns the entities, their properties and the properties' relations. Visualisation is crucial in supporting the reasoning development of young students and favours the transition from the reasoning over objects to the reasoning with abstract concepts [15].
- The combination of *modelling tools with real world simulations,* not abstract ones: The simulations (necessary in order to validate some models) that are being produced from most of the existing modelling systems are merely abstract. It is important to have the possibility to test and validate models through simulations that represent the phenomenon itself in an obvious visual way.
- The incorporation of *alternative and multiple forms of representations***:** the alternative forms of representation concern the models (with their entities) as well as the different kinds of data produced by models. The students' ability in making and using models depends on the representational tools, disposable at their command [7]. The multiple representations provide cognitive assistance for reasoning and consequently for learning.
- The support of the *development of metaconceptual awareness* by inviting students to write down their thoughts and especially their predictions and interpretations on a *special notebook.* Previous research on children interaction with simulation systems [4] has shown that, when children explore a simulation, they often find out things by trial and error and they have difficulties in interpreting the simulated situation when the results are opposite to their predictions. They distort the new information in a way that is consistent with their existing cognitive structures [17]. Inviting children to write down their thoughts in a systematic way during the interaction, on one hand permits the externalisation of these thoughts, and on the other, gives them the possibility to recall these notes later, in order to revise them or think about the evolution of their ideas [5].

Concerning interface design and human – computer interaction, the following requirements were specified:

- Support of the *distinction of different actions and functions* during modelling process by *appropriate distinction of working areas and types of models.* It is needed to assure the distinction among the empirical reference (real-world situations), the models' creation and the representation tools, in order to facilitate students' understanding [9] and avoid their confusion. Especially for young students, it is important to clearly specify the significance of actions and functions, such as designing a model, testing a model, working on representations of deriving data, etc. This consideration has consequences for the separation of the situations' presentation from the modelling space, the distinction between the different types of entities (concrete, abstract), and also the distinction among the different types of models (qualitative, quantitative, etc).
- *Direct manipulation interface and ergonomics suitable for young students*. This requirement tries to satisfy two criteria, this of «minimisation of the distance of execution» (the distance between the students' intentions and the sequence of actions which are required for the execution) and that of "minimisation of the distance of meaning" (the meaning of the choices created by the designers has to be recognisable by the students) [16].
- *Direct support of collaborative activities* between groups of students and teachers in a local area network and in global area networks through Internet. It is important for the software produced for use in school settings to support exchange and collaboration between students, not only on the local network but also on the Internet. This perspective requires an easy management of files' exchange.

## 4. Architecture and functionality of MODELSCREATOR

The MODELSCREATOR consists of four main components (figure 1): the space of "Study Themes", the "Modelling Space", the "Notebook" and the "Encyclopaedia of Models". It also contains a "Communication system", a "File Management system" and a "Help system".

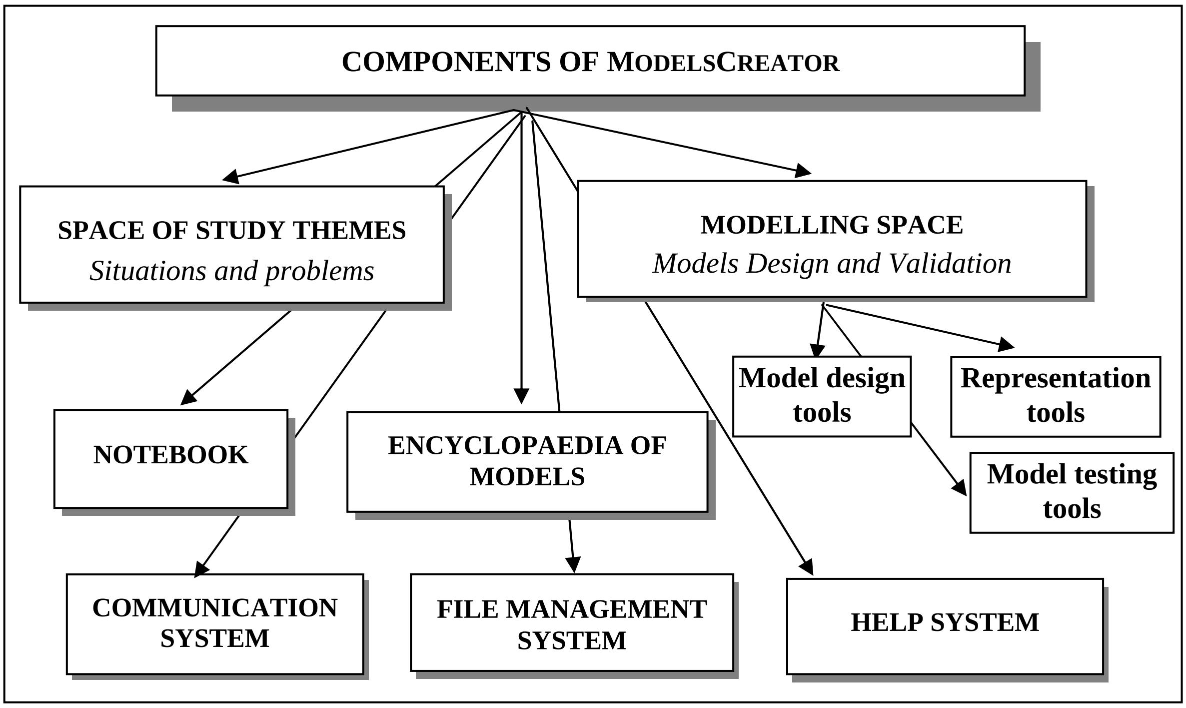


Figure 1: The architecture of MODELSCREATOR

1. The component *"Study Themes"* contains a number of situations that are proposed for modelling, while it allows for the creation of new problems by teachers and students. This special editor allows the presentation of new situations or phenomena by writing and formatting texts and by inserting various multimedia elements such as images, photos, sounds and videos.
2. The "*Modelling Space*" permits the design, testing and validating models. It consists of the area where the models can be designed. It contains the tools available to design them, the representation tools and the tools that are necessary to run the model. In order to design a model, students have to determine the model' s entities, their properties and the relations between them. The model design tools contain the lists of entities (left of screen, fig. 2) and the lists of relations (right of screen, fig. 2). There are two kinds of entities: the concrete ones (that correspond to objects) and the abstract ones (that may correspond directly to concepts). The designation of each entity either requires both the iconic and the textual determination which are able to specify the concept, or the variable referring to this object or only the textual determination which directly refers to a concept. For each entity, one or more variables or concepts have to be determined as well as the estimation of their values (if necessary). The effect of these values appears directly in a visual mode. For instance, in the semi-quantitative reasoning mode, the fact that the value of the volume of the water (variable) in a barrel (object) is high or low, can be seen from the water level in the icon of the barrel.
The students can choose and determine the desirable relation between two entities among the available relations of the four great categories:

- *Qualitative logical relations*: these relations can be expressed by logical operators (and, or, not) and control conditions (if…then), useful in decision making (see Figure 3).
- *Qualitative semantic relations*: they are able to produce concept maps. The concept maps are particularly useful to present and study the relations between concepts in various subjects (environmental education, physics, history, etc).
- *Semi-quantitative relations*: these relations are in terms of variation of properties' values and direction of this variation. In the current version, the student can use simple relations that correspond to simple algebraic relations which are common in mathe-

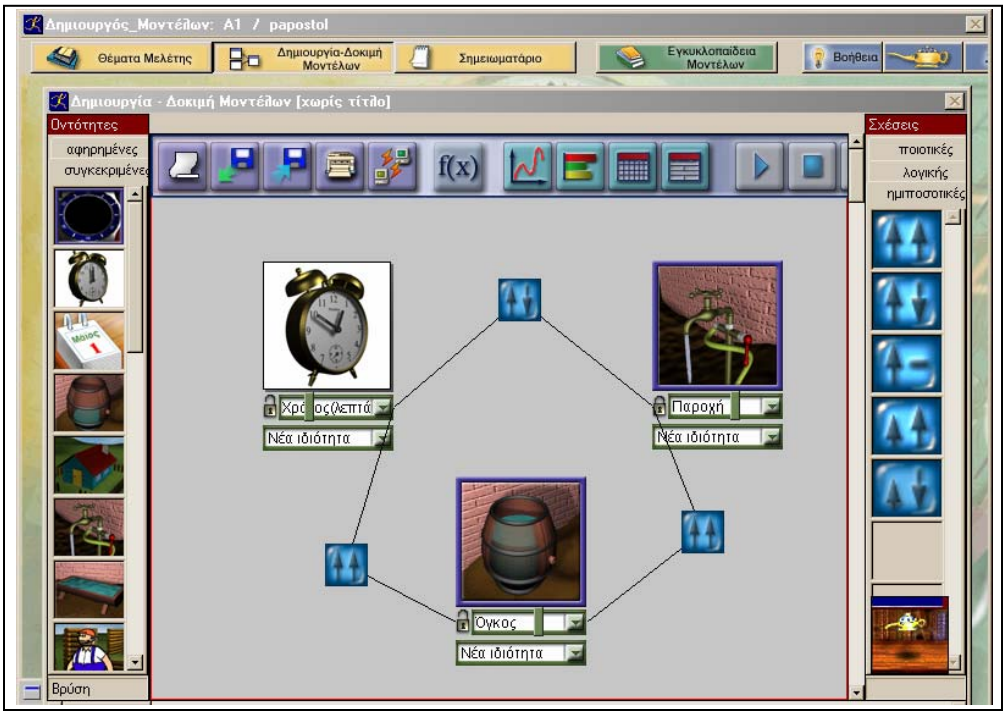

Figure 2: The Modelling Space of MODELSCREATOR

matics and physics. Each relation is represented by a symbol. For instance, the relations of analogy or inverse analogy are expressed through the reasoning “If the one entity increases, the other one might increase, decrease, or remain unchanged” and are represented by special graphic symbols (↑↑,↑↓,↑↔,↑↑, or ↑↓).

- *Quantitative simple algebraic relations*: they are defined by arithmetic operators (+, -, *, /, =). In a direct manner, a dialogue box permits to relate some of the variables -previously defined in a model- with arithmetic operations in order to determine a quantitative algebraic relation.

The student having created a model can now run a dynamic model during which the simulation of the modelled phenomenon appears in the area of entities’ icons. For example, when the model that is presented in Figure 2 runs, the student can see the water filling up the barrel for as long as the tap is turned on. If the relation between the barrel’s volume and tap’s rate of flow is an inverse analogy, it will result in the decrease of the water’s volume in the barrel while the tap is on. In the case of decision models (as in the example shown in Figure 3) the student can see -in the icon related to the effect (‘then’)- the simulation of the decision’s consequences (a boy will either cross the street safely or will have an accident).

Before or after model running, the student can activate the “Representation Tools” which include: tables of data, graphs, bar-charts, and tables of decision associated with the desirable entities or variables that are specified through a simple dialogue box. It has to be pointed out that the table of data permits the entrance of external numerical data because it is an open table. This characteristic enables the user to represent data from external experiments, possibly from the real world, and compare them with the data from the model, -a necessary step in the phase of testing the model’s validity.

3. The *"Notebook"*: stimulates students to take notes during the modelling process. The specially designed notebook contains three folders “determination of situation”, “ model designing”, and “model interpretation” (see Figure 4), in order to encourage students to put their thoughts down during the initial study of the situation (determination of situation, objectives and usefulness of model), during the design of models (which factors are considered as important and which are negligible, what are their predictions), and finally during the test and validation of model (how the model behaves, how this behaviour can be interpreted, what are the differences from reality, etc).

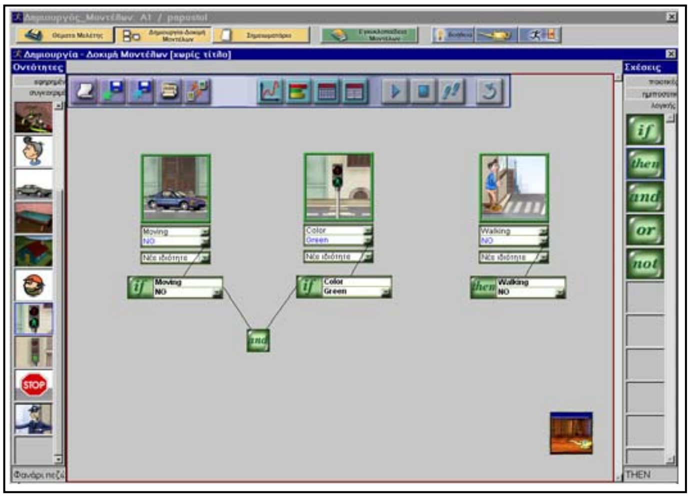


Figure 3: A decision making logical model


Figure 4: The special Notebook

4. The *"Models' Encyclopaedia":* constitutes a multimedia presentation, which aims to present and explain in a simple way the status and the nature of models and modelling processes in sciences and every day life, using graphics, icons, video, narration and texts. This presentation has been developed because of the lack of any kind of appropriate reference sources related to the matter of models.

5. The *“Communication system”*: allows the exchange of problems, models, and notes (in an associated whole) between any users of MODELSCREATOR whether they are in a local area network (LAN) or in a distant Internet node. The exchange of data doesn’t require the user to invoke a third party application (mail/ftp/etc. clients) since MODELSCREATOR works as both a server and a client for such type of transactions using protocol TCP/IP internally. Apart from avoiding the training of users on using other applications, such an integrated solution also helps to keep the system clean and functional without human intervention since the system knows by itself where to write the received data, in order to be readable by the users, without risking the spreading of multiple copies around the hard disk or overwriting other useful data.
6. The *“Files’ management” system:* implements a customised and personalised view of the file system hiding the file’s real location on the hard disk and showing the hierarchy of the classes and their students/users instead. In addition, a special tree is ‘assigned’ to every user (student or teacher) which represents the various themes of study and the underlying created models. As a result, all a user needs to know to access their created models is their name in the system, the class they belong to, and the specific subject of study they are interested in. The real location of the files on the disk is invisible to them, protecting them from dangers that direct access to the underlying file system inherently creates, especially when given to inexperienced users. The file management system and the communication system (described above) auto-complement each other, providing risk-free, higher level capabilities of data storage and exchange through integrated simple interfaces that don’t require any prior knowledge of the underlying operating system and its tools.
7.The *“Help system”*: It contains three sub-components, an on-line help (a hypertext system), an immediate context sensitive help (functioning like Office Assistant) that gives audio guidelines on using the various components, and an intelligent help system, which is activated in specific interface actions providing audio and textual comments, explanations and hints.

Most of the above components have been developed in Microsoft Visual C++ using the Win32 API (Application Programming Interface) while two components (the representation tools and the notebook) have been developed using MFC (Microsoft Foundation Class). The multimedia presentation of Models’ Encyclopaedia has been developed in Macromedia Director.

## 5. The use of the MODELSCREATOR in real school settings

In the context of the MODELSCREATOR, modelling takes different forms and can favour the exploratory as well as the expressive way of learning. During exploratory activities of learning the student examines ideas over a subject using prepared models which have been expressed from someone else (other students or teachers). During expressive activities the student expresses his own ideas by producing new models. Actually, there are a number of proposed themes of study referring to mathematics, physics, environmental education and every day decision-making. Most of the proposed situations are created in order to treat themes where students present difficulties in the implicated concepts, i.e. the notion of analogy in mathematics, or the notion of acceleration and force in kinematics.

The modelling method aims to correct many weaknesses of the traditional lecture-demonstration method including fragmentation of knowledge, student passivity, and persistence of naive beliefs about the real world. Some elements of the suitable pedagogical approach are that the teacher sets the stage for students’ activities, and then, in small groups, students collaborate in investigation and validation of models in order to answer or clarify a question. Students are also required to present and justify their conclusions in oral or written form, including a formulation of models for the phenomena in question and an evaluation of the models through comparisons with the real world phenomena.

Aiming to face the problem of the necessary support of every innovative educational software use, three measures have been taken:

- An extended manual for teachers composed by a user's guide, general guidelines of suitable pedagogical approaches, and detailed guidelines in order to help them managing the proposed modelling activities.
- Web site especially for MODELSCREATOR in order to support teachers, providing new material (texts concerning modelling activities, strategies, and new themes for modelling), serving also as a space where the teachers can exchange experiences related to this environment.
- Teacher education (organised through a special agreement with the minister of education). Teachers can not easily use this kind of innovative educational software. Special teacher education is needed in order to incorporate educational software and contribute in the restructure of their current educational practices.

During the development process of MODELSCREATOR a spiral prototype evaluation process has been conducted including successive experimental evaluations by a small number of students and global evaluations in class settings. The objectives of the former evaluation were mainly the interface determination and themes' specification, while the objectives of later evaluation were the research and specification of the appropriate pedagogical strategies. The analysis of the evaluation results makes us optimistic about the possibility of a rich exploitation of this environment. What seems to be particularly difficult to integrate in the current educational settings is the interdisciplinary approach of modelling.

## 6. Conclusions

The MODELSCREATOR has been developed on the basis of recent pedagogical approaches and recent software' s development approaches. The development of this project was supported by an interdisciplinary group (scientists from the fields of science education, cognitive psychology, computer science, teachers and also multimedia producers). It has been necessary to obtain a close collaboration between two Computer Science Departments, a Department of Education, and a multimedia production company. We have planned to continue the research and the development of MODELSCREATOR by inserting new relations and objects that would extend the actual range, and by exploring suitable pedagogical approaches further.

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