An innovative teaching and learning environment for school mathematics

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Abstract

The paper presents the main characteristics, the background reference, and educational aims of an innovative teaching and learning environment designed and implemented for promoting arithmetic problems solving skills in children of compulsory school.

The project is partially funded by the European Community Research and Development Project ITALES "Innovative Teaching and Learning Environments for Schools" (IST 2000-23356).

The research addresses a sector (that of arithmetic problem solving) which has always proved difficult for children and in which traditionally teachers find major problems about the pedagogical approach to follow.

Problem solving is normally seen as an individual activity. The student's role is to solve the problem, while the teacher is there to assist the student in performing this task and provide educational mediation. In the system here presented these roles are remodelled by the system's action and communication possibilities and, as a consequence, are transformed.

The overall aim of our work is to study how new technologies, if inserted in suited contexts, can contribute to the construction of innovative learning environments that can enhance teaching and learning processes and can also change traditional approach to school teaching.

Introduction

At the Istituto Tecnologie Didattiche of CNR innovative ICT-based learning environments are being studied. They aim at improving learning quality both from the standpoint of acquired abilities and of motivation, in various subject areas and with a special attention to mathematics.

The overall aim is to study how new technologies, if inserted in suited contexts, can contribute to the construction of innovative environments which can enhance learning processes and can also change traditional approach to school teaching.

In this context we are now completing the design and implementation of ARI-LAB-2, a multi-environment system oriented to the development of arithmetic problem solving abilities. This research activity is partially funded within the 5th European Community Framework Program: ITALES Project (IST-2000-26356).

The theoretical framework adopted in the design of ARI-LAB-2 is the socio-constructive one (Bottino & Chiappini, 2002). According to such framework, ARI-LAB-2 makes available tools that can make concrete abstract concepts and tools for developing pedagogical activities based on the comparison and the negotiation of the mathematical meanings involved. ARI-LAB-2 can be considered as an example of a new generation of ICT-based learning systems for primary and secondary school education which is characterized by a strict integration of visualisation, communication and re-elaboration tools aimed to support both the creative exploration of problems and the representation, validation, and communication of knowledge. Such systems support not only students learning but offer the teacher as well functions and environments to design, monitor, and manage the teaching activity within their classes. In the following we refer to such innovative systems as "*situated multi-environment teaching learning systems*".

The approach adopted by situated multi-environment systems is innovative if compared to the great majority of ICT-based systems for education at compulsory school level, which, even now, are mostly "drill & practice" systems.

The new model of innovative learning environments that ARI-LAB-2 contributes to define is characterised by the possibility to be integrated in school curricula to develop not only single and specific abilities but concepts and understandings which requires a long period of time to be developed and learned (as it is the case, for example, of arithmetic problem solving). At the basis there the idea that learning is the result of the student's exploration and active construction mediated by the tools made available by the technology, and by the social interaction developed in the activity the student is engaged in. This approach emphasises the social nature of cognitive development and the importance of taking into account the relationships which are established between the student, the mediating tools, the teacher, and the other students of the class.

Situated Multi-Environment Teaching and Learning Systems

Research on ICT-based learning and instruction has undergone a deep transformation in the course of time, due to the parallel evolution of pedagogical and cognitive science theories, and to technological progress which constantly opens up new opportunities (see, also, Bottino, 2001).

First came systems informed by a transmission metaphor, these were principally behaviourist drill and practice and tutorial systems, which were useful for remedial work and basic competence topics but did not really address the way the student interacts with knowledge. This phase was followed by the advent of learner-centred systems, characterised by a constructivist outlook, problem-based approaches and the use of microworlds. The focus on the creative exploration of a knowledge domain was a step forward but these approaches have tended to use technology as an add-on to classroom practice, which has limited their impact, and led to a need to revise strategies, aims and activities. In recent years an interest on the whole teaching and learning situation has increasily emerged. This means that progressive consideration is given to the needs of the teachers who will be using the technology, the ways in which it will be used, the curriculum objectives, the social context and the way in which teaching and learning activities are organised. Moreover important consideration is given to the definition of meaningful practices through which technology can be used effectively. At

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theoretical level, we have assisted a progressive move from cognitive theories that emphasize individual thinkers and their isolated minds to theories that emphasize the social nature of cognition and meaning (Resnick, 1987). The metaphor of participation can be used to describe this phase where the focus shifts from the individual as the centre of learning to the idea of learning as a social process. The approach adopted is a long term one that attempts to transform the whole teaching and learning situation, centred on the interactions in the classroom over a period. The term "learning environment" no longer describes a software tool, but it has come to refer to the whole context (Salomon, 1996).

Situated multi-environment teaching and learning systems can be considered as a new generation of open-learning systems which are more suited to mediate the new ways of looking at teaching and learning processes that are now progressively affirming themselves. They understand the need to support a variety of approaches, methodologies, and also be capable of dealing with needs that evolve over time, and with the variety of relationships involved. Thus, these systems makes available tools able to support not only the relationship of the student with the knowledge to be learnt (learning object) but also all the relationships that are established between participants during a teaching and learning activity.

They are typically designed with the classroom in mind. Rather than constrain the learning experience to be narrowly individualistic, this next-generation technology supports socially situated interaction and investigation.

It is possible to delineate some general indications for the design and analysis of such systems. Of course, these indications are to be detailed and specified according to the characteristics of the specific field of application and educational context considered.

In particular, in the design of situated multi-environments teaching learning systems, the following issues assumes a crucial importance:

- The computational objects and interactivity that a system makes available to the user and their relationship with the cognitive processes involved in the acquisition of the knowledge for the learning of which the system has been realized.
- The tools offered to validate student's actions and the support they offer to the evolution of student's knowledge.
- The tools offered to support the re-elaboration of personal experience and its sharing within the class.
- The tools offered to support the setting up of a social context able to assist students' performance and the evolution of competencies and knowledge.

In general, situated multi-environment systems are characterised by a strict integration of tools for supporting visualisation, re-elaboration of knowledge, and communication. The aim is to offer tools for problem exploration, for representing solution strategies and processes and for communicating such processes as well as tools to support learning evaluation, the management of the teaching activity, and the evaluation of learning. Of course, tools and features cannot by themselves guarantee learning. They have to be used to support the construction of activities in which learning could be the result of a social construction of meaning and of its justification.

An example for mathematics education

ARI-LAB-2 is an innovative multimedia learning system for school education aimed to develop arithmetic problem solving abilities.

Problem solving, and, in particular, arithmetic problem solving, is a field in which usually primary and lower secondary school students show great difficulties as pointed out by many research studies and often experimented by teachers in their class work (see, for example, the Third International Mathematics and Science Study, IEA: http://timss.bc.edu/). These difficulties have deep repercussions on students' self-esteem and future school choices. The activity of problem solving for many students is limited to 'guessing' the right operation and accurately carrying out the written calculations since the semantic they associate with arithmetic symbols is poor and frequently limited to what the result of a computation denotes. These considerations put in evidence the importance of research efforts as well as experimental evaluations in this area.

The ARI-LAB-2 project addresses such problems. It is based on an epistemological analysis of arithmetic knowledge with particular attention to the study of the pedagogical difficulties and obstacles that students often encounter.

In the following a short description of the main features of ARI-LAB-2 is provided with the aim of giving some practical exemplification to the general indications previously outlined.

The ARI-LAB-2 learning environment

ARI-LAB-2 is designed to support the students in the solution of arithmetic problems and the teacher in designing arithmetic problem solving activities with his/her classes.

ARI-LAB-2 is implemented to be used in a school computer laboratory (on in a class where computers are present) equipped with PCs connected through a local network. In ARI-LAB-2, two different kinds of user are expected: the teacher and the student.

- The teacher uses ARI-LAB-2 in order to plan and manage the educational activity for the students of his/her class. ARI-LAB-2 offers the teacher the possibility to edit texts of problems; to impart them, through the local network connection, to a student (or a group of students), or to all the students of a class; to construct examples of problems solutions, to send them to the whole class or to a specific student of the class; to look at the solutions of each student and to comment them, etc.
- The student uses ARI-LAB-2 in order to solve arithmetic problems imparted to him/her by the teacher. The student has at his/her disposal environments (Microworlds) to solve the problems

imparted by the teacher, and a specific environment (the Solution Sheet) to build the solution to a problem. Moreover a communication environment is available to give users the possibility to exchange messages and problem solutions.

ARI-LAB-2 is a multi-environment open system; this means that it is constituted by a number of interconnected environments that supports different and complementary pedagogical opportunities. Let us examine briefly the system from this perspective, that it, considering the pedagogical benefits it supports.

Cognitive approach

Representation systems play a central role in mathematical education as a way to ease the access to such an abstract domain of knowledge. The symbolic re-constructive approach to mathematics concepts, which is fundamental for expert mathematicians, often constitutes a serious obstacle for students. Researches in cognitive science and in maths education have shown the importance of making reference to students' experience in their every-day world. ICT can play a crucial role in approaching a mathematical domain of knowledge, which is abstract and formal, through the exploration and the manipulation of concrete representations that help them to deal with such knowledge from a visual and motor perceptive perspective.

ARI-LAB-2 supports students in the solution of arithmetic problems by making them available a set of microworlds where they can visually represent and manipulate problem situations in a variety of concrete contexts, which are meaningful also from the mathematics point of view. The microworlds currently available are: "Euro", "Calendar", "Abacus", "Number Building", "Number Line", "Graphs", "Spreadsheet", "Arithmetic Operations", "Fractions", and "Arithmetic Manipulator". Microworlds make available both tools for actions in relation to the problem at hand (e.g. to visually represent the problem situation, to perform a solution step, etc.) and tools for the validation of the solution strategy performed. Some microworlds (such as Euro or Calendar) have been designed to model common situations in every-day life such as "purchase and sales" or "time measure" problems. Others have been designed to model different arithmetic fields and tools for solving problems (graphs, spreadsheets, etc.).

Let us examine an example. To solve a problem involving measuring days and intervals of days the student can enter the "Calendar" microworld where s/he can visualise a month, sign intervals of days, pass from one month to the another, etc. Analogously, to solve a problem involving a money transaction the student can enter the "Euro" microworld where s/he can generate Euros, move them on the screen to represent a given amount, change them with other Euro coins or banknotes of an equivalent value, etc. Figure 1 shows the main interface of the Calendar microworld.

Validation and Feedback to actions performed

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ARI-LAB-2 is an open-learning system, so, differently than in other approaches, validating a solution strategy does not mean to receive a "correct or wrong" feedback from the system. The responsibility of the overall validation of the student's work is left to the teacher and to the social context in which the problem solving activity is inserted. However the system offers a specific feedback for some crucial actions. Such feedback is done in such a way to give students hints for correction, if necessary. For example, in the Euro or in the Abacus microworld, it is possible to select a coin or group of coins (or a configuration of balls in the abacus) and to hear the corresponding amount pronounced orally by means of a voice synthesizer incorporated in the system. In this way the student can find a contradiction in his/her work and that validated by the system (e.g. the number he had to represent on the abacus and the one he have actually generated), and this can give him/her hints for modifying and correct his/her strategy. This validation tool takes on a crucial importance for the counting process.

Moreover, in each microworld, some tasks performed by the user are controlled by a set of rules integrated in the system which prevent her/him from taking specific incorrect steps. For example, if the user tries to perform an incorrect change of coins, or of balls in the Abacus, the system prevents her/him to continue and addresses a specific error message.

Elaboration of personal experience

ARI-LAB-2 makes available a specific environment, the Solution Sheet, where it is possible to elaborate the solution process enacted within the microworlds, transforming it into a product to reflect on and to share with others (teacher, other students, etc). The underlined metaphor is that of the math workbook where usually a student does her/his exercises and builds solutions to problems.

In the solution sheet the user builds up a solution to the problem at hand by copying into this space the graphic representations produced in the microworlds that s/he considered meaningful for working towards the solution. The student can employ verbal language and arithmetic symbolism to comment on the graphical representations copied and thus to explain the solution performed. This can be done by means of the "post-it" function. This function allows editing a short note or comment that it is possible to add, remove, correct, and move about in the solution space.

From the solution sheet it is possible to access directly microworlds and the other environments of ARI-LAB-2. Figure 2 shows the interface of the solution sheet environment with an example of a problem solution.

Multiple representations

Since ARI-LAB-2 offers the possibility to access a number of different microworlds while solving a problem, it is possible to obtain different representations of the same mathematics concept or entity. As the matter of fact, in the solution sheet, the student can copy representations obtained in different microworlds thus better supporting their comparison and the passage from one representation register to another. For example, an amount represented with Euro coins can also be represented interacting

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with the Abacus and with the Number Line microworlds. Thus different representations of the same value can be obtained and put into relation. The comparison and conversion into different registers of representation is a crucial cognitive activity to give meaning to mathematical concepts (see, for example, Duval, 1993).

Cooperative learning

The learning activity in ARI-LAB-2 is inserted in a social dimension where communication and collaboration activities among students and teacher assume a crucial importance. While solving a problem with ARI-LAB-2, an environment, the Communication Environment, can be accessed. In such environment it is possible, at any time, to establish a connection with other users and share messages with them. A local network is foreseen at this regard. The communication environment allows not only to exchange messages but also solutions among students and with the teacher. A variety of interaction modes are supported. The user can choose the partner/s to communicate with at a given time, decide whether or not to read a message or a solution when received, look at them later, display the entire dialogue held with partners. The opportunities given by the communication environment allow to insert the problem solving activity in a social interaction practice which can change students' attitude towards the problem, the validation context in which the resolution process is set, and the way in which assistance can be given to students. For example, a student can confront his/her solution to a given problem with those of his/her classmates and discuss with them the evidenced differences; a student can be given responsability for controlling the solution produced by a partner; pair of students can be given symmetrical roles and tasks to develop a join problem solving activity (e.g. buyer and seller), etc.

Learning by analogy

Interacting with the Solution Sheet, the teacher can build examples of problems solutions that can be sent to students for reference. Moreover, the exchange of solutions, not only with the teacher but also with other students, allow the student to compare them with his/her own thus favouring the enactment of learning by analogy strategies.

Configurability and personalisation

ARI-LAB-2 offers the teacher an environment, the Teacher's Environment, where s/he can write texts of problems, prepare problem solutions, and manage the local network.

A number of configurability and personalisation opportunities are offered. For example, the teacher can send, through the local network, texts of problem and solutions to the students of her/his classes. It is possible to send them to all the students of a class or only to the ones chosen by the teacher in the class list. Moreover, the teacher can choose the microworlds to be made available for the resolution of a specific problem; he/she can also select the validation tools to be made available during the solution of a specific problem (e.g. the voice synthesizer). The teacher can as well impart different problems to different students, and send messages and solutions both to groups of students, to the whole class, or to each individual student. From the teacher environment, through the local network, the teacher can also control the work performed by a student by looking at the problems s/he has solved.

Supporting students with special needs

In some of the microworlds of ARI-LAB-2 are integrated functions to support the learning activity of deaf children. For example, in the Euro Microworld the user can see in a film clip in signs language the amount of a selected coin or group of coins (instead of hearing it pronounced with the voice synthesizer). The integration in a unique environment of tools to support children with special need (such as deaf) introduces a new way of looking to ICT-based special education (integrated in the activities of the entire classroom and not a-part from it).

Conclusions

The work briefly reported in this paper is concerned with the design, the implementation and the experimental evaluation of an innovative ICT-based learning system aimed at enhancing teaching and learning processes in mathematics.

We have studied how to develop new ways to give meaning to math concepts by means of the exploration and manipulation of computational objects. We have studied as well how the learning activity can be changed by new form of interactions between teacher and students made available by the technology. In our work we refer to the multi-environment paradigm in order to be able to develop rich learning activities within the arithmetic problem solving domain.

The analysis of contexts of use able to assist students during the development of the educational activities is an integral part of our work. Results of this research are of different types: theoretical analysis, definition of models and methods, design and implementation of educational software systems, experimental evaluation, and actions for knowledge transfer.

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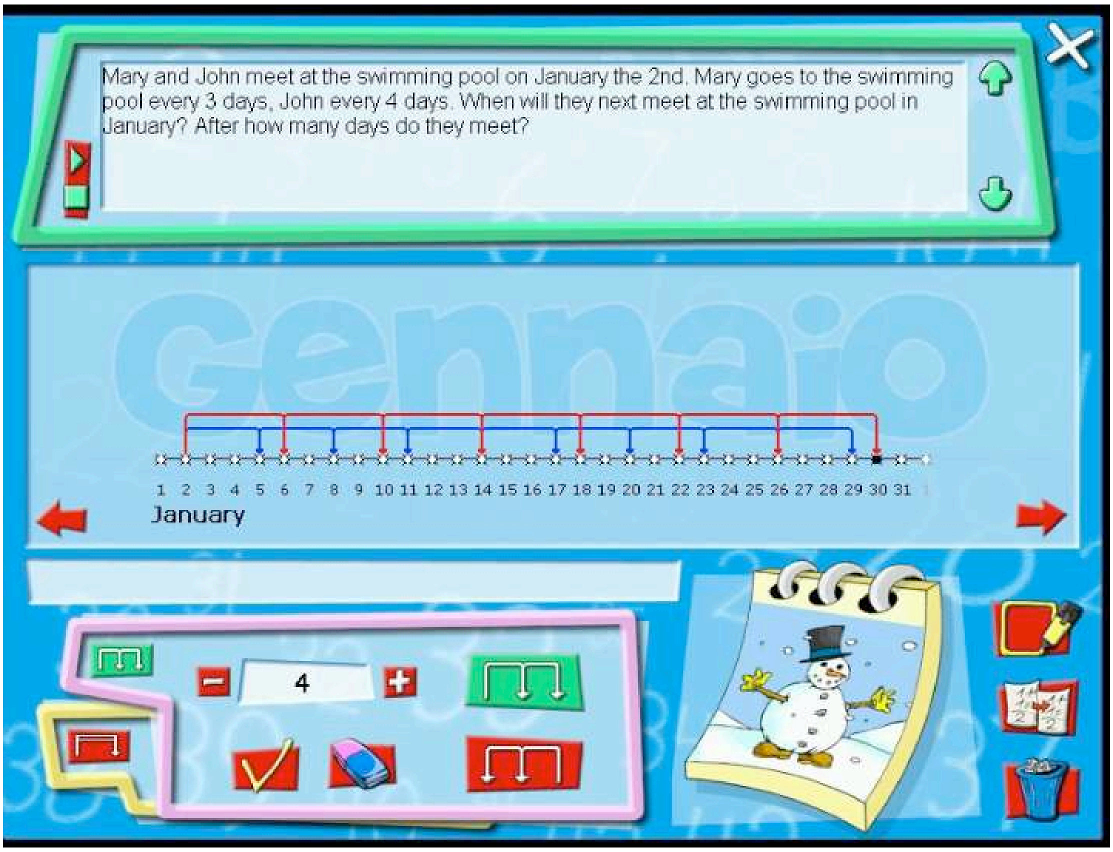

Figure 1: Interface of the Calendar Microworld

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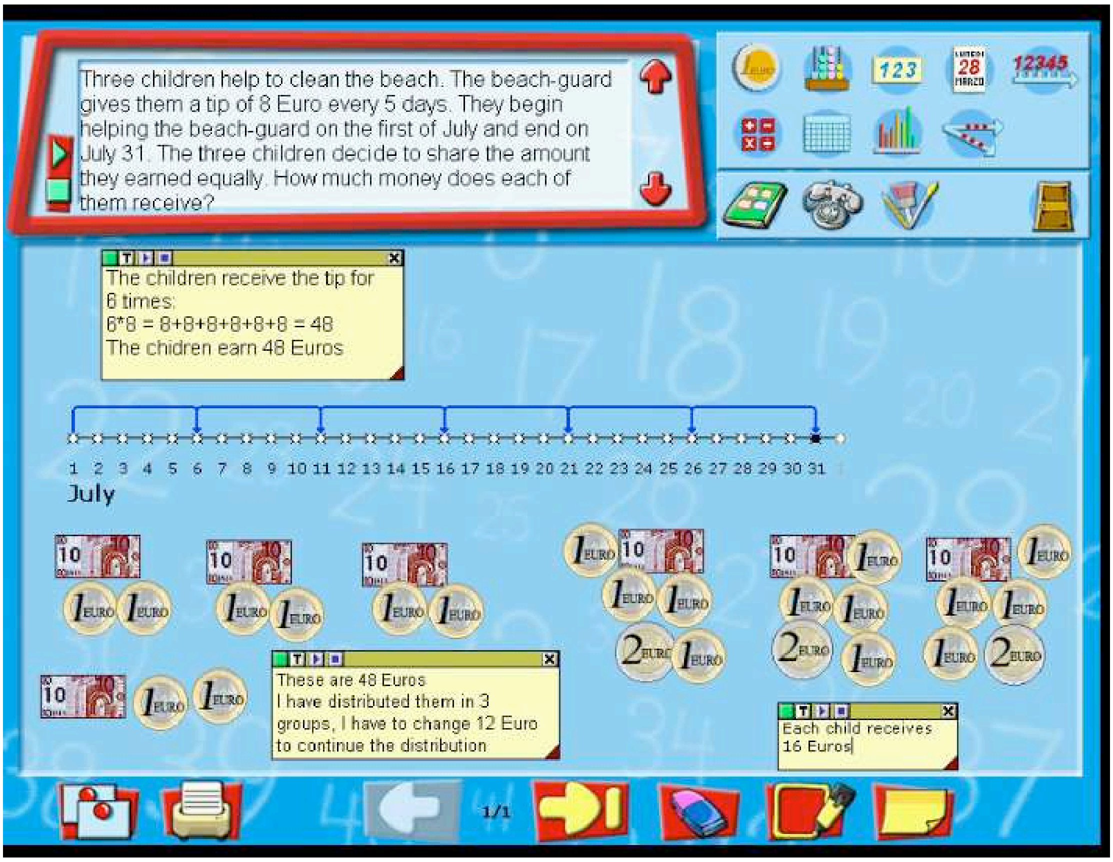

Figure 2: Interface of the Solution Sheet environment with an example of a problem solution