Transforming classroom teaching & learning through technology: Analysis of a case study

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ABSTRACT

The paper discusses the results of a research project based on the field testing of a course aimed at developing arithmetic problem solving skills in primary school pupils. The course was designed to incorporate e-learning techniques, including the use of ARI@ITALES authoring tools. These tools allowed the integration in the course of constructivist activities based on interaction with a set of different microworlds. The aims of the project were twofold: to analyse how the adopted approach and tools could help the teacher design and manage classroom activities integrating technology; and to evaluate the effectiveness of the ARI@ITALES tools for supporting pupils' acquisition of mathematical skills.

Keywords

E-learning, Authoring software, Primary education, Numeracy, Problem Solving

Introduction

Despite the positive results obtained in a number of experimental settings and the large investments made by many governments for equipping schools with hardware and software, it can be said that the integration of computer technologies in the classroom still remains a limited phenomenon at primary school level (see, for example, Venezky & Davis, 2002; Sutherland, 2004). This is true also for disciplines like mathematics, which, from the beginning, has been one of the school subjects that has attracted considerable educational research attention concerning the development and use of ICT tools (Artigue, 2000; Lagrange, Artigue, Laborde & Trouche, 2001). One of the main reasons for this low impact is that technology has often been introduced as an addition to an existing, unchanged classroom setting (De Corte, 1996). Even though it now appears necessary to adopt a more integrated vision in which ICT is considered in conjunction with educational strategies, contents and activities (Bottino, 2004), this change of perspective is unlikely to be straightforward and means taking different perspectives into account. The perspective considered in this paper is that of teachers and of the difficulties they encounter in integrating ICT tools in their classroom practice. In order to bring meaningful innovation to teaching and learning processes, changes are required in content, organization and management of classroom activity – changes that cannot be accomplished effectively by a teacher operating alone.

In this paper the use of an e-learning approach, supported by specifically designed authoring tools, it is examined with the objective to understand how effectively it can support the teacher in the development of classroom activities integrating technology. In particular, the paper analyses the design, implementation and field testing of an online course aimed to promote the development of arithmetic problem solving skills in primary school pupils. This course was built using a set of authoring tools (ARI@ITALES tools) that were developed for implementing interactive constructivist activities in mathematics.

In the following, the ARI@ITALES tools are briefly examined as well as the approach used to build the course using these tools. Selected findings from the field testing of the course with a fourth-grade primary school class (age 9-10) are then analysed. This analysis focuses on understanding whether the approach followed in designing the course and the authoring tools adopted effectively supported teachers' efforts in integrating new technologies in their classes. Furthermore, the paper considers whether this integration had a positive impact on students' learning of mathematics content.

Background

Our research group has been involved in the design and experimentation of mathematics educational software since several years. In particular, the ARI-LAB system has been developed to promote arithmetic problem solving skills in pupils of primary and lower secondary school.

ARI-LAB is a multi-environment open system based on constructive principles that was widely experimented and used in a variety of class situations (Bottino & Chiappini, 2002). Such experiments showed its remarkable cognitive potentialities but evidenced also that its effective use in classroom practice (like the use of any other open interactive environment) requires the teacher a considerable work for integrating it in class activities that effectively impact on students' learning. The design and the management of such activities are often difficult to be performed by a single teacher without a proper support.

Such considerations led us to design and to implement tools and methodologies able to sustain the teachers in carrying out ICT-based activities in their classes. We performed this work within ITALES, a European Commission co-funded project (IST-2000-26356) with several objectives. Among them, the development of a set of authoring tools to enable teachers to prepare digital content for personalised learning, and the development of a new learning management system that can be used by teachers to plan and build their own online courses.

Within ITALES, our research group designed and implemented ARI@ITALES tools based on the ARI-LAB2 system, the new current version of the ARI-LAB system. Information on ARI-LAB2 system and on ARI@ITALES tools can be found at: http://www.itd.cnr.it/arilab/.

ARI@ITALES is a set of authoring tools for building and implementing e-learning activities in mathematics. Using ARI@ITALES tools, e-learning courses have been designed and tested in real class situations. One such course is analysed in this paper.

It is worth noting that the term e-learning is not used here to indicate a particular delivery strategy but rather an evolution in educational organization aimed at supporting teaching and learning processes through the use of social and technological resources (Alvino & Sarti, 2004). ARI@ITALES tools allow an innovative shift towards e-learning since they permit to design courses which integrate a constructivist learning approach (activities in microworlds) with the learning object philosophy (production of digital resources for online learning).

Field experiments involving the use of ARI-LAB and ARI@ITALES tools have been carried out not only at the local level but also considering a wider perspective. For example, within the TELMA (Technology Enhanced Learning in MAthematics) joint research activity of the Network of Excellence Kaleidoscope (http://www.noe-kaleidoscope.org - accessed January 2007) a cross-experimentation project was organised to compare the different approaches to the study of ICT-based teaching and learning environments adopted by the European teams participating to TELMA. The key idea was that each team designed and implemented a teaching experiment in a real classroom making use of an ICT-based tool developed by another team. ARI-LAB has been, in particular, experimented by French and Greek teams. First results of such cross-experimentation project are reported by Artigue et al. (2006; 2007). One of the findings that has been pointed out is that it is necessary to support teachers not only with knowledge about how to use a software tool but also with its key theoretical and educational principles, explicating the settings and the pedagogical practices which can foster its educational potential. This suggests that the tools and the approach here reported can be useful for supporting teachers in designing not only specific learning activities integrating technology but also in building the whole pedagogical itineraries where such activities are to be inserted in order to suit stated learning objectives.

The ARI@ITALES tools

ARI@ITALES is a set of authoring tools for building and implementing mathematics e-learning activities at primary and lower secondary school levels (from grades 2 to 8).

The ARI@ITALES tools were designed to support the teacher in the preparation of mathematics learning activities based on interaction with a number of microworlds. In these activities students can approach abstract and formal concepts (e.g. the number concept) by working with concrete representations (e.g. money, calendar, abacus, etc.).

The tools of ARI@ITALES are: the **Text Editor**, the **Microworlds**, the **Solution Sheet**, the **Simulator**, and the **Player**. These are currently available in three languages: Italian, English and Spanish.

The Text Editor allows the editing and saving of problem texts as objects to be included in a course. When a text is saved, the Text Editor automatically inserts a command that allows the course participant to solve the problem by accessing the Solution Sheet and then the Microworlds. The Solution Sheet and Microworlds are automatically instantiated with the text of the problem at hand.

Microworlds are mediating tools for building the solution to a problem. Within microworlds, the user, through the creation and manipulation of computational objects, can visually represent problem situations in a variety of concrete contexts, which are meaningful also from the mathematics point of view. The Microworlds currently available in ARI@ITALES are: "Euro", "Calendar", "Abacus", "Number Building", "Number Line", "Graphs", "Spreadsheet", "Arithmetic Operations", "Fractions", and "Arithmetic Manipulator".

Some microworlds (such as Euro or Calendar) were designed to model common everyday situations such as 'buying and selling' or 'time' problems. For example, to solve a problem involving counting days, students can enter the Calendar microworld and visualise a month, mark intervals of days, pass from one month to another, etc. Similarly, to solve a problem involving a money transaction students can enter the Euro microworld and generate Euros to represent a given amount, move coins on the screen, change them with other Euro coins or banknotes of an equivalent value, etc. Figure 1 shows the interface of the Euro microworld with an example of interaction.

Figure 1. Interface of the Euro Microworld with an example of interaction

Others microworlds are designed to offer different ways of representing and manipulating numbers (Number Line, Abacus, Graphs), of performing calculations (Spreadsheets, Arithmetic Operations), and of dealing with more abstract mathematical concepts (Fractions, Arithmetic Manipulator). During problem solving, microworlds allow the users to manipulate computational objects and interact with them using operational tools specific to each micro-world. While interacting with microworlds, users receive various kinds of feedback that may foster the emergence of goals for problem solution and the construction of meaning for the strategies developed. 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. Moreover, in each microworld, some tasks performed by the users are controlled by a set of rules integrated in the system that prevent them from taking specific incorrect steps. For example, if the users try to perform an incorrect change of coins, or of balls in the Abacus, the system prevents them to continue and addresses a specific error message.

In the **Solution Sheet** 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. The underlined metaphor is that of the math workbooks where usually students do exercises and build solutions to problems. In the solution sheet users builds up a solution to the problem at hand by copying into this space the visual representations produced in the microworlds that they consider meaningful for working towards the solution. Students can employ verbal language and arithmetic symbolism to comment on the graphical representations copied and thus to explain their solution. This can be done by means of the "post-it" function. This function allows editing a short note, a comment, or, also, a mathematical expression, that it is possible to add, remove, correct, and move about in the solution space. Figure 2 shows the interface of the solution sheet with a solution produced by a student tackling a "purchase and sale" problem.

Figure 2. Interface of the Solution Sheet with an example solution

The **Simulator** allows the building of a 'simulation', in that it automatically records a sequence of actions performed by the users (in one or more microworlds and/or in the Solution Sheet). These can then be viewed as a sort of movie in the **Player** environment, possibly with an accompanying audio commentary. A simulation can be used to illustrate a concept, to describe how a specific problem can be solved, or, also, to explain the functioning of a microworld.

The course on arithmetic problem solving

This course was designed to introduce 9-10 year-old students to the solution of arithmetic problems of additive and multiplicative structure. The course was designed to be carried out in the classroom under teacher supervision, not for individual distance learning outside this context.

Objectives

The main research objectives underlying the design of the course on arithmetic problem solving were twofold: firstly to study whether and to what extent ARI@ITALES tools could support teachers in designing and managing classroom activities integrating technology and to assist them in overcoming some of the difficulties they usually encounter in this process; and secondly, to understand whether the designed activities could enhance students' learning of arithmetic concepts and problem solving strategies.

Mathematical content and structure

The course consisted of three modules comprising activities built with the ARI@ITALES tools: explanations, simulations, examples, problems to be solved, solutions to be completed by pupils, tests, consolidation exercises. All the modules were designed in collaboration with the two teachers who then ran the course in their class.

Simulations were prepared that explained how to use a microworld or a specific function therein (e.g. the change function in the Euro microworld) as well as to introduce concepts like monetary equivalence. Examples of solved problems were included to present a new solution strategy or to introduce a new mathematics concept. Tests were developed to assess the learning of specific concepts and procedures and to provide diagnostic feedback, with suggestions for further activities. Problems (mainly verbal problems) were formulated according to questions of increasing difficulty. Sometimes different versions of the same problem were proposed to different groups of students according to their level of ability. The course was initially assembled using the LRN Editor of Microsoft LRN Toolkit 3.0, then using the ITALES course assembly tool.

As to the mathematics learning objectives, the course was mainly focused to the development of arithmetic abilities of increasing level of formalization: counting, reading and writing numbers and making calculations; building strategies in microworlds for solving concrete arithmetic problems; converting the solution produced in a microworld into written verbal language and then into arithmetical relations; recognizing invariant properties in the structure of a problem and in its solution (e.g. reduction to the unit for proportionality problems).

More specifically, the activities proposed in Module 1 were mainly dedicated to develop counting capabilities and to solve additive and multiplicative purchase and sales problems by applying different strategies (e.g. total/part/remainder, completion, containment, partition). These activities entailed the use of the Euro and Abacus microworlds. Module 2 activities were aimed at reinforcing counting strategies in various situations (e.g. counting days and intervals of days) and at introducing concepts such as multiple, sub-multiple, and lowest common denominator. They mainly involved the use of the Calendar microworld. Module 3 was designed to introduce concepts pertaining to data representation by means of tables, histograms and graphs and involved the use of the Graph microworld. The calculation of parameters such as mode, arithmetic mean and median were introduced using the Spreadsheet microworld. Exercises were also included to foster reflection on simple formulas involving variables so as to make pupils aware of possible generalizations (e.g. direct and inverse proportion problems).

The field testing

Methodology

The course was tested in 2004 in a fourth-grade class composed of 20 pupils. The teaching experiment took place in the school computer laboratory equipped with 12 computers with web connections. For the lab sessions, the students were divided into two groups: in this way each pupil had a computer at his/her disposal. Each group attended the lab two hours per week for four months.

The experiment took place during normal school hours and was carried out by the two class teachers, alternatively one taking the group in the lab while the other followed the other group in class. Elisabetta Robotti participated in all the laboratory sessions as observing researcher. During class work, when all pupils were present, the teachers always sum up the activities performed in the laboratory and discussed them with the whole class.

By the end of the field experiment all the pupils had completed the first two modules of the course; time limitations prevented all but a few from completing Module 3. Consequently in the following section data from this last Module are not presented.

Data gathering

In order to collect data for evaluating the teaching experiment, two different types of observational assessment sheet were prepared. Such sheets were filled in for each pupil and for each laboratory session.

The first type of sheet ('*course sheet*') was designed to measure the efficacy of the course organization and components (simulations, problems, explanations, tests, etc.) as a support for the teacher. The second type of sheet ('*tools sheets*') was designed to measure the efficacy of the ARI@ITALES tools as a support for students in carrying out arithmetic problem solving activities.

In both types of sheet, the observations made during the experiment were clustered around three different issues: 'ease of use', 'impact', and 'effectiveness'. Each aspect was attributed, by the observing researcher, a numerical score from 1 (poor) to 4 (very good); space was also provided for comments. Issues considered in the sheets are mediated from Technology Acceptance Model theory (Davis, 1989). Such theory proposes a model to describe how users come to accept and use a technology, and states that acceptance and use of a technology was determined by two factors: perceived usefulness and perceived ease of use. In the analysis here reported the meaning of these crucial factors was adapted taking into account the specific educational and pedagogical objectives of the study under examination. More specifically, in the course sheets, 'ease of use' indicated the degree of difficulty encountered by a pupil in dealing with an activity in the course, e.g. downloading a simulation on the computer and using it. 'Impact' gave a general evaluation of the pupils' reaction to a course component, especially when they used it for the first time. For example, the impact of a simulation was evaluated in terms of the level of acceptance (whether the pupils liked it), possible impeding factors like length (overly long simulations might be boring, overly short ones vague), and the clarity of the explanation. 'Effectiveness' estimated whether a component fulfilled the aim for which it was designed in a given context. For example, simulation effectiveness was measured in terms of its success in explaining a concept and in helping the pupil understand errors.

The *Tools Sheets* evaluated how ARI@ITALES tools supported students in the problem solving process. Particular attention was dedicated to the main functions of the Solution Sheet and of the Microworlds. This evaluation was aimed at analysing the characteristics of the computer transposition of arithmetic knowledge and at studying whether the design of the learning activities successfully exploited those characteristics.

In the *Tools sheets,* 'ease of use' and 'impact' indicated respectively the degree of ease with which a function was used and the way in which pupils perceived it. 'Effectiveness' measured the extent to which the functions incorporated in the Solution Sheet and in the Microworlds were useful in promoting the development of specific arithmetic competencies and in helping students validating their actions. For example, it was demonstrated that some functions in the Euro microworld, like generating and moving coins on the screen, fostered the development of counting strategies (e.g. making groups of the same value, completing an amount to obtain a whole, etc.). Similarly functions in the Solution Sheet like the post-it function promoted pupils' abilities in explaining and verbalizing their solution strategies.

Tables 1 and 2 show an elaboration of the evaluation data collected with the *course* and *tools sheets*. Table 1 shows the evaluation given to the considered issues at three different moments in the experiment: the beginning and the conclusion of Module 1 and the end of Module 2. Table 2 shows the development of the pupils' arithmetic competencies at the beginning and at the end of Module 1.

Table 1. Results concerning the course components

Course components	**Ease of use**			**Impact**			**Effectiveness**		
	Module1 Start	Module1 End	Module2 End	Module1 Start	Module1 End	Module2 End	Module1 Start	Module1 End	Module2 End
Simulations	(2) 100%	(2) 17% (3) 82%	(2) 22% (4) 77%	(2) 100%	(2) 17% (3) 82%	(3) 100%	(3) 55% (4) 30%	(3) 70% (4) 29%	For first explanations: (2) 11% (3) 33%; (4) 55%; For help: (0) 45% (1) 55%;
Tests	(2) 25% (3) 40% (4) 30%	(2) 3% (3) 8% (4) 88%		(3) 50% (4) 35%	(3) 17% (4) 82%		(3) 32% (4) 23%	(3) 35% (4) 44%	

Consolidation exercises	(2) 10% (3) 20% (4) 60%	(2) 10% (3) 31% (4) 58%	(2) 11% (3) 11% (4) 55%	(3) 50% (4) 25%	(3) 58% (4) 41%	(2) 11% (3) 22% (4) 44%	(4) 85%	(4) 58%	Intersection of time intervals (2) 11% (3) 11%; (4) 66%; Number composition and factorisation (1) 33% (2) 22%; (4) 33%;
Solution completion exercises	(2) 10% (3) 40% (4) 45%	(2) 15% (3) 26% (4) 58%		(2) 25% (3) 55% (4) 20%	(2) 1% (3) 82% (4) 17%		(2) 25% (3) 70% (4) 5%	(2) 1% (3) 52% (4) 47%	Partition of time intervals: (1) 11% (2) 22%; (3) 22%; (4) 33%; Numerical partition: (1) 33% (2) 11%; (4) 33%;
Explanations				Used them: 20% Did not use them: 80%	Used them: 5% Did not use them: 94%	(3) 55% (4) 44%	(3) 50% (4) 50%	(3) 17% (4) 82%	Support for the learning of a new concept: (2) 55% (3) 11%; (4) 33%; Recalling of specific concepts: (3) 55% (4) 44%;

Table 2. Results concerning ARI@ITALES tools

ARI@ITALES Tools		**Ease of use**		**Impact**		**Effectiveness**	
		Module1 Start	Module1 End	Module1 Start	Module1 End	Module1 Start	Module1 End
Solution Sheet	Cut & Paste	(2) 5% (3) 20% (4) 55%	(4) 100%	(2)5% (3) 25% (4) 60%	(4) 100%	(2)10% (3) 20% (4) 100%	(4) 100%
	Post-it	(4) 65%	(4) 100%	(4) 65%	(4) 100%	Assigned Task (4) 45% Free use (4) 35%	Free use (4) 100%
	Accessing microworlds	(2)10% (3) 25% (4) 50%	(4) 100%	(2)10% (3) 25% (4) 50%	(4) 100%		

Euro Microworld	Voice synthesizer	(4) 65%	(4) 100%	(4) 65%	(4) 95%	For validating: 75% For counting: 25%	For validating: 29% For counting: 64%
	Moving coins on the screen	(2) 5% (3) 10% (4) 60%	(4) 100%	(4) 65%	(4) 98%	Arranging coins in groups: 0% Counting coins of the same value: 75% Forming groups of integer value: 25% Counting in sequence: 55%	Arranging coins in groups: 17% Counting coins of the same value: 21% Forming groups of integer value: 57% Counting in sequence: 15% Completion strategy: 4% Total/part/reminder strategy: 11% Additive strategy: 90%
	Changing coins		(4) 76%		(4) 76%	Understanding monetary equivalence: 82% Changing coins in a suitable way for enacting a solution strategy: 47% division as repetition of subtractions: 41%	
		Module 2 Start	Module 2 End	Module 2 Start	Module 2 End	Module 2 Start	Module 2 End
Abacus Microworld	Changing balls in the abacus	(2) 40% (3) 60%	(3) 30% (4) 70%	(2) 40% (3) 60%	(3) 70% (4) 30%	Representing a number: 90% Performing additions and subtractions: 40%	Representing a number: 90% Performing additions and subtractions: 80%

Discussion of findings

In the following, a brief analysis, both qualitative and quantitative, of some findings from the experiment is provided linking them with the objectives of the project. This analysis provides indications on the course and on its components that may give suggestions for future work in the field.

Supporting teachers in the design and management of classroom activity

First of all, the teachers appreciated the opportunity that the course offered for better following the learning rhythm of each pupil and for monitoring pupils who had been absent from time to time. Although the students participated in class activities, the course allowed them to follow the proposed learning itinerary on an individual basis. In this way students who missed classes could resume their learning itinerary without gaps, and those who experienced difficulties with some concepts could go back to pertinent explanations, simulations and examples.

The teachers also appreciated the possibility of designing activities to meet the needs of different students. For example, they found it useful to submit different versions of the same problem to pupils with different ability levels. Moreover, they considered it very useful to be able to save on their computers the work completed by each student during a session. In this way they could check and compare the different solutions and thus personalize the activities better during subsequent lessons.

As to course components, the activities entailing completion of a partially implemented solution proved to be effective for gradually consolidating pupils' acquisition of mathematical concepts. These activities were autonomously and correctly completed by 75% of the pupils in the initial sessions of the course and by 99% of them in the final sessions. Moreover, while at the beginning of Module 1 only 5% of pupils obtained a very good evaluation (score 4), at the end of this module this percentage rose to 47%.

Simulations proved to be quite useful for helping the teacher introduce a concept or a particular function of a microworld. Table 1 shows that, at the beginning of Module 1, simulations were perceived as effective by 30% of pupils. At the end of Module 2, this percentage increased to 55%. Nevertheless a significant percentage of pupils (45%) did not use simulations autonomously, after a first launch attempt, to recall a concept or a procedure, preferring to ask their classmates or the teacher instead. This was probably due to the fact that launching and watching a simulation was not straightforward and so many pupils avoided repeating this process.

The tests helped to verify the acquisition of specific procedures or concepts (e.g. 'changing' coins in the Euro microworld or balls in the Abacus). The tests were designed not only to provide evaluation feedback but also to introduce the pupil to specific remedial activities. This approach proved effective for the management of the activity, since the teacher did not have to rush from one pupil to another for checking and offering suggestions. The data show that, at the beginning of Module 1, 55% of pupils completed the tests correctly. At the end of this Module this percentage rose to 79%.

The ARI@ITALES microworlds have specific functions for validating crucial arithmetic competencies. For example, as said before, in the Euro microworld it is possible to select a coin or group of coins and to hear the corresponding amount pronounced by means of a voice synthesizer incorporated in the system. During the experiment, this function took on a crucial role in helping the pupil to learn how to count money. The voice synthesizer allowed pupils to compare autonomously what they thought they had done (e.g. generating 1,50 euro worth of coins) with what they had actually done (generating a sum of 1,05). This allowed pupils to correct their work autonomously by practising the rules governing the counting of coins. At the same time, the teacher was freed from the need to check the students' work for errors. The voice synthesizer was mainly used at the beginning of the course, when pupils had to strengthen counting and representation skills. As work progressed, they resorted to it less and less, although some pupils continued to use it as part of a trial and error strategy so as to avoid the effort of counting. This brought to light the need to provide the teachers with a function for disabling the voice synthesis as they saw fit.

During the course, the voice synthesis was also used for reading aloud problem texts. This proved useful for pupils who had difficulties due to reading or sight problems and who would otherwise have asked the teacher repeatedly to read the problem text aloud during the solution activity. So in this case the voice synthesizer made it easier for the teacher to manage class activities.

Other feedback functions incorporated in ARI@ITALES microworlds also proved to be effective. For example, the feedback provided by the system when students perform a change of coins in the in Euro microworld or of balls in the Abacus. Since this feedback is formulated to help students identify the error committed, if any, and correct it, it was frequently exploited during the experiment. For example, the teachers designed and proposed additional practice exercises for students with difficulties and asked them to perform these autonomously, relying on the system's feedback for checking their answers.

Development of arithmetic problem solving skills

Arithmetic problem solving is a field in which primary school students often experience difficulties, as indicated by many research studies and reported by many teachers (see, for example: Mullis, Martin, Foy, 2005). These difficulties have strong repercussions on students' self-esteem and future mathematics performance. Even at primary school level, students frequently perceive 'doing maths' as the execution of repetitive exercises according to formal rules whose meaning they often do not understand, or master only at the syntactic level. For many pupils problem solving is limited to 'guessing' the right arithmetic operation and carrying out the written calculations, since the semantics they associate with arithmetic symbols is poor and frequently limited to what the result of a computation denotes. These considerations highlight the importance of developing new methodologies and tools to better support the development of meanings for arithmetic operators and for problem solving strategies.

One of the objectives of the work here reported was to study how ARI@ITALES tools could be used to assist pupils in visually representing and solving arithmetic problems. Visual representation systems play a central role in mathematics education as a way of linking the symbolic approach to mathematics concepts to perceptive experience. ARI@ITALES microworlds were designed to offer pupils a variety of computational objects for representing and manipulating problem situations and resolutions steps.

Consider, for example, the development of counting strategies, which are crucial for arithmetic problem solving (Adetula, 1996). The Euro microworld allowed pupils to represent amounts concretely by means of coins. At the beginning of the course, 75% of the pupils counted coins in sequence, according to their value, and often made errors when dealing with an increasing number of coins or with higher amounts. Becoming familiar with the Euro microworld and taking advantage of the movement and change opportunities it offers, the pupils gradually learnt strategies better suited to facilitate the counting process. For instance, by moving coins on the screen, they composed groups of coins whose amount corresponds to an integer value, e.g. 1 euro, first using coins of the same value (e.g. groups of five 20-cent coins) and then coins of different values. The acquisition of progressively structured counting strategies was assisted by inserting examples of problems solved in the course. Looking at these examples, pupils were exposed to new ways of arranging and counting coins and banknotes. These skills were then consolidated by proposing partially solved problems that pupils had to complete. At the end of Module 1, 57% of pupils were able to count mentally without moving coins on the screen since they had internalised the process of moving and grouping coins and only used the mouse pointer to support the counting process and the voice synthesizer to validate their results.

As to the development of solution strategies, the possibility of moving coins on the screen helped the pupils to put in action total/part/remainder strategies and supported the attribution of a concrete meaning to the obtained groups of coins (the part, the remainder).

The generation of coins facilitated pupils in mastering completion strategies in additive problems. These strategies, which are crucial for mental calculation, are usually rather difficult for pupils to control. With the support of the Euro microworld, they were able to control all the phases of the process. For example, starting from a given quantity, they first generated the cents necessary to reach the successive decimal and then the decimals needed to reach the whole, and so on until they reach the target amount.

The change function of the Euro microworld supported the learning of the additive composition and decomposition of numbers by means of monetary equivalence. Results showed that a good percentage of pupils acquired these competencies from the early sessions of the course (82%). Almost half of the pupils also changed coins correctly with given constraints (e.g. changing a given amount using the least number of coins); this demonstrated that they had achieved a firm grasp of the manipulation of coins and numbers. The change function was used by a considerable number of pupils (47%) to perform the partition of a given amount into groups of given value. It is worth noting that the direct intervention of the teacher helped to avoid some possible misuse of the microworld functions (e.g. the opportunistic use of the change function or of the voice synthesizer).

The activities in the Abacus microworld were designed to support both the exploration of the rules involved in the decimal positional writing of numbers and the acquisition of concepts involved in adding and subtracting decimal numbers (e.g. the carry over concept). At the beginning of Module 2, about 90% of pupils represented correctly in the Abacus a monetary value previously built up with coins, and 40% were able to perform operations (additions and subtractions) by changing balls properly. At the end of Module 2, the percentage of students performing correct operations in the Abacus reached 80%.

The ARI@ITALES Solution Sheet supported the elaboration of the solution process enacted within the microworlds by allowing pupils to describe the strategy they had adopted both by means of the visual representations obtained in the microworlds and by means of verbal and symbolic language (using the 'post-it' function). The possibility of comparing different representations for the same value (for instance copying in the Solution Sheet the representations obtained in different microworlds, e.g. the Euro, the Abacus, and the Number Line microworlds) was used in the course to induce pupils to think over the symbolic representation of decimal numbers and to develop the capacity to handle more formal representations and their related properties. At the end of the course, almost 90% of the pupils were able to shift correctly from the verbal representation of a number to its decimal writing and to describe verbally in the Solution Sheet a procedure previously accomplished in a microworld; they subsequently managed to formalize this description using arithmetic symbols.

The activities in the Calendar microworld proved effective for developing meanings for some mathematical concepts, such as those of multiple, sub-multiple, and lowest common denominator (seen, for example, as the multiple interval of two or more time intervals). Then problems concerning the integer partition of a given amount were proposed. Eventually, more formal ways to tackle the concept were gradually introduced. Multiple problems were correctly solved by 80% of pupils, while 55% managed to solve problems related to the concept of lowest common denominator and integer partition.

Conclusions

Many research studies reveal that it is pointless from a pedagogical point of view to make computers and educational digital media available in schools if their use is not properly embedded in suitably articulated educational itineraries in which the whole learning context is taken into account, including the pedagogical and curriculum objectives, the tools and the way in which they are used, the teaching/learning paths, the different actors and their social relationships, etc. (Dias De Figueiredo & Afonso, 2006). Proper contextualization therefore becomes decisive in making educational software effective; otherwise, the potential of even the best program will remain largely unexploited. The design of effective contexts of use for ICT-based tools is a complex process that also requires changes in content, organization and management of classroom activity, innovations that are difficult for a teacher to accomplish effectively. One of the objectives of the project discussed here was to analyse whether an e-learning approach, supported by specifically designed authoring tools, can help the teacher in facing such changes.

The analysis of the teaching-learning activity carried out during the class experiment pointed out elements of the course and of the ARI@ITALES tools that had proved to be effective in supporting the management of classroom activities and the development of students' cognitive processes in arithmetic problem solving.

For example, the experiment highlighted the crucial supporting role of the feedback provided by ARI@ITALES tools. Direct diagnostic feedback proved useful in the acquisition of specific skills or procedures and in preventing students from making further incorrect steps. Indirect diagnostic feedback, such as that provided by the voice synthesizer, was helpful for supporting pupils in validating their work, thus fostering the development of crucial competencies such as counting. Moreover, some course components, such as tests, were designed to provide feedback in a way that would help students to understand errors made and to guide them in correction.

Backtracking and the possibility of revising the work previously done proved useful for supporting the ability of verbalizing and explaining the actions performed. This ability was also supported by the Solution Sheet, which allowed elaboration of the solution process enacted within the microworlds, transforming it into a product to reflect on and to share with others.

Some of the activities proposed stimulated students' attitude to anticipate mentally hypotheses and problem solutions. For example, exercises that involved completing a partially implemented solution, letting students concentrate on single steps, facilitated acquisition of gradually articulated solution strategies.

A decisive role was played by the pupils' interaction: they often discussed and exchanged opinions and advice on strategies to be used, and compared results. This important aspect of the activity was only partially supported by the technology used, since at the time the experiment was conducted the ITALES platform was not fully implemented and the online communication function could not yet be used. This was certainly a limit that prevented the design of course activities that exploit computer-mediated communication to promote mathematics learning. In previous work, the rich learning opportunities offered by such activities were analysed on the basis of a small-scale experiment carried out using a simple local network connection and an early version of the ARI-LAB system (Bottino, 2000). In future, a rethink of course design will be needed in order to include computer-mediated communication and collaboration activities. It can be said that the flexibility of the approach followed in course design will make it easier, than in a traditional setting, to modify and reorganise learning activities and to change their content.

Finally, it is worth noting that, even though this paper mainly focuses on analysing aspects related to teachers' management of ICT-based activities and on evaluating students' learning of arithmetic concepts, future work in the field will examine how the adopted approach can mediate the growth of communities of researchers and teachers who collaboratively develop, share and discuss the design of classroom activities based on the use of technology. This analysis will be carried out under the REMATH European project (EC-IST-4-26751-STP) that it is currently under development.

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