Studying Changes in Learning Environments Brought About by ICT-Based Systems

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Abstract. Aim of our work is to briefly introduce the main aspects of a methodology for the analysis of individuals and environmental changes brought about by the introduction of Information and Communication Technologies (ICT) in learning environments. The theoretical framework underpinning our work is that of Activity Theory. More specifically, we draw on the Cole and Engeström modelling of the complex relationships between elements in an activity. We have worked out our contribution on the basis of the experience we have developed in the design and use of ICT-based systems for mathematics education. In particular, in this work we refer to a project concerning the design, implementation, and experimentation of an open learning multi-environment system we have carried out for the development of arithmetic problem solving capacities in compulsory school students.

Keywords: ICT-based systems, learning environments, methodology, Activity Theory

1 Introduction

Aim of our work is to give a contribution to the definition of a methodology for the analysis of individuals and environmental changes brought about by the introduction of Information and Communication Technologies (ICT) in learning environments.

Our work is grounded on the assumption that learning cannot be fully understood if we look at it as an individual process without taking into account the whole teaching and learning situation where such process develops.

Often the introduction of ICT in education has been linked to a vision of learning as an individual process whereby knowledge emerges from the interaction between the student and the computer. This vision is borne out by the terminology frequently adopted in the literature, where educational software applications are often referred to as learning environments, thus focusing attention on the fact that it is the software itself, through interaction with the student, that is to form the environment where learning can be developed.

In our work we consider the relationship between learning technologies and learning environments according to a different perspective. In adopting the term learning environment, we consider the teaching and learning situation as a whole. That is to say, we consider the learning environment according to the definition given by Salomon in (Salomon, 1996, page 365):

> *A learning environment can be described as a composite of constituent factors: physical setting, set of agreed behaviours, consensually held expectations and understandings, particular tasks, around prespecified contents for explicitly stated goals that are guided by a person who has been given the responsibility over that setting, its participants, and activities. In other words a learning environment is first and foremost a system that consist of interrelated components that jointly affect learning in interaction with (but separately from) relevant and cultural differences.*

Attention towards the learning environment is bringing about a shift of focus in the analysis of the changes that take place in classroom practice due to technological innovation. The changes in the individuals' learning are in fact a part of a larger change, that of the learning environment. Consequently, it becomes clear that technology cannot be designed and evaluated in isolation of the environments in which it is used.

According with this view, the common and traditional separation of individual's attitudes and achievements from social-interpersonal variables fades, while a closer relationship between individuals' learning and social interaction is assumed.

The study of how the changes in students' learning are connected to the changes distributed over the whole learning environment as a consequence of the use of technology appear nowadays a necessity for the research.

In this work we introduce the main ideas of a methodology we have developed for studying the individual and environmental changes that occur in learning environments with the introduction of ICT.

The theoretical framework underpinning our work is that of Activity Theory (Leont'ev, 1974; 1978; Engeström, 1987). This theory has given us a reference point for explicating and analysing the main components that contribute to shape technology mediated learning environments, and has suggested a way to examine how such components interrelate. More specifically, our study of the changes in the learning environments brought about by the technology has drawn on the Cole and Engeström modelling of the complex relationships between elements in an activity (Cole and Engeström, 1991).

We have worked out our contribution on the basis of the experience we have developed in the design and use of ICT-based systems for mathematics education.

In particular, we refer here to a project concerning the design, implementation, and experimentation of an open learning multi-environment system we have carried out for the development of arithmetic problem solving capacities in compulsory school students: the ARI-LAB system (Bottino et Al., 1994, 1995).

2 Reference framework

As observed above, the theoretical reference we have adopted for analysing the relationship between technology and learning environments is that of Activity Theory. Activity Theory is a philosophical and cross-disciplinary theory for studying different forms of human practice, like teaching/learning practice, as development processes mediated by tools, where individual and social levels are interlinked at the same time (Kuutti, 1996).

In Activity Theory an activity is a form of acting directed towards an object, and it is the object that distinguishes one activity from another. Transforming the object into an outcome motivates the existence of an activity. Activities consist of actions or chains of actions, which in turn consist of operations. If we consider Activity Theory applied to the educational field, the object of an activity is the learning of a given knowledge or the development of a given ability; the outcome of this activity, the motive for which the activity is developed, is students' acquisition of that knowledge or that ability (Bellamy, 1996). Previously we have evidenced that individual learning can not be understood without considering the learning environment in which it takes place. Using the framework of Activity Theory we can state that the learning environment is constituted by the enactment of a teaching/learning activity oriented towards an object involving students, teacher and tools. Studying the learning environment means studying the teaching/learning activity oriented to a didactical objective.

In other words, studying the changes that learning environments undertake as consequence of the introduction of a computer tool means analysing how activity changes and how this change is meaningful for the students and the teacher.

Cole and Engeström (1991) have devised a model in order to formulate the complex relationships between elements in an activity (see Figure 1) that is particularly appropriate as to study the relationships that take place in the teaching/learning activity. Their systemic model highlights three mutual relationships involved in every activity, namely the relationship between subject and object, that between subject and community and that between community and object. Each of these relationships is mediated by a third entity. The relationship between subject and the object is mediated by tools that both enable and constrain the subject's action. The relationship between subject and community is mediated by rules (explicit or implicit norms, conventions, and social interactions), while that between community and object is mediated by the division of labour (different roles characterising labour organisation). The model depicted in Figure 1 also reveals that each entity mediates all the relationships described in the model.

Tools used in the activity mediate not only the relationship between the subject and the object but also that between subject and community and that between community and object. Moreover, mediating entities are not mutually independent but exert influence over one another. For example, the introduction of a new tool in an activity influences both the norms regulating participant interaction in the activity and the roles that the participants can assume.

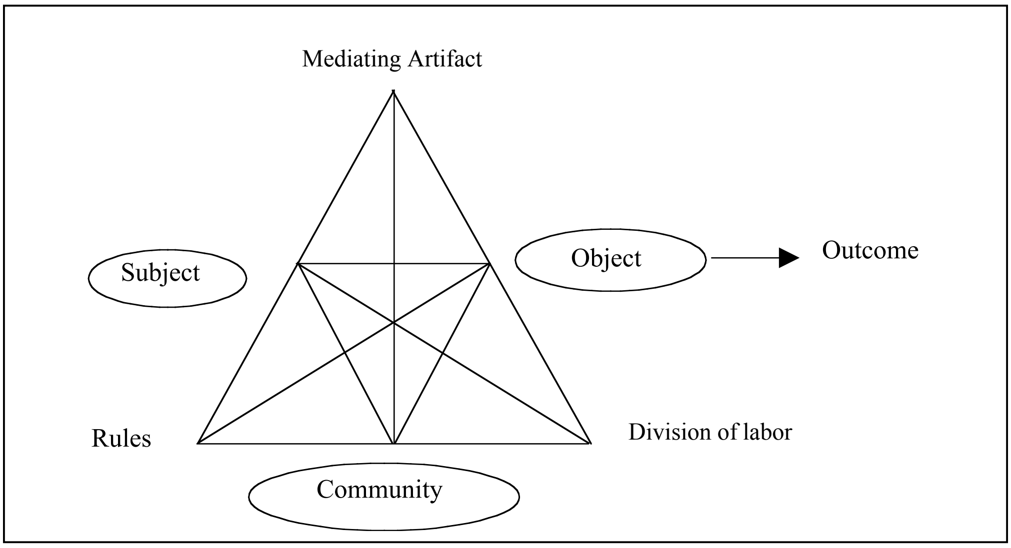

Fig.1: The Cole and Engeström's model of activity

3 A methodology for studying learning environments mediated by technology

In this section we briefly outline the main elements of a methodology we are developing for studying the relationships that are established between technology and the learning environment, drawing on our experience in the design and experimentation of an educational software for arithmetic problem solving.

In our work the technology has been utilised according to an approach that can be defined as an "orchestration" approach. According to it, learning is seen as the result of an active exploration and construction from the student, mediated by the tools made available in the activity and by the social interaction that develops within it. This approach emphasises the social nature of cognitive development and of meaning construction, ascribing a key role to the relationships established in the activity among the individual, the social group (the class) and the mediating tools used. According to this approach, technology is to be considered in relation with the whole teaching and learning activity and not only for the development of specific abilities or particular tasks. It follows that technology is to be used and evaluated in medium-long term teaching and learning processes of the kind needed for the development of complex articulated knowledge (e.g., arithmetic problem solving, comprehension and communication in language, etc.). For the development of such abilities, the mediation offered by a given software to cognition, is not sufficient to explain the learning aspects related with motivation, with goals formation and with the attribution of a meaning to the whole activity which goes beyond the meaning of the single actions involved in the performance of a task.

Drawing on the Cole and Engeström's model of activity, it is possible to identify three main elements of analysis for studying and designing technology-mediated learning environments:

1. How the educational technology used can mediate new ways for the learner of accessing and representing the concepts, procedures, and rules that are involved in the acquisition of a given knowledge or ability which constitutes a learning object for a teaching and learning activity.
2. How the educational technology used can contribute to the design and the enactment of didactical practices based on the explication of contradictions in the use of the rules related to the knowledge to be learnt and to the construction of appropriate ways of use for them.
3. How the educational technology used can contribute to mediate the assumption of new and old roles by participants in the didactical practice.

In the following we briefly discuss the above mentioned elements of analysis giving some examples taken from the work we have performed in the design and evaluation of the ARI-LAB system.

ARI-LAB is a multi-tools system that combines hypermedia and network communication technologies in order to support the teaching and learning activity in arithmetic problem solving with primary and lower secondary school students. The project of ARI-LAB is based, on the one hand, on research on hypermedia and communication systems and on the design and implementation of visual microworlds. On the other hand, it takes into account the research in mathematics education with particular reference to the studies on situated problem solving, on the role of visual representations in learning processes, and on interactive learning. The development of ARI-LAB has been an iterative process based on a number of experiments we have performed on the long term in real classroom settings. Thus, the current version, now available on the market (ARI-LAB, 1999), is deeply changed from the first prototype implemented (Bottino et Al., 1994).

3.1 How technology mediates the relationship between the student and the learning object

The analysis of the way in which technology can mediate new ways of accessing and representing concepts involved in the acquisition of a given knowledge or ability, should start from the consideration of 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 realised. It has to be considered how the student interacts with these computational objects and the way in which the feedback received from the system supports the emergence of goals during task performance. Moreover it should be considered the kind of tools offered to validate student's action and the support they offer to the evolution of student's knowledge.

For example, as far as arithmetic problem solving is concerned, in the design of the ARI-LAB system we started from the pedagogic consideration that primary school pupils (and often secondary school students) usually have serious difficulty tackling arithmetic problem solving and that teachers have trouble assisting them adequately. The school tradition relies on the early introduction of arithmetic symbols and written computation algorithms as the only way to describe the solution process and to obtain the result. This approach seldom works well, as is witnessed by the fact that too many students, when solving a problem, try to "guess" what operation is necessary: they are not able to give meaning to the arithmetical symbols in relation with the situation described in the problem. The introduction of arithmetical symbols and written computation, can be introduced more fruitfully when children have already experienced the potentialities of a numbering system, and are able to enact informal strategies within concrete problem situations. Research in mathematics education has highlighted the importance of developing problem solving activities within cultural contexts that are of significance to students. That is, contexts permitting the linking up of mathematics with out-of-school motivations, experiences and applications. During the ARI-LAB design phase these considerations have led to the creation of microworlds that model the resources and limitations of fields of experience both in the real world and in arithmetic via computational objects that the student can interact with by means of ordinary cognitive mechanisms (such as those used for basic spatial relations, like groupings, motion, distribution of things in space, etc.). For example, the field of experience of "purchase and sales" has been modelled through a microworld, the "coin" microworld, that allows to generate on the screen coins of both the Italian currency system and of the EURO, to move them in the working space, to change them with others of the same value, to select a coin or group of coins to copy it into another environment ("The Solution Sheet") in order to build up a solution for the problem at hand. Moreover, in the coin microworld, it is possible to hear the amount of a coin or group of coins (previously generated) pronounced orally by means of a voice synthesiser incorporated in the system.

Others microworlds incorporated in ARI-LAB are: "Abacus", "Calendar", "Line of Numbers", "Histogram", "Simplified Spreadsheet", "Art Bits".

The pedagogical objective for which the microworlds have been implemented is to offer students a space in which they can explore and manipulate graphical and computational objects designed to mediate the development of solution processes and thus the construction of meanings for arithmetic operations. The system supports the validation of specific actions or processes (e.g. counting, changing coins or balls in the abacus, etc.) offering a perceptive feedback (e.g. voice synthesis). The feedback obtained allows the user to progressively acquire competencies on specific aspects of the knowledge involved in the interaction with the microworlds and can support the development of didactical activities aimed at fostering the acquisition of crucial capabilities such as, for example, the co-ordination of verbal, graphical and written representations of numbers.

In Figure 2 the main interfaces of the Coin, Abacus, Number Building and Simplified spreadsheet microworlds are reported (in reduced size). Figure 3 shows the solution sheet produced by a user tackling the problem whose text is reported in the upper right-hand side of the figure. In the solution sheet the user builds up his/her solution to the problem at hand by copying into this space the visual representations produced in the microworlds that s/he considered meaningful for problem solution. The user employs verbal language and arithmetic symbolism to comment on the visual representations copied and thus to explain the solution performed. From the solution sheet it is possible at any time to access the microworlds and also the other environments (e.g. the Communication environemnt) the systems is composed of.

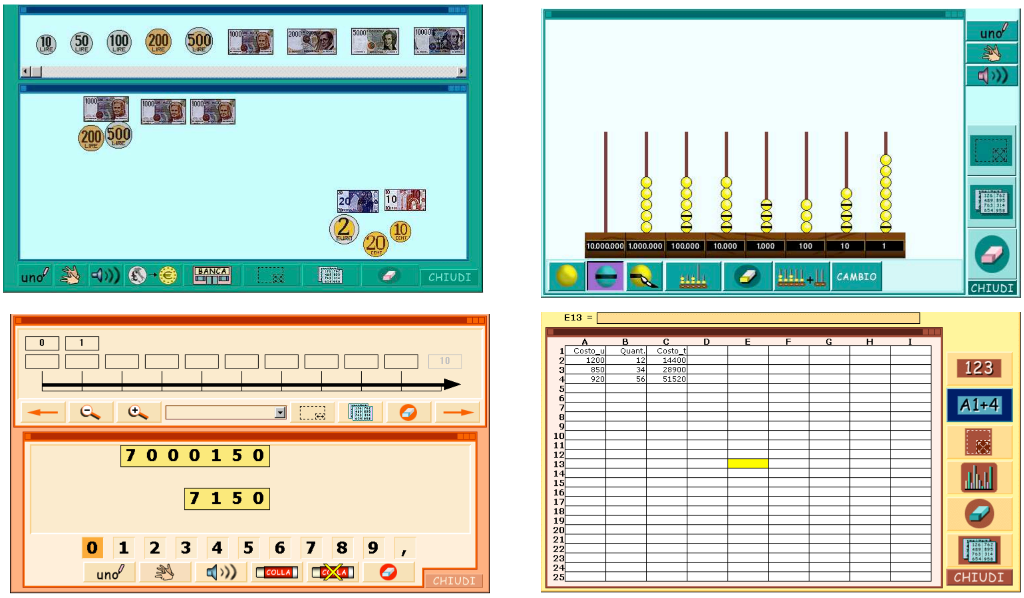

Fig.2: Interfaces of the Coin, Abacus, Number Building and Simplified spreadsheet Microworlds

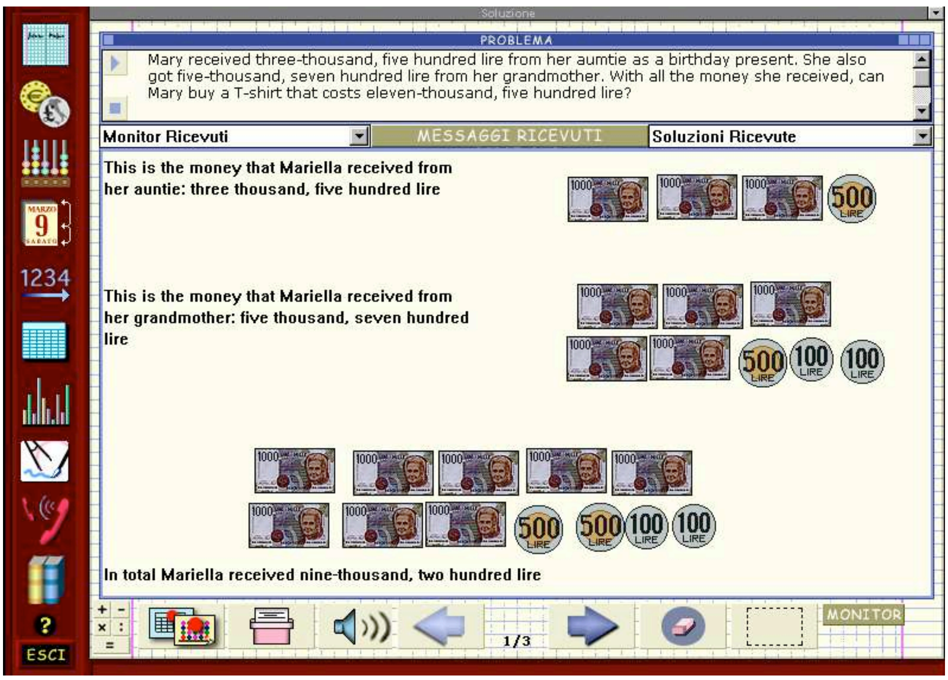

Fig. 3: Interface of the ARI-LAB Solution Sheet

3.2 How technology can contribute to change the way in which rules mediate the relationship between subject and community

The acquisition of a given knowledge or ability is not just the result of the interaction of the student with the computational objects a system makes available but also emerges from the social interaction developed in the classroom during activities mediated by the technological tools at hand.

Within the Activity Theory framework, Cole and Engeström's model allows to perform detailed analysis of the changes brought about in the learning environment as a result of technology-mediated activity and to examine how these influence the students' learning processes.

In particular, Cole and Engeström's model shows that the relationships between the student involved in an activity and the learning community (the teachers and the other students of the class) are mediated by rules. Rules define what is and what is not acceptable practice in performing a task related to the acquisition of a given learning objective. We note that, within the educational context, these rules are not to be considered as acquired by the students, but represent an object of learning themselves.

The transformation of rules from being individual-community mediators to objects of learning takes place in a network of activities where shifts of focus and breakdowns occur within the tool mediation.

For example, in the activity mediated by ARI-LAB, a breakdown occurs when the work is interrupted because a gap has emerged between what the subject had anticipated and what he/she had actually accomplished with the system (e.g. a difference between the coins generated by a student to represent a given amount and their actual value pronounced by the voice synthesiser). A breakdown can occur also because contradictions arose among the participants during system mediated activity. ARI-LAB includes a communication tool that allows the user to establish a connection with another user and to exchange messages and problem solutions by means of a local network. So contradictions can emerge among students as result of a communication activity expressively designed by the teacher.

The breakdown always represents a marker of the contradiction in the individual-community relationship about what is considered acceptable use of the rules. A focus shift is a change in the activity or in the purpose of the action that may emerge in system' use as a consequence (but not necessarily) of a breakdown.

Through the shift of focus, the rules cease to be a reference element mediating the operations the student performs automatically and unconsciously, and become an object of his/her targeted actions.
It follows the necessity to offer teachers tools that allow them to focalise on these rules the attention of the students during the activity. Two characteristics of the ARI-LAB system play a crucial role at this regard.

From one hand the validation opportunities it offers (both those embedded in the system and those it mediates through the possibility of performing appropriate communication activities) allows to develop activities based on the exploration of rules and conventions underlying the different representation systems incorporated. For example, students can be engaged in prediction-validation processes during counting activities which can allow them to develop control capabilities over these processes and that can foster their evolution.

From the other hand, the opportunity the system offers of converting the solution to a problem into different representation registers providing tools for co-ordinating them (e.g. a problem solution can be represented in different microworlds, it can be described through written language and graphical representations in the solution sheet, it can be sent to another student that can compare it with his/her own, etc.) allows the realisation of activities aimed to foster the passage from rules and conventions related to specific fields of experience (i.e. that of buying and selling) to representations more general from the mathematical point of view.

3.3 How technology can contribute to change the roles assumed by participants in an activity

Cole and Engeström's model shows that belonging to a community implies a division of labour, that is the repeated and renegotiated distribution of work tasks, power and responsibilities among participants. In practice, the division of labour determine the area of responsibility to be managed by each participant (student or teacher) within the activity, with respect to the knowledge to be learnt, and for which each will respond to the community. Consequently, when studying a learning environment, it is important to analyse how a learning situation may support the student in the assumption of responsibilities when tackling a task related to the knowledge at play. In addition it is important to consider how a learning environment can support the teacher in assuming roles suited to assist the students in the social construction of the knowledge involved in the activity. A number of different strategies may be adopted at this regard (see, Tharp and Gallimore, 1989): modelling, contingency management, feedback, instruction, questioning, and cognitive structuring.

For example, the particular characteristics of the ARI-LAB system allow assistance roles to be widely shared among participants in the activity rather than being exclusive charge of the teacher. For instance, the ARI-LAB communication feature, which permits students to share solutions, allows the teacher to orchestrate situations whereby those experiencing difficulty can be provided with models and strategies for imitating more proficient students, who, in this way, assume a cardinal role in steering classmates towards action schemes conducive to problem solution.

The interiorisation of these action scheme and solution strategies is necessary for the student to be able to use them in different contexts and situations. This interiorisation is related to the possibility of operating a reflection over them aimed to convert them in different representation systems. The ARI-LAB system offers tools to support the re-elaboration of personal experience and its sharing within the class. In particular, it makes available a tool, the Monitoring, that allows to view, in a sort of movie form, all the actions performed by a users while solving a problem. The use of this tool, within appropriate didactical practices, can support the transformation of the solution procedure into an object that can be used as a basis for discussion in the social context of the class. This discussion may have different aims, such as the comparison of strategies, the analysis of the mathematical properties involved in the solution processes undertaken, etc.

The action, communication and monitoring possibilities offered by the ARI-LAB system allow the teacher to foster the evolution of students' solution processes through the performance of activities based on control, comparison, and reconstruction strategies. These strategies allows the teacher to assist students in performing those abstraction in situation processes that are necessary to construct a meaning for arithmetic symbols which is at basis of arithmetic problem solving.

4 Conclusions

From what briefly sketched in this work, it emerges how the relationship between advanced technologies and learning environments should be studied considering the whole teaching and learning activity which develops in a given context. ICT offer new tools that can allow changing the didactical practices oriented to the acquisition of a given knowledge and, consequently, the learning processes carried out. In order for these objectives to be pursued it is necessary that the design phase of an educational system is not disjoined from that of design and validation of didactical practices meaningful as far as the knowledge and abilities to be learnt. The design and evaluation of new didactical practices is to be considered as an integral part of the design and implementation of an educational software (Bodker, 1996).

Changes in learning environments brought about by the introduction of ICT needs to be considered as a two-way process: not only do technological tools influence and transform the activities performed with their mediation, but the results of these activities also deeply influence the technology used. This influence can be seen at two levels. On the one hand, computer tools can change during use without being altered technically since use in context brings to light new possible uses of the features incorporated in the technology. On the other hand, use in context may contribute to the outlining of new practices and, as a consequence, may reveal new needs that in turn lead to the design of new tools.

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