METHODS AND TOOLS TO FACE RESEARCH FRAGMENTATION IN TECHNOLOGY ENHANCHED MATHEMATICS EDUCATION

Bottino Rosa Maria & Cerulli Michele

Institute for Educational Technology, C. N. R. - Genova, Italy

This paper, addresses the issue of how to successfully bring into school practices the results in technology enhanced mathematics learning obtained at research level. The distance among different research teams and between researchers and teachers is addressed in terms of fragmentation of the research field. A methodology is presented to reduce such fragmentation illustrating a pathway followed at the European level in the EC co-funded projects TELMA and ReMath.

INTRODUCTION

In the CERME 5 conference two plenary sessions (Ruthven, 2007; Artigue, 2007), drawing from the discussions developed in different working groups, highlighted key issues concerning Technology Enhanced Learning (TEL) in mathematics.

According to Ruthven (ibid pp. 52), despite of a generalized advocacy for new technologies in education, these have had a limited success in school. As a matter of fact, he observes that, even if technologies had some positive impact on the instruction of teachers, they remain marginal in classroom practice. This is true, in particular, for mathematics, even if, from the beginning, a wide number of researchers have been concerned with the study of the opportunities brought about by new technologies to the teaching and learning of this discipline (Lagrange, Artigue, Laborde, & Trouche, 2003). As a matter of fact, despite the positive results produced in a number of experimental settings and the budget invested by many governments for equipping schools, actual use of ICT tools in real school environments is still having a limited impact. Recent studies witness difficulties encountered by teachers in implementing teaching and learning activities mediated by technologies due to variables such as working environment, resource system, activity format, curriculum script and time economy (Cuban, 2001; Sutherland, 2004). The coordination of such variables is necessary in order to develop a coherent use of technological tools and to form an effective system. According to Ruthven (ibid pp. 64), this challenge "involves moving from idealised aspiration to effective realisation through the development of practical theories and craft knowledge". Drawing from our own experience, we identify as a crucial issue the necessity to establish effective interactions among the different actors involved in the process, that is researchers, teachers, policy makers, curriculum developers, software designers, etc.

Such a view is coherent with what is reported in (Pratt, Winters, Cerulli & Leemkuil, in press) from the perspective of educational technology designers. Authors, making reference to the specific field of games for mathematics education, speak of the necessity of a multi-disciplinary approach to design and deployment of technologies as opposed to the frequently experienced design fragmentation. Such fragmentation is often due to the fact that the different communities involved are not fully cognisant of the structuring forces that impinge on each other's activities. From one hand, discontinuities between design and deployment of technological tools impede the effective use of such tools in school practice and, on the other hand, the development of isolated projects that often do not go beyond experimental settings, do not contribute to cumulative knowledge about the design process that could inform future work. Pratt et al. advocate the need to integrate key stakeholders in the creation of technology enhanced learning tools, as "the problem of design fragmentation remains a real impediment to widespread innovation in the field". They thus state the opportunity of creating multidisciplinary teams focusing on the design and deployment of educational technology that bring together the perspective of different stakeholders: designers, educators, researchers, etc.

Fragmentation, however, is not only a problem experienced among different communities of stakeholders, but it is a problem often experienced also within each community. In particular, as highlighted by Artigue (2007) during her plenary speech at CERME 6, this is one of the key issues of concern within the community of the researchers in mathematics education, and, in particular, within the community of researchers focusing on technology enhanced learning in mathematics. Such a fragmentation is rooted at theoretical level, as witnessed also by the work of the working group 11 of ERME that has been established to discuss such specific issue (Prediger, Arzarello, Bosch & Lenfant, 2008). As a matter of fact the theoretical background of a research team has an important bearing on the epistemological assumptions, the research methodologies, the way in which tools, and, in particular, technology enhanced tools, are perceived and used.

At the European level, where a great variety of different approaches and background is present, there is a specific sensibility to the problem of fragmentation and to the necessity to find feasible ways to overcome it, since, as observed in (Arzarello, Bosch, Gascón & Sabena, 2008) a too wide variety of poorly connected conceptual and methodological tools does not encourage consideration of the results obtained as convincing and valuable. Moreover, in the specific area of TEL, there is the need of designing and implementing tools and methodologies that have a wide scope of application and that are not restricted to a particular community or context. For these reasons, following the impulse given by projects funded by the European Community, efforts have been made to try to overcome such fragmentation.

Our Institute has been involved in European research projects concerned with Information Society Technologies (IST) for several years and, in particular in Networks of Excellence (NoE) and Specific Targeted Research Projects (STREPs). These are two instruments of the European Community 6th and 7th Research Framework Programmes that aim at promoting research integration and collaboration in several fields including technology enhanced learning.

This paper presents some methods and tools, developed within the context of such European projects, which have been developed and tested to address the fragmentation issues discussed above.

Firstly we report on the work performed within the TELMA (Technology Enhanced Learning in Mathematics) initiative that explored the conditions for sharing experience and knowledge among different research teams interested in analysing mathematics learning environments integrating technologies, in spite of the differences in the theoretical frameworks and in the methodological approaches adopted. For this purpose, the notions of "*didactical functionality*" (Cerulli, Pedemonte & Robotti, 2006) and of "*key concerns*" - issues functionally important (Artigue, Haspékian, Cazes, Bottino, Cerulli, Kynigos, Lagrange & Mariotti, 2006) - together with a methodology based on the idea of a "*cross experiments*" (Bottino, Artigue & Noss, in press) were defined and conceptualized as concrete methods to address the problem of fragmentation.

Secondly, we give account of some of the outcomes of the ReMath project that, building on the results of the TELMA project, has addressed the fragmentation problem from the perspective of the design, implementation, and in-depth experimentation of ICT-based interactive learning environments for mathematics, thus involving not only researchers but teachers and technology designers as well. In particular, within the ReMath project, the problem of how to effectively support collaboration in pedagogical planning has been faced. Efforts have been made to provide a solid basis for accommodating the different perspectives adopted, for analysing the factors at play, and also for understanding the initial assumptions and theoretical frameworks embraced. A web-based system, the Pedagogical Plan Manager (PPM), was developed to support researchers, tool designers and teachers to jointly design and/or deploy mathematics pedagogical plans involving the use of technological tools (Bottino, Earp, Olimpo, Ott, Pozzi & Tavella, 2008).

Summing up, in the following sections, we delineate the process that has brought us to afford the problem of the fragmentation of approaches and frameworks, in the field of mathematics teaching and learning mediated by technologies, from different but complementary perspectives.

A COLLABORATIVE METHODOLOGY FOR NETWORKING RESEARCH TEAMS IN TECHNOLOGY ENHANCED LEARNING IN MATHEMATICS

NoEs have been established by the European Commission within the last Framework Research Programmes as instruments to promote integration and collaborative work of key European research teams and stakeholders in given fields. In particular, the network of Excellence Kaleidoscope was established and funded with the aim of shaping the scientific evolution of technology enhanced learning (http://www.noe-kaleidoscope.org, accessed March 2009). Since each knowledge domain raises specific issues either for learning or for the design of learning environments, within Kaleidoscope a number of different joint research initiatives, covering a wide range of domains, have been carried out. Among these, TELMA was specifically focused on Technology Enhanced Learning in Mathematics. It involved six European teams[1] and had as its main aim that of building a shared view of key research topics in the area of digital technologies and mathematics education, proposing related research activities, and developing common research methodologies.

In TELMA, each team brought to the project particular focuses and theoretical frameworks, adopted and developed over a period of time. Most of these teams have also designed, implemented and experimented, in different classroom settings, computer-based systems for supporting teaching and learning processes in mathematics. It was clear from the beginning that, to connect the work of groups that have different traditions and frameworks it was necessary to develop a better mutual understanding and to find some common perspectives from which to look at the different approaches adopted. It was also necessary to develop a common language since the same words were sometime used with different meanings by each team, causing misunderstanding and hindering productive collaboration. Moreover, it became clear that the theoretical assumptions made by each team, were often implicit and thus not accessible to the others.

The notion of didactical functionalities

In order to overcome these difficulties it was decided to focus the work of TELMA on the theoretical frameworks within which the different research teams face research in mathematics education with technology. A first level of integration has been then pursued through the definition of the notion of *didactical functionality* for interpreting and comparing different research studies (Cerulli et al., 2006). Such notion has been used as a way to develop a common perspective among teams linking theoretical reflections to the real tasks that one has to face when designing or analysing effective uses of digital technologies in given contexts. The notion of didactical functionality is structured by three inter-related components:

- a set of features/characteristics of the considered ICT-tool;
- an educational aim;
- the modalities of employing the ICT-tool in a teaching/learning process to achieve the chosen educational aim.

The different didactical functionalities designed and experimented by each team have been compared trying to delineate how different theoretical backgrounds can influence the design of an ICT-based tool, the definition of the educational goals to be pursued, and the modalities of use of the tool to achieve such goals. At the beginning, this analysis was conducted on the basis of a selection of papers published by each team. This approach, even if useful, was considered not sufficient to enter the less explicit aspects of the research work of each team. Thus, TELMA researchers decided to move toward a strategy that could allow them to gain more intimate insights into their respective research and design practices. This strategy relies on the idea of ‘cross-experiments’ and on the development of a methodological tool for systematic exploration of the role played by theoretical frames.

The cross-experiments methodology

The idea of cross-experiments was developed in order to provide a systematic way of gaining insight into theoretical and methodological similarities and differences in the work of the various TELMA teams. This is a new approach to collaboration that seeks to facilitate common understanding across teams with diverse practices and cultures and to elaborate integrated views that transcend individual team cultures. There are two principal characteristics of the cross-experiments project implemented within TELMA that distinguish it from other forms of collaborative research:

- the design and implementation by each research team of a teaching experiment making use of a ICT-based tool developed by one of the other team involved;
- the joint construction of a common set of questions to be answered by each team in order to frame the process of cross-team communication.

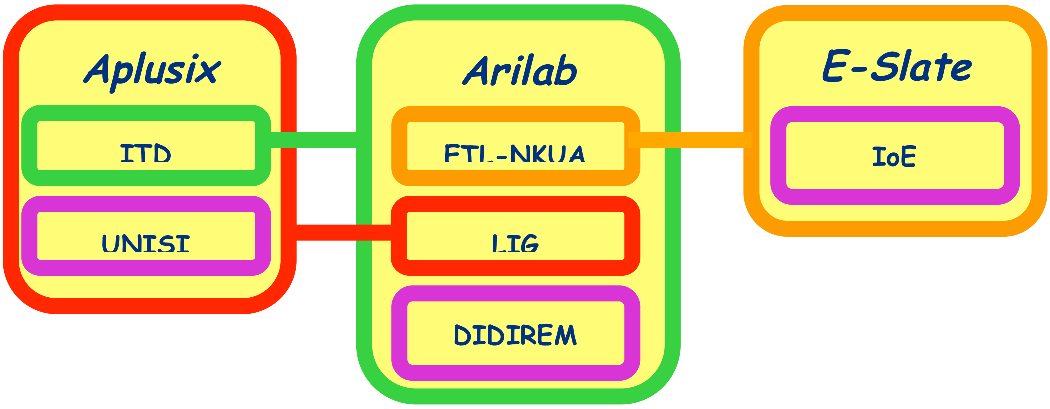

Figure 1: *Aplusix*, developed by Metah, was experimented by ITD and UNISI. *Arilab*, developed by ITD, was experimented by LIG, ETL-NKUA and DIDIREM. *E-Slate*, developed by ETL-NKUA was experimented by IoE.

Each team was asked to select an ICT-tool among those developed by the other TELMA teams (Figure 1). This decision was expected to induce deep exchanges between the teams and to make visible the influence of theoretical frames through comparison of the didactical functionalities developed by the designers of given tools and those implemented by the teams experimenting the tools. Moreover, in order to facilitate the comparison between the different experimental settings, it was also agreed to address common knowledge domains (fractions and introduction to algebra), to carry out the teaching experiments with students between the 5th to 8th grade, and to perform them for about the same amount of time (one month).

Guidelines (Cerulli, Pedemonte & Robotti, 2007) were collectively built for monitoring the whole process: from the design and the a priori analysis of the experiments to their implementation, the collection of data and the a posteriori analysis. Beyond that, reflective interviews (using the technique of "interview for explicitation" (Vermesch & Maurel, 1997)) were a-posteriori organized in order to make clear the exact role that theoretical frames and contextual characteristics had played in the different phases of the experimental work, either explicitly or in a more naturalized and implicit way.

It was hypothesized that, for each team, the use of a non familiar (alien) tool would have made problematic, thus visible, design decisions and practices that generally remain implicit when one uses tools developed within his/her research and educational culture, and that this visibility would have been increased by the guidelines' request of making explicit the choices performed.

The cross experiments provided interesting insights on the complexities involved in designing and implementing mathematics learning environments integrating technology and allowed to make some reflections (Bottino et al., in press; Cerulli, Trgalova, Maracci, Psycharis & Georget, 2008).

The first reflection was on the conditions that can facilitate the sharing of experience and knowledge among researchers in spite of the differences in the theoretical frameworks adopted. Theoretical frameworks, while influencing design and analysis of a teaching experiment, were far from playing the role they are usually given in the literature. As a matter of fact, in the design of the cross-experiments, theoretical frameworks acted mainly as implicit and naturalized frames, and more in terms of general principles than of operational constructs. Even if some variations could be noticed, all the teams experienced a gap between the support offered by theoretical frames and the decisions to be taken in the design process. The acknowledgment of such a gap can be a starting point for establishing a better communication channel not only among researchers but also with teachers. As a matter of fact, a marked emphasis on theoretical assumptions is often too far from the practical needs of teachers. For this reason it is important to establish the exact role that theoretical frameworks play in the planning of an effective teaching experiment. In particular, it was found that researchers tend to overestimate such role, thus making the distance with teachers' needs even bigger. A methodology for making explicit, and justifying, the choices made, proved a useful tool for reducing communication disparities.

A second observation concerns the understanding of what it means to adapt an ICT based tool to a context different from the one it was designed for. In our work this was accomplished by experimenting in each country tools developed in other countries by different teams. Thanks to the adopted methodology and to the request of making explicit assumptions, choices and decisions taken, it was possible to individuate some variables that strongly affect the development of teaching experiments involving the use of technologies. For instance, the attention paid to different *research priorities* (e.g. the detailed organization of the milieu; the social construction of knowledge; the teacher's role) and to *local constrains* (e.g. curricular; institutional; cultural) appeared to be crucial. Such variables are to be deeply considered and made explicit in the communication with teachers to effectively support them to adapt research experiments to their teaching contexts. In other words, researchers should find ways to make explicit all the key assumptions at the basis of their experiments. Of course, this is not enough, since, as suggested in (Pratt et al., in press), it is also necessary to promote a more strict collaboration between researchers, tool designers and teachers also at the level of the design and the implementation of ICT based tools, and in the planning of the experiments.

Taking into account these needs, and on the basis of the results obtained in TELMA, a new European project was thus developed, involving the same research teams: the ReMath project (IST - 4 – 26751 - STP). In this project the issue of collaboration between different stakeholders was addressed by developing a specific tool to be used to design teaching experiments involving ICT based tools.

A TOOL TO SUPPORT THE COMMUNICATION OF DIFFERENT STAKEHOLDERS IN THE PLANNING OF LEARNING ACTIVITIES INVOLVING TECHNOLOGY

The TELMA project provided a strategy for reducing the difficulties of communication among researchers; this strategy proved to be quite effective, thus it was decided to adapt it to the needs of the ReMath project where communication in a wider community, including software designers, researchers and teachers, has been addressed. The Remath project has two main goals: the development of ICT-based tools for mathematics education at secondary school level and the design and experimentation, in different contexts, of learning activities for classroom practice involving the use of such tools (see: http://remath.cti.gr/default_remath.asp; accessed March 2009). In order to pursue this last goal, a cross-experiment methodology, widening the one developed by TELMA, was adopted. A tool, the Pedagogical Plan Manager (PPM), was, thus, developed to support communication between researchers and teachers when planning learning activities involving ICT tools. The idea was originated by the analysis of some the difficulties, pointed out by researchers in the wide field of learning design (Koper & Olivier, 2004), concerning dialogue and transfer between teachers, researchers and designers. To overcome such difficulties the PPM was realized, relying on the concept of *pedagogical plan*, as a specific system for supporting the process of pedagogical design, namely the description of learning activities to be enacted during cross-experiments (thus also enabling and fostering their reusability).

Pedagogical plans are conceived as descriptions of pedagogical activities to be carried out in real contexts (e.g. a class, a laboratory, etc.) where a number of different indicators could be made explicit, at different level of details (Bottino et al., 2008): educational target (What learning outcomes? What learning contexts? Who are the target learners?); pedagogical rationale (Why those learning outcomes? Why applying a certain strategy? Why using a give tool?); specifications (Which activities are to be carried out? Which roles are to be assumed by the different actors? Which resources and tools are to be used? etc.).

The PPM is a web environment, organized as a flexible structure allowing a three-alike representation of *pedagogical plans* as hierarchical entities which can be built and red at different levels of detail. This structure supports both “authors” of pedagogical plans, providing them with the possibility to work with a top-down structure, and “readers”, who in top-down organization have a facilitating factor for navigating from the general to the particular and vice versa.

In other words the PPM presents a flexible structure that tries to respond to the different needs of both researchers and teachers; the first, in fact, were mainly interested in sharing ideas about aspects such as the theoretical frameworks and the pedagogical rationale behind each educational intervention, while teachers were mainly interested in retrieving suitable information about the most suitable ways to carry out educational activities in their classes (Earp & Pozzi, 2006).

For space reason, we cannot provide here a detailed description of the model adopted and of the prototype implemented (more details can be found in Bottino et al., 2008). Outputs of its use are currently under examination and will be further analysed at the end of the ReMath project (May 2009).

CONCLUSIONS

Software designers, researchers and teachers may have different needs, different constrains, and different perspectives. This can be an obstacle for the effectiveness of technology enhanced learning in mathematics, also in terms of impact in school practice. The projects briefly presented tried to develop a coherent methodology for reducing the distance between the different stakeholders. In TELMA it was addressed the problem of networking research teams with different backgrounds and approaches by means of a specific collaborative methodology. In ReMath such methodology was extended, also through the development of a specific web-based tool, to involve all the stakeholders in the design, development and deployment of teaching and learning activities involving the use of technologies.

The outlined pathway includes researcher’s explicitation of the actual role played by theoretical frameworks in the effective use of ICT tools and the individuation of the gap between theory and practice. This can help reducing the distance with teachers. The tool for pedagogical planning developed in the ReMath project is aimed at the same goal by involving teachers, from the beginning, also in the design of teaching activities with ICT-based tools. Such activities are seen as integral part in the design process of a technology. In this way we believe it can be possible to develop communities of practice that bring together teachers and researchers so that teaching practice and research could nurture one from each other favouring a better impact of technology enhanced learning in school practice.

NOTES

1. TELMA teams (whose acronyms are indicated in brackets) belong to the following Institutions: Consiglio Nazionale delle Ricerche, Istituto Tecnologie Didattiche, Italy (ITD); Università di Siena, Dipartimento di Scienze Matematiche ed Informatiche, Italy (UNISI); University of Paris 7 Denis Diderot, France (DIDIREM); Grenoble University and CNRS, Leibniz Laboratory, Metah, France (LIG); University of London, Institute of Education, United Kingdom (IOE); National Kapodistrian University of Athens, Educational Technology Laboratory, Greece (ETL-NKUA).

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