Teachers and Technologies: Shared Constraints, Common Responses

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Abstract This chapter presents a synthesis of a set of studies focusing on teachers' technology-based activity at the classroom level. Each of the studies is contextualised, singular and deals with individual teachers. Cross-analysing the findings of these separate situations aims to identify common characteristics in terms of common responses to shared constraints (in the French context) related to the use of technology by *ordinary* mathematics teachers. The synthesis is developed with the aim of analysing regularities in the practices of ordinary teachers integrating technologies into their teaching. These regularities are structured along three issues: How to simultaneously teach mathematics and use technology in class? (cognitive axis); How to teach mathematics in new teaching environments? (pragmatic axis); How to manage the time of teaching and learning when using technology? (temporal axis).

Keywords Technology integration • Teachers' practices • Mathematics teaching • Teaching environments • Didactical approach • Professional constraints

Introduction

In recent years, an increasing interest has been paid by educational research to teachers' practices in technology environments. Constraints and difficulties encountered by mathematics teachers' integration of technologies has also been an ongoing issue. Researchers have investigated different aspects of teachers' practices in technology-rich classrooms by using or developing different theoretical frames. Kendal and Stacey (2002) studied the discrepancies and variability in the ways

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teachers use technology in their mathematics classrooms. Ruthven and Hennessy (2002) investigated teachers' ideas about their own experience surrounding lessons incorporating the use of digital technologies and developed a model that included different levels of teachers' expectations and ideals. In order to understand the key factors of teachers' activities and roles through a holistic approach, Monaghan (2004) used Saxe's cultural model centred on emergent goals under the influence of four parameters. Drijvers et al. (2010) investigated, within the general frame of the instrumental approach (Vérillon and Rabardel 1995), the types of orchestrations that teachers develop when using technology. More generally, in the latest ICMI study (Hoyles and Lagrange 2010), research studies addressing the theme of teachers and technology revealed that integrating technology is not an easy task for teachers who have to cope with an increasing complexity in preparing lessons and managing the classroom while taking into account several features going beyond familiar formats and routines in a paper and pencil environment.

The aim of this paper is not to present the results of a single research study related to these same concerns, but rather to offer a synthesis of a set of studies that I have conducted over the past decade and that have yielded outcomes focusing on the teacher's activity at the classroom level. Each of these studies is contextualised, singular and deals with individual teachers. Through the study of these singular situations, I aim to identify common characteristics related to the integration of technology by *ordinary*[1] mathematics teachers, to analyse certain regularities in teaching practices and to investigate the factors that determine them. Of course, the professional group 'secondary mathematics teachers who use technology' is not homogeneous. My goal is to try to identify, beyond this heterogeneity, some homogeneity in responses to shared constraints and various institutional incentives (in the French context) to integrate digital technologies in mathematics teaching.

Three Research Studies

Background

In the early nineties I was engaged in a project where researchers worked with a group of teachers, who were experts in digital technology, to identify the potential offered by Computer Algebra Systems for teaching and learning (Artigue 1997). One of the results of this work was that technology-expert teachers have a poor sensitivity to the changes that technology integration implies, due essentially to their technology expertise. We highlighted a complex balance between achieving learning goals and working with technology that is unfamiliar to students, where the

[1] 'Ordinary teachers' means in this chapter, teachers who are not technology-experts and who are not involved in experimental projects.

role of the 'expert teacher' is essential in maintaining the mathematics activity and management of students in a satisfactory manner.

A few years later, I was a member of a group of French researchers leading a review of research literature that looked at more than 600 international publications (published before 2000) dealing with Information and Communication Technology (ICT) in the teaching and learning of mathematics (Lagrange et al. 2003). My own contribution within this group was to examine publications that focused on the 'teacher dimension'. The major finding was the relative paucity of systematic studies investigating mathematics teachers' integration of ICT into their classroom practices. Most of the existing studies aimed at studying beliefs and knowledge of teachers regarding technology integration or at examining innovative technology-based activity of teachers working in experimental situations.

The findings of these two research studies and the questions they raised led me to focus on investigating ordinary teachers' use of digital technology in their lessons with an emphasis on their classroom practices. By ordinary teachers, I mean teachers who are neither technology-experts nor participating in experimental research projects but whose daily professional contexts reflect real school conditions. I then participated in several studies about teaching practices in technology environments that involved experienced teachers using either dynamic geometry or online exercises and trainee teachers who experimented with several technological tools during their first year of teaching. The three studies presented in this paper are qualitative in nature and are based on direct observation of classroom practices or on traces of classroom practice, as reported by teachers.

First Study: An Experienced Teacher's Practice

The first study involved an ordinary teacher using dynamic geometry (Abboud-Blanchard 2009). The teacher observed was not engaged in any innovation or research project and had an episodic, as opposed to significant use of technology with her students. The lesson was on spatial geometry with a grade 9 class (fourth year of the lower secondary level, aged 14/15 years) and it took place in the computer room. The students used dynamic geometry software in assigned groups of two or three working with one computer. The lesson observation was videotaped. The topic concerned the cutting of a pyramid by a plane parallel to the base, and the teacher used an activity that was pre-designed by the software developers.

This case study sought to investigate the approaches that an experienced teacher develops when using dynamic geometry system in an ordinary classroom context in order to characterise the teacher's activity and its impact on students' learning with technology. The analysis provided findings that related to: the tasks proposed for the students' learning; the management of the students' groups; and the teacher's discourse and the interaction with students. These findings were contrasted with the results of a similar analysis of a non-technology-based lesson with a class of the same level, on the same aspect of problem solving in order to highlight the characteristics of a technology-based lesson (Abboud-Blanchard and Paries 2008).

Second Study: Experienced Teachers' Practices

The second study involved five secondary mathematics teachers using online Electronic-Exercise-Bases (EEB) with grade 10 students (first year of the upper secondary level, aged 15/16 years). These specific technological tools are software applications that mainly consist of classified practice tasks within a tutoring environment that can include guidance, corrections, explanations and sometimes reminders of mathematics courses.[2] The research questions were addressed within the context of a regional French project focused on encouraging mathematics teachers to use the EEB (Artigue and al. 2008). The aim of the project was pragmatic in that it involved observing the potential of such tools in ordinary classes, with an emphasis on helping the weaker students (Abboud-Blanchard et al. 2007).

The general issues related to the investigation of teachers' practices within the project were: Why and how do teachers use EEB?; What effect does this use have on their teaching activity? To answer these questions, we observed volunteer teachers using EEB over a period of 3 years. Most of the teachers were familiar with classroom use of technology at the beginning of the project (Abboud-Blanchard et al. 2009). The data analysis was qualitative and it related to: lessons preparations; class observations and answers to questionnaires and interviews. All of the observed lessons were EEB lessons on the topic of algebra and took place in the computer room. The students worked on a common on-line worksheet that had been prepared by the teacher before the session.

Third Study: Beginner Teachers' Practices

The aims of this third study were to investigate the initial professional uses of technology by pre-service mathematics teachers in order to understand the conditions in which these uses take place. In France, pre-service mathematics teachers benefit from a one year professional course in order to obtain their master's degree in secondary education. They teach mathematics, advised by a tutor, in one or two classes throughout the year. Over the last few years training teachers to the use of technologies has become more and more significant and a set of competences in the area of ICT for teaching have to be fulfilled by the trainees at the end of the training year. However, obstacles to technology use still persist even if, during their pre-service training, the

[2] See for example: http://mathenpoche.sesamath.net/.

trainees benefit from conditions that might help them develop professional uses of technology (Abboud-Blanchard and Lagrange 2006).

The study focused on five pre-service mathematics teachers as case studies (Abboud-Blanchard et al. 2008). The data was of two types: professional dissertations about using technology in the classroom and interviews carried out with them at the end of the training year. During this period, pre-service teachers have to write a professional dissertation about their teaching practices as part of their final assessment and they are free to choose the topic. Some trainees, as in these five cases, choose to deal with the use of technology in the classroom. In this study, these professional writings are considered as *traces* of genuine practices (Van Der Maren 2003), as a way to approach what the pre-service mathematics teachers consider as significant practices and also their reflections on these practices. The interviews provide complementary information on how they deal with technology-related potential and possible restraints within technology-based lessons.

The five mathematics pre-service teachers considered in the research had various profiles with regard to technology (profiles drawn throughout the analysis of the interviews). The training in the use of technology had various effects depending on the one hand on these profiles, and on the other hand on differences relating to their original didactical concerns.

The analysis of the lessons reported in the dissertations enabled an exploration of the uses of technology by trainees in two phases of the teacher's work, which are preparation work and classroom work. Thus, the research provided a closer look at what pre-service mathematics teachers' technology-based activity developed throughout the year of training and how they reflect on these first teaching experiments.

Theoretical and Methodological Considerations

The studies presented above used the same theoretical frame as a route to better understand the complexity of teachers' technology-based practices within the general frame of the *double approach*, developed in France by Robert and Rogalski (2005). It is this frame that is presented in the first sub-section. My aim is to build on these studies by synthesising their results in order to emphasise the regularities in the way that teachers integrate technology into their classroom practices. This gives rise to a new theoretical construct introduced in the second sub-section.

The Double Approach Framework Used in the Three Studies

The general framework used is the *double approach*, which combines both a didactical and an ergonomic perspective in analysing the teacher's activity in classrooms, as well as the factors that determine it. Rogalski (2008) argues that the frame of reference for the *double approach* is that of *activity theory*, which was initiated by Leontiev (1978), enriched by Vygotsky (1986), and then exploited and developed within the context of ergonomic psychology (Leplat 1997; Rogalski 2004) before being articulated within the context of teaching mathematics.

The *double approach* was introduced and developed by Robert and Rogalski (2002, 2005) to incorporate, on the one hand, a didactical perspective, which views the teachers' activities that involve task choices and classroom management as a key to accessing students' activities, and on the other hand an ergonomic perspective, which considers that in order to study their activity, teachers must be seen as professionals having craft knowledge, beliefs and previous experience whilst working in given institutional and social conditions. On a methodological level, Robert and Rogalski distinguish five components that can be observed or questioned, and whose reconstitution provides access to the teacher's practices. The *didactical perspective* takes into consideration the fact that there are two main types of channels used by the teacher for and during classroom activity; the organisation of tasks prescribed to students (cognitive component) and the direct interactions through verbal communication (mediative component). The *ergonomic perspective* of analysis is associated with the teaching profession. It considers the teacher as performing a given professional activity. His/her performance depends on a multiplicity of factors, the main ones being: professional history, knowledge and beliefs (personal component); institutional constraints and rules (institutional component); and social interactions in the work environment (social component). The five components of the double approach are thus:

1. The *cognitive component* is linked to the mathematical intentions and goals of the teacher. The analysis relating to this component focuses mainly on the scenario the teacher sets for students in terms of mathematical tasks. These scenarios include the time allocated for the students to work on tasks, the form of this work and the tools to be used, such as paper-and-pencil, technological tools and blackboards.
2. The *mediative component* is related to all of the interactions, verbal or not, observed as the lesson progresses, such as the interactions between teacher and students (explaining the tasks or giving aid), and interactions between students. The data analysis focuses on how the teacher engages and maintains the students' activities and on the type of help he/she provides to enable the students to achieve the tasks. Robert (2008) distinguishes two types of help, depending on whether they modify the activities scheduled or promote directly mathematical knowledge. The first type, *procedural help*, deals with the prescribed tasks by modifying activities with regard to those planned from the presentation of the task. It corresponds to indications that the teacher supplies to students before or during their work. The second, *constructive help,* adds something between the strict activity of the student and the expected construction of the mathematical knowledge that could result from this activity.
3. The *personal component* deals with the teacher's conception of mathematical knowledge, of teaching processes and of the way students learn mathematics, as well as his/her own professional history. In the case of using technology, more

specific features could be added to the former, such as familiarity with technology or beliefs related to the impact of technology on mathematics learning.

4. The *social component* is about how teacher adapts to the conditions of the work environment in a given school, to the habits of the class, to the colleagues as individuals and also as a community. For instance, if it is not a rule of action in the school, the teacher might not let the students work in small groups although he/she is convinced of the usefulness of this type of class management.
5. The *institutional component* mainly concerns the influence of institution, for example, via the curriculum, institutional guidelines, hierarchy requirements, and so on. It might also concern compulsory textbooks or assessment forms. In the case of pre-service mathematics teachers, it could also depend on what is highly recommended by teacher educators or training programmes. These factors are often considered by the teacher as constraints to deal with while practicing the teaching profession.

An analysis using the double approach aims to locate the characteristics of each component within the activity of the teacher in situ. The recombination of these components provides access to a teacher's practices. The double approach postulates that these practices are both complex and stable, that is, a teacher's activity in classroom has its own logic and consistency, and practices do not change easily. For pre-service teachers. It is less clear whether their practices have stabilised but we assume that the coherence of their practices is already established. Indeed, Lenfant (2002) shows that the practices of pre-service mathematics teachers develop and organise into a coherent system in the early months of teaching career and stabilise quickly during the first year. Stability does not, however, mean invariance as practices evolve over time, especially depending on external constraints, but in a coherent manner specific to each individual teacher.

In my work, I consider the complex articulation between the stability of practices and the evolution of the activity in the classroom due to the use of technology. My study of technology-based lessons focuses on the analysis of tasks and scenarios (cognitive component) and on the development of the lesson in the classroom (mediative component). This analysis makes it possible to understand what occurs in classroom when integrating technologies. The interpretation of the regularities and discrepancies of the findings relates to the three other components that reflect the personal determinants of the teaching practices and those related to the teaching situation. These components are accessed indirectly since they are mainly deduced from what the teachers declare (through interviews or questionnaires) about their activity and work conditions.

Synthesising the Results: An Emerging 3-Axis Structure (CPT)

The practices analysed in the three studies are certainly shaped by the socio-educational and institutional conditions in which each teacher accomplishes his/her job as well as by the personal trajectory. Even though the research questions and contexts were diverse, a close examination of the results discloses some regularities that go beyond this factual diversity. These regularities seem to be directly related to the common constraints and difficulties that teachers face when using technology and the way that they handle them. Variety does certainly exist as it could be related in the first place to personal history and professional experience (personal component) but also to belonging to a professional group (institutional and social component), such as for the pre-service mathematics teacher group.

This view of the outcomes as a whole aims to provide a means to analyse both the constraints felt by the teachers in their work and the responses they give in their technology-based practices that are consistent with the usual paper and pencil practices. These responses reveal what seems possible with regard to the stability and coherence of practices. In other words, these are choices (though certainly related to the personal component) that reflect how teachers invest the few options left, given the institutional and social constraints.

The cross-analysis of the findings of the studies shows regularities that crystallise around three major issues:

- How to simultaneously teach mathematics and use technology in the classroom?
- How to teach mathematics in new teaching environments?
- How to manage the time for teaching and learning when using technology?

In other words, the search for regularities in the results lead to a structure along three axes that relate to: the mathematical content taught with technology; what the teacher does and says when implementing a class situation using technology; and different aspects of time management of this situation. The synthesis is therefore organised in accordance to this structure: *Cognitive axis, Pragmatic axis* and *Temporal axis*.

The results referring to the first two axes are derived from the analysis of the cognitive and mediative components of practices. Although the first axis is naturally named cognitive, the second one's name (pragmatic) reflects that it is first based on the effective observation of teacher classroom activity, i.e. what really happened and not what might have, enabling subsequent access to its interpretation. Examining the results with respect to this axis certainly incorporates elements of the mediative component (articulated with the other four components). Nevertheless, the study of practices in technological environments shows ubiquity of transversal aspects in the lesson management that go beyond the single achievement of tasks, which is the primary objective of analysis within the mediative component.

As to the third axis, class observation analyses and teacher interviews reveal the complexity of teaching in technology environments with respect to time. This complexity concerns several aspects: the length of time needed for the organisation of teacher's work (preparing lessons, planning lessons, evaluating the outcomes of lessons); the dynamic time of the class; and the didactical time of learning. Of course, the question of time is recurrent in education research and it is present either as an explicit object of study or as an implicit element in the analysis. In our work, the issue of time was a study parameter that was taken into account during the analysis. Cross-analysing the results brings me to highlight the crucial role that time plays when it comes to technology-based lessons, and which sometimes allows a better understanding of the choices and actions that relate to the other two axes.

This synthetic structure is therefore a means to describe, in a global way, the results obtained from the analysis of practices by successively following each of the three axes. Moreover, these three axes are intertwined and some interpretations relating to one of them could relate to the other. In the next section, I will define each axis and corresponding results more precisely.

Result Synthesis According to the Three Axes

How does an ordinary teacher cope with the increased complexity that arises from the implementation of technology? The outcomes of the three studies are synthesised in terms of individual or collective responses to conditions and constraints related to technology integration. What regularities emerge from studies in various contexts in dealing with different technology tools? What are the possible determinants of these regularities? What remains variable among teachers and why? The synthesis that follows will emphasise these considerations within the descriptions of the three structuring axes.

Cognitive Axis: How to Simultaneously Teach Mathematics and Use Technology in Class?

The institution has various means to encourage teachers to use technology, such as the curricula, assessment recommendations, training and institutional resources. This kind of incentive determines some of teachers' choices when preparing student tasks and the way that teachers address the role of technology in learning activities. The results would then reflect the balance that teachers achieve, consciously or not, between institutional incentives to use technology, interpretations they make of curricula, and their own routines of teaching mathematical topics (or even their own experience as learners in the case of pre-service mathematics teachers).

In our studies, and despite the diversity of tools and contexts, all of the observations showed that the tasks in technology environments are essentially identical to those in paper and pencil environments. These findings concur with other research findings that have addressed similar issues. They are close to what Kendal and Stacey (2002) underline about CAS, which is that mathematical knowledge and skills stay globally within the range of those expected in non-technological environments. Moreover, research dealing with experienced teachers shows that they view the use of technology firstly through the lens of their usual practices (Ruthven and Hennessy 2002) and tend to integrate it *a minima* in their classroom sessions (Lagrange and Erdogan 2009). Of course, many studies have recently shown teachers implementing challenging related-technology situations into their teaching (Hoyles and Lagrange 2010). Still, the teachers investigated in almost all of these studies were involved in collaborations with researchers or educators, and therefore could not be considered as 'ordinary' teachers as stated previously.

In the case of teachers using EEB, student tasks are usually the same as those proposed in paper and pencil environments, although facilitated in the EEB environment which contributes by improving the graphic and geometric dimension and providing fewer repetitive exercises on the same mathematics topic. Moreover, only knowledge in development or previously acquired knowledge is the topic of such tasks. It seems unlikely to make students work on wholly new knowledge with EEB because such tools are essentially designed only for skills practice activities. However, we observed similar phenomena with more open software that embodied different principles of design and architecture. Teachers who use dynamic geometry set tasks where the contribution of the software is limited to improving spatial awareness through the dynamic manipulation of more familiar paper and pencil figures, so as to support the proof process. Laborde (2001) examining the tasks that teachers made with Cabri, noted also that they started by using the software mainly as an amplifier for visualising properties, but not really as the source of the tasks that they gave to students.

In the case of trainee teachers, analyses show that they almost all choose dynamic geometry environments to carry out their first technology-based lessons, which might be because dynamic geometry has been emphasised in their training programmes. We note on the one hand, referring to the discourse of teacher-educators, the potential abundance of these environments for student activity, especially for the visualisation of mathematical phenomena. But on the other hand, this declarative intention does not necessarily translate into actual uses in classrooms. Indeed, when a pre-service mathematics teacher uses dynamic geometry software with the intention of allowing the student to make the right conjectures by himself/herself through experimentation, observations show that this supposed experimental activity of the student is often reduced to him/her following a well-guided worksheet, with manipulation instructions, thus considerably lessening the potential of the software in the student activity.

More generally, we observe that in order to take full advantage of technology tools, teachers prepare mathematical tasks that are globally more complex since they require many adaptations, such as the construction of stages in geometric reasoning with dynamic geometry software or the articulation of algebraic and graphical frames with EEB. However, analyses of classroom observations reveal that the teacher's interventions almost always lead to a division of the tasks into simple sub-tasks, thereby reducing the opportunities for students to achieve enriched mathematical tasks with technology tools. This last observation can also be attributed to the difficulties related to classroom and time management (pragmatic and temporal axes). This issue is discussed in the next sections.

However, long-term studies of EEB and pre-service mathematics teachers (see also Laborde 2001) show that changes will take place and seem to affect mainly the cognitive component of teachers' practices. These trends emerge from a perceived need to find a better articulation between technology-based sessions and paper and pencil sessions in order to reduce the student's perception of the former as an unusual session and to take advantage of the potential of technologies to improve learning in the latter.

For example, pre-service teachers do not feel this need early in their training year, but highlight it at the end of the year, as was the case for this pre-service mathematics teacher interviewed at the end of the training year:

> *at the beginning, I did not see usefulness of technology, in the sense that, for me, it was doing the same exercise using computer instead of using paper-and-pencil. To me, it was nothing more than a change of tool without any other change. Now I see that I can do something else with technology and thus complete what I do with paper-and-pencil.*

All of the observations emphasise the fact that teachers promote quickly the use of paper records within the students' activity involving technology. For instance, teachers using EEB insist that students use a sheet to keep notes and some of them promote the use of a specific notebook devoted to technology sessions. This use of paper evidences an aspect of the articulation of technology activity with the ordinary activities. The written forms enable work which has been completed with technology to remain accessible within the whole learning process. The integration of technology activities in the ordinary sessions can also influence the assessment phase, i.e. most teachers who develop significant uses of EEB also incorporate similar EEB exercises within their traditional tests.

Pragmatic Axis: How to Teach Mathematics in New Teaching Environments?

Technology-based lessons often involve changes in the working environment, particularly when technology facilities are not available in classrooms (Ruthven 2007). The observations on which this synthesis relies all took place in a computer room with generally two students to a computer. In addition, the use of technological tools is, by itself, a source of difficulty, especially when teachers are not familiar with its handling. What influence does this specific environment have on the lesson in progress? One can assume that the management of the lesson will combine both the difficulties of organising work in small groups and those of technical work with the computer, the implications of which will now be examined more closely.

The Teacher's Role

In general, computer environments seem motivating for students and the teacher's interventions may be much less frequent than those observed in paper and pencil sessions. Nevertheless, we note that the teacher's presence is essential for the students to get started in their work even with software designed to be used autonomously (EEB, for example). Indeed, many students could not progress without the teacher's assistance, but also because they have difficulty interpreting the feedback of the software, which sometimes does not correspond with their expectations. Thus the teacher is kept very busy interacting with students, often in response to their difficulties, throughout the session. Indeed, when the software itself incorporates guidance to solve exercises (e.g. EEB), one might expect to see teachers acting more as observers of students' work and being less interactive with them. The observations show this is not the case. It is the same when it comes to more open software such as dynamic geometry, where the teacher is constantly asked to help interpret the phenomena observed on the screen in terms of geometric conjectures, although it was planned that students would discover the conjectures for themselves.

However, even if this heightened interactivity with students seems to be prevalent amongst the experienced teachers, we note that trainee teachers prepare highly structured worksheets, allowing them to lessen their interventions while students interact directly with the software without their mediation. This role of beginner teachers might be due to several factors including the fact that (these teachers) have not yet developed classroom management routines enabling them to incorporate a new environment. That is to say that the mediative component of practices is in progress but not yet stabilised. Another factor is the low degree of familiarity with the use of the technology tool, which does not allow teachers to have confidence in their ability to know how to manage learning using software that they have not yet fully mastered. Indeed, didactic research in the field of technology has shown that supporting the instrumental genesis of students is a complex task for the teacher (Trouche 2004). A teacher's degree of familiarity in the use of the tool is one of the factors inherent in this complexity. Our research has shown that teachers who are unfamiliar with the software organise the students' tasks in a fairly guided way. The low level of students' instrumentation reinforces this trend. This is particularly observable amongst trainee teachers. The student tasks are often specified in a written worksheet distributed to students at the beginning of the session. This document typically includes a large number of technical tips for the handling of the software as well as questions related to mathematical issues to guide the individual student's work. In the case of EEB, because of the apparent simplicity of these tools, teachers tend not to consider the instrumentation question as a central obstacle to their uses. However, during the first uses of EEB by experienced teachers, we observe similar phenomena as above, that is, when using EEB for the first time the teachers propose guided worksheets for their students.

Finally, when some experienced teachers planned a marginal role relative to students' interaction with the software, this was due to an expressed desire to give more autonomy to students. It is in fact consistent with a feature of the personal component of these teachers who perceive that the teacher's role is to help students be more autonomous in their learning. Let us examine, for example, the case of a teacher working with EEB. She tries to make the students commit themselves to solving a mathematical task by using the software as a privileged partner that controls and validates answers. She considers that her primary role is to help the students to use the software correctly in order to perform mathematics tasks. Her intervention within mathematical tasks consists of providing only constructive help to students. This finding relates to her desire to help the students be more autonomous. Indeed, when she started to work with EEB, she stressed that her main goal was to enable students to work by themselves without any external intervention, in order to acquire 'good solving processes'.

The Teacher's Interventions

Analyses of observations show few collective interventions and a majority of individual interventions to assist the students' work. The teacher focuses on providing local mathematical help without decontextualising the students' work, that is, his/her assistance consists almost exclusively in procedural help aiming at simplifying the students' activities. They are of various kinds: controlling the solutions to problems and associated calculations; validating an answer or helping to find the error (often at the request of students); and structuring the solution or asking students to do it. They sometimes reduce the efficiency of a student's activity, for instance, when the teacher indicates the theorem to be used or questions the student about the mathematical rule referred to by the exercise.

In some cases, breaking tasks into simple sub-tasks is so evident that sometimes the teacher has practically dictated the work that the students needed to do. Often, when the teacher is interacting with a group, students only follow his/her instructions or even finish a sentence that he/she begins. This type of support is partly motivated by the teacher's concern about the progress of the students' work, in order to ensure that all the tasks prepared for the session are completed. This echoes a strong trend in teaching practices in the computer room highlighted by several researchers (see, for example, Monaghan 2004). It is worth noting that the teacher stays with every group for a very short time and thus his/her assistance must allow the students to pursue their work on their own. This last issue is also related to time constraints which are discussed in the next section (the temporal axis).

Some interventions are rather technical and related to the use of the software. They consist primarily of explaining how to resolve a technical problem such as how, in EEB, to switch from one exercise to another. They are usually brief, local, and allow the student to continue towards a solution. Other interventions consist of helping the student in the meticulous execution of a set of software commands (which are sometimes even provided in the worksheet) in order to perform a mathematical task. The latter could not be qualified as procedural help, since there is no modification/simplification of the planned student activity. It is not characterised in the typology defined within the frame of the double approach. This leads me to define a new type of help (add to the existing procedural and constructive types): *handling help* that consists of supporting the student to use the software in order to achieve the planned mathematical task without modification. This type of help is directly dependent on the use of tools. It is present in technology-based lessons (but it also can be observed in a non-technology environment when a tool is used for the first time), especially when the students cannot all handle the software with ease. The frequency of this type of help, which is not common in a mathematics course, disrupts the usual class management and adds to the previous difficulties that teachers have encountered in technology environments.

Furthermore, to provide effective help the teacher must be familiar with the tasks proposed in both their dimensions related to the technical use of the software and to doing mathematics with the software. Indeed, to understand the difficulty encountered by the student, it is often not enough to look at the computer screen, notably when there are few traces providing information on the progress of the student prior to the arrival/intervention of the teacher.

Finally, the use of support materials or teaching aids is less frequent. These aids provide an opportunity to support the students to accomplish the tasks on which they are working and, at the same time, to retain knowledge that goes beyond what is directly mobilised to solve the problem. The analysis of the aims of this kind of help often shows that the need for these aids is motivated by the fact that the sole didactic interaction implemented within the software is insufficient for the students to achieve the learning objectives set by the teacher. It also shows that these aids are all the more difficult to predict by the teacher as they should be adjusted to the particular path of each pair of students working with machine. Moreover, within computer based sessions, the generalisation of constructive help to the whole class, as it is often the case within a paper and pencil environment, seems very difficult for teachers to achieve, as explained in the following paragraph.

The Class Split into 'Mini-Classes' and the Disappearance of Collective Phases

Working in a computer room generally entails students working together in groups of two or three per machine. After an initial collective phase (where the teacher explains the work to be done), which is frequently very brief, we observe that the class splits into several 'mini-classes' (one, two or three students per computer) with whom the teacher interacts separately from the remainder of the class. For each of the mini-classes, the teacher adapts to whatever the students are doing and to their current reasoning, whereas in paper and pencil lessons, it is more often the students who have to adjust themselves to the teacher's path (Abboud-Blanchard and Paries 2008). This appears to be an important characteristic of the class management of a technology-based lesson which differentiates it from a non-technology one. Monaghan (2004) also pointed out this difference by specifying that the teacher's talk is generally directed to groups of students around a computer.

Moreover, the analysis of the teacher's discourse shows similarities in the successions of his/her interventions among the mini-classes that could be described as follows:

- The teacher arrives at a mini-class;
- The teacher finds out how far the students have progressed;
- The teacher tutors the students in their problem solving activity by structuring the reasoning and introducing sub-tasks;
- When students start to execute these sub-tasks correctly, the teacher moves on to another mini-class.

Indeed, the time the teacher spends with each mini-class is actually limited (see below temporal axis), which might explain this systematic division of tasks in order to enable students to have clear work to be completed even in the teacher's absence. This mode of student management seems to be a feature of computer room sessions, which can be tiring and uneconomical for the teacher. We observe teachers repeating the same comment several times, making the same suggestion, giving the same help.

It is also to be noted that working in the computer room implies a special pattern of how the teacher moves around the classroom and manages students' work. Drijvers (2011) identifies this type of teaching practice as the *work-and-walk-by* practice, that is the students work individually, or in pairs, and the teacher walks around the room and monitors the students' progress. Of course, this pattern is not specific to ICT environments. However, we agree with Drijvers when he stresses that within an ICT environment, this practice puts high demands on the diagnostic skills of the teacher. Indeed, a look at the computer's screen is not always enough to understand what the student has already done and to determine the most appropriate form of help.

Consequently, there is a quasi-disappearance of collective phases when technology based-lessons take place in the computer room. The students work at different paces and the teacher cannot, in certain cases, generalise the support that is given only to some mini-classes whereas they could be useful to many others. Artigue and al. (2008) encountered the same feature, notably that individual interactions substitute for collective interactions and that institutionalisation phases are non-existent because of the different trajectories of students. Furthermore, the final stages of the sessions do not give rise to any institutionalisation of knowledge. However, this regularity has a relative significance given that the sessions we observed did not aim to introduce new knowledge and were designed as revision sessions by the teachers.

Looking through the lens of evolutions of practice we note that teachers, after only a few sessions, move towards an awareness of the absence of these phases. Indeed they tried to compensate for this void when it seemed necessary, by returning in the following session to collective phases in order to unify the students' knowledge that was involved in the previous technology-based lesson.

Temporal Axis: How to Manage the Time of Teaching and Learning When Using Technology?

The issues concerning time management need to be taken into account when analysing the teacher's activity, whether within one lesson or several lessons organised over time. It concerns not only what happens in the classroom but also includes the time outside the class, i.e. preparing lessons, searching for resources, collaboration with other teachers, and so on. The notion of time requires a distinction between two types of time, didactic time and physical (clock) time. Didactic time is the time that regulates the learning process and involves knowledge construction, which can be one of two kinds, *meso time* and *micro time* (Chevallard and Mercier 1987). Meso time is somewhat linear and relates to the scheduling by the teacher of the learning objectives in a sequential way whereas micro time takes into account the dynamics of practices in the context of the classroom (Chopin 2005). Our analyses of classroom observations lead us to consider the micro didactic time in relation to the physical time and in our analyses of the evolution of practices we also consider the meso didactic time.

First, we observe that preparing technology-based lessons with new software, or software not yet enough explored could be costly because it requires a time of appropriation, to determine its potential for learning and to anticipate the aid to provide to students both at mathematical and technical levels. For example, teachers using EEB declare that they had to test all messages and feedback displayed by the software for nearly every task. Thus, even teachers who became familiar with this type of technology stated, during interviews, that the preparation and updating of work plans is very time consuming.

Secondly, on investigating the time management during the sessions, we observe in all cases a difference between the time expected by the teacher and the actual time taken. In addition to the technical problems that can sometimes interfere within the session, disparities in the students' pace when performing the tasks are magnified in technology based lessons in particular, as shown above, because of the mini-classes and the multiplicity of individual paces. In the French context, classes are usually mixed ability classes. Thus, teachers generally plan long lists of tasks in order to keep fast learners fully occupied until the end of the session. It is slow learners who are responsible for the low pace of the class. This slowness may be due to less able students who experience difficulty in performing mathematical tasks, which often leads the teacher to support them, to help them and sometimes to even execute the task with them so they can reach what he/she considers to be the minimum objective of the lesson. This slowness can also be the result of meticulous students who are interested in detailed tasks not planned by the teacher. For example, students try to draw precise geometric figures although the objective of the teacher is rather to explore properties of this figure, regardless of its conformity to precise measures. Often, when the teacher realises the gap between the planned and actual time, he/she reminds the students that they have to speed up or asks them to skip some tasks and move on to others. This observation of class management seems characteristic to technology-based lessons where the different paces of students determine the pace of the whole class. This contrasts with the management of paper and pencil tasks where the pace of the lesson prescribed by the teacher impacts on the pace of individual students. (Abboud-Blanchard and Paries 2008).

Let us examine the case of the teacher from the dynamic geometry study. She had prepared simple technology based tasks in the form of a guided worksheet in order to help the students to move on quickly to mathematical tasks. The time devoted to the former was intended to be limited to 5–10 min. Perceiving that these tasks were taking more time than expected, she tried to accelerate their completion by doing the work herself or by coaching students step by step in the execution. We note, however, that the teacher failed to reach the goal of students doing all the mathematical tasks within the allotted time. Indeed, some of them were still trying to accomplish the first tasks at 10 min from the end of the session. This is also due to the division of the class into groups and the fact that she could not stay with each group for more than a few minutes at a time.

As to trainee teachers, the time issue turned out to be very important in their reflection on their first steps within the teaching profession. They quickly realised that the preparation and implementation of a technology-based lesson are time-consuming, especially in terms of scheduling mathematics lessons over the year. It seems difficult for them to reach an acceptable balance between two kinds of institutional incentives, namely integrating technology-based sessions on a regular basis and fulfilling all of the curriculum recommendations over the course of the year:

> "*ICT lessons, while remaining useful and interesting, are difficult to implement and costly in both time and energy*". "*On one side I am told to advance in my learning program, and on the other to do ICT. Where could I find time to do all this?*" (Interview of pre-service mathematics teachers at the end of the training year).

At the same time, exploring the potential of software leads pre-service mathematics teachers to perceive a time economy of didactical time over the long term:

> "*If I wanted to do exactly the same thing with paper-and-pencil, it would have taken a much longer time*". "*I realised all the time I can gain by using dynamic 3D geometry*" (Interview of pre-service mathematics teachers at the end of the training year).

Finally, changes observed in practices are consistent with a search for a cost-benefit balance between time gain in terms of learning when the potential of technology is well exploited and time loss in the preparation and management of sessions (see also Ruthven 2007). The impact of the latter, however, tends to decrease with an improved appropriation of technologies. Evolutions of technology uses considered relative to the issue of time are also present at an economic or an institutional level, that is to say teachers invest in the development of technology-based lessons only when they estimate the existence of real benefit for learning or when they are strongly encouraged or prompted by the institution.

Discussion

The challenge in doing this synthesis was, and still is, to understand better what characterises ordinary teachers' technology-based-practices, what is shared, what is different, what may evolve and under what conditions? Aiming to investigate teachers' practices in a qualitative way gives rise to local and contextualised research. This is true for the studies presented in this text and of others quoted throughout the synthesis, which could limit the generalisation of results to other teachers working in other contexts and using other technologies. Despite such limitations, I believe that the similarities between the findings of all of these studies is a good argument for such a generalisation.

Furthermore, trying to synthesise the results of a set of research, beyond the issues, contexts and theoretical frameworks that produced them, seems legitimate at the current time. It is supported on the one hand by the fact that the integration of technology in mathematics teaching is still weak and problematic, and on the other hand by the existence of a body of research on teachers' practices which brings insightful analyses and outcomes which can help understand the barriers to a wider integration. In addition, identifying the collective dimension in teachers' responses to constraints that do exist in professional *ordinary contexts* and pointing out common features and routines which take place, could have a direct impact on teacher education by enriching the body of knowledge available to teacher educators (Abboud-Blanchard 2011).

In my development of the 3-axis synthetic structure (CPT) there are some aspects that bear a similarity to the *double approach*, but with an emphasis on the technology-based practices. From the consideration of a wide literature base, Ruthven (2009, 2010, chapter 14 of this volume) has developed a conceptual framework that identifies five key structuring features shaping patterns of technology integration into classroom practice: *working environment; resource system; activity format; curriculum script*; and *time economy*. How may these structuring features relate to my original theoretical frame (the double approach) and to the structuring of my resulting synthesis? The first two key features (working environment and resource system) are not explicitly present in the double approach but could be related in particular to institutional and social components of practices. Indeed, the physical environment in which the lesson takes place and the resources used affect directly the cognitive and mediative components. Work environment and technology resources are, however, generally dependent[3] on the school equipment and the institutional decisions and on collective decisions of the group of mathematics teachers of the school. In the studies presented in this text, the nature of the technology environment was considered in the sense of an environment in which teachers and students act, and how that impacts on the activity of each of them. In the synthetic stucture (CPT), the new teaching environment indicates an environment in which teacher develops his practices and it surrounds the issues raised in the three structuring axes. It therefore may refer to both the work environment and resources system defined by Ruthven. My understanding of the second two key features (activity format and curriculum script) lead me to relate them to a central idea in the double approach, which is the stability of practices. According to Ruthven, experienced teachers repeat general models for action in the classroom and their lessons are constructed and conducted around these familiar patterns. This observation refers, within the double approach, to the stability of mediative and cognitive components. In addition, Ruthven considers the curriculum script feature from a cognitive perspective, globally similar to some aspects of the cognitive component defined within the double approach. However, Ruthven's construct relates more specifically to aspects of technology. The application of the double approach in the three studies to technology environments, examined not only the scenarios related to a given mathematical topic and the nature of the tasks prescribed to students, but also the considerations specific to technological aspects. In the synthetic structure, the cognitive and pragmatic

[3] At least in the French context.

axes, both specified to technology environments, might be seen as a sort of meshing of these two features from Ruthven's frame and the cognitive and mediative components of the double approach. Finally, the time economy feature of Ruthven's frame within the double approach refers mainly to the study of mediative component, but it could also relate to the study of the institutional component. In the synthesis above, I was also sensitive to time issues in teachers' practices that related to preparing the lesson and to carrying it out in the class, and also to programming lessons over the year, which led me to define a temporal axis.

More generally, Ruthven's frame is structured around five key features, each illustrating the professional adaptation on which technology integration into classroom practice depends. Starting from the hypothesis that it is not sufficient to study technology integration through the lens of learning objectives and technology affordances, my synthetic stucture (CPT), organised along three interrelated axes, aims also to shed light on these adaptations. The fact that these two approaches for the synthesis of research on the practices of teachers who are integrating technology lead to a convergence of views, regardless of the difference of cultural and theoretical contexts, is encouraging considering their common aim to provide a 'meta-view' of teachers' practices. However, I join Ruthven when he points out that this type of conceptualisation, which describes developments that are closer to the teachers' experiences, may be of limited theoretical scope. It aspires, rather, to fulfil a mediating role helping to translate insights from more decontextualised theories into practical ideas and action (ibid.).

Other researchers have also tried to overcome the local contextualised view of their own research with the ambition of creating a coherent lens for looking at teachers' technology-based practices. Lagrange and Monaghan (2009) associated, in a useful way, the double approach and Saxe's four parameter model in an attempt to understand the difficulties which the teachers they were researching experienced. Drijvers et al. (2010) found some of the concepts within the double approach helpful to underpin their findings about orchestrations types. These kinds of initiatives could be a fruitful way to gain greater insight into the complexity of technology-based practices.

The last point I would like to make is with regard to teachers' evolutions in practice. This synthetic presentation not only indicated homogeneity in the answers brought by the teachers to some shared professional constraints, but also served to stress common evolutions of practice. Do these answers and evolutions occur at the same time in a trajectory of technology integration in practices? Or are they rather milestones in this trajectory which do not correspond to a temporal order common to all the teachers? Indeed, the specificity of technology integration sometimes requires long-term studies to make it possible to identify regularities in the evolutions of practices, to interpret them and to find their corresponding determinants. To investigate these evolutions, we are currently developing a new frame based on the concept of 'geneses of technology uses' (Abboud-Blanchard and Vandebrouck 2012; Abboud-Blanchard et al. 2012). This perspective assumes that the teachers' uses of technologies develop via a dynamic path linked to both a personal and professional appropriation of these technologies and to a growing awareness of their potential and limitations.

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