CALCULATORS AS DIGITAL RESOURCES
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Abstract: New handheld calculators can be seen both as artefact allowing calculation and representation of mathematical objects, and resources for students and teachers allowing to store and to share data. Both teachers and students get hold of these potentialities and develop their own uses in distinct dynamics. Studying the interactions between teachers and students gives clues to understand the trajectories of these dynamics and the role played by the calculators in the construction of knowledge. Taking the opportunity of a wide introduction of handheld calculators in classrooms, we observe the conditions allowing transforming the artefacts into documents, part of the set of resources of teachers and students. The methodology takes into account long time observations, in a qualitative case study. The results show how different functionalities can be shared among teachers and students but also why and how other functionalities remain private and hidden.

INTRODUCTION

There is a call for renewal of teaching methods in secondary science education as Rocard, Csermely et al. (2007) state. The question of the place and the role of technology in the scientific classes in order to acquire “good scientific knowledge and an understanding of technology” (ibid., page 6) should be addressed. There is a general agreement that technology brings an increase in collaborative forms of work (Peschek and Schneider, 2002, Kieran and Drijvers 2006, Zbiek et al. 2007). In the same time, new handheld calculators appear in the classrooms with both calculation possibilities, representation of data, interoperability between applications and data storing and sharing properties. This very new nature of calculators can be considered as an early variety prefiguring capabilities that will soon become available to students and teachers in portable digital work environments. It gives them a particular role in teaching and learning mathematics. The evolution of the role of a calculator in the system of resources of teachers and students, inside and outside the classroom has to be studied. Even if the activities of storing, retrieving and sharing documentation are subsidiary to the production of meaning and understanding, they play an important role for teachers in the construction of lessons and for students in their learning process.

“The first challenge concerns extending the notions of mathematical situations and their orchestrations to out-of-school learning environments. The second challenge concerns renewing, from a practical and theoretical point of view, the notion of artefacts for learning and teaching. To enter these fields, we need to be aware that HHT1 is no longer

1 HHT: Handheld technology
an isolated artefact, but integrated in and articulated with a network of resources, particularly online resources.” (Trouche & Drijvers, 2010)

In this paper, we want to take into account the calculator as an element of the network of resources of both students and teachers and study the handheld calculators not only for their calculation properties but also for their documentary properties.

THE RESEARCH SETTING

We took the opportunity of a wide introduction of handheld technology in different classes to study the impact of such a technology on teaching and learning of mathematics. In the first school and during the school year 2008-2009, all the students of the scientific classes (16-18 years old students) have been equipped with a TI-Nspire handheld calculator. In the second school during the school year 2009-2010, two classes (16-17 years old students) were equipped with the same calculators.

In the first school (called S1 in this paper) the most part of the teachers are experienced teachers with a low rate of technological integration (Aldon & Sabra, 2009). In the second school (called S2 in this paper) the two followed teachers are experienced with a high rate of technological integration. These experiments appear to be natural experiment in the sense that the classes’ contexts were not built by researchers but by the teachers’ teams. Both in S1 and S2 a particular teacher plays a role of leader: J1 in S1 and J2 in S2 are involved in the French research team e-CoLab (Aldon et al., 2008).

Our choice to study the introduction of this calculator is linked to its particularly new nature; apart from the fact that it includes a computer algebra system, a spreadsheet, a graphical and geometrical environment, this calculator has specific properties which allow storing, sharing, and organizing data. Files can be organized into directories, each file being constituted of one or more activities of one or more pages. The different pages, using each a particular software are connected together; for example, starting from different measurements in the geometrical environment, variables can be stored and computed in other applications, spreadsheet, CAS, ..., using a different framework. Finally, it is possible to link calculators and computers and to work equally with the calculator or the computer. In the two schools, computer laboratories were equipped with the software.

A team of the INRP (Institut National de Recherche Pédagogique) has monitored these experiments and has built a global methodology in order to study the interactions between teachers and students, the modification of the teachers’ systems of resources and the instrumental genesis (Guin et Trouche, 2002) of both teachers and students.
THEORETICAL FRAMEWORKS

The study focuses on the modifications brought by the introduction of such a technology in teaching and learning. We assume that the calculator is both a tool allowing calculation and representation of mathematical objects but also an element of students’ and teachers’ sets of resources (Gueudet & Trouche, 2008a, b, 2009). As a digital resource, the handheld calculators possess the main functions required for documentary production:

“The two cognitive functions, memorization and organization of ideas, seem to be the fundamental basis for the documentary production.[...]

The function of creativity comprising enrichment due to the domain of interest related to the document surpasses that kind of organization just mentioned.[...]

The third and last constitution function of the documentary production is the transmission function.” (Pedauque, 2006, p.3)

These properties can be used in different domains of mediation; the private or individual domain, where the resource is part of her own documentation, of her personal library and is designed for her own use; the collective domain, where the resource is designed to be shared in a particular community and the public domain where the resource is addressed to the public sphere. Crossing the properties and the domains of mediations offers a grid of analysis of the position of the calculator in the students’ and teachers’ sets of resources. We speak here of sets of resources in a wide sense, following Gueudet & Trouche (2009, p.200) we consider resources as “everything likely to intervene in teacher’s documentation work: discussions between teachers, orally or on line; students worksheets, etc.” And we extend this citation to students’ documentation work taking into account the fact that the handheld calculator plays a specific role, both as an element of the set of resources and an artefact allowing to mediate the teachers’ and students’ mathematical activities. Several studies (e.g. Artigue, 1997, Guin et Trouche, 2002, Laborde et al., 2005) have shown that the integration of technology into the classroom is a slow process in which the artefact becomes an instrument through the double movement of instrumentation and instrumentalization. The instrumentation is the process where the artefact modifies the subject’s activity and the instrumentalization is the process where the subject modifies the artefact for her own use. This slow process, called instrumental genesis (Rabardel & Pastré, 2005) transforms the artefact into an instrument through the equation: artefact + scheme of utilization = instrument. A scheme, following Vergnaud (1996) is an invariant organization of activity. We introduce a distinction between artefact and resource to stress the different properties of the handheld calculator. The functions of memorization, organizations of ideas and transmission give to the calculator a specificity of resource which can be transformed into a document through the process of documentational genesis (Gueudet & Trouche, 2009). This documentational genesis has a dual nature:
“The instrumentalization dimension conceptualizes the appropriation and reshaping processes [...] The instrumentation dimension conceptualizes the influence on the teacher’s activity of the resources she draws on.”(Ibidem, p.205)

From this double movement of instrumentation and instrumentalization, resources become documents, that is to say, in a given time, resources with scheme of utilization. We assume that documentary production’s properties are both for teachers and students an important element of this transformation of resources into documents through this documentational genesis. Looking at the calculator with its different potentialities, we consider it as an artefact with possibilities of calculation and representation (properties of creation) and a digital resource with possibilities of data processing and data sharing (properties of memorization, organization of ideas, and communication).

**METHODOLOGY**

The purpose of the methodology is to catch and to follow the dynamics of the different geneses crossed by the dynamics of knowledge construction. In the context described previously, we construct our methodology to obtain information on the processes instead of the results of the processes. We have chosen to passively follow the experiments, without intervention of researchers. In S1, the teachers and students that we followed are in the last class of the high school (Lycée, Terminale S, scientific class, 18-year-old students). The choice of this class level comes from the practical examination that students have to take at the end of the year. This practical examination was an experiment carried out by the ministry of education during which students have to solve a mathematics problem with the help of software or calculators. We thought that this examination would be a good opportunity for teachers to develop in the classrooms the use of calculators and for students a sufficiently precise goal which could lead them to use their calculators in the maths classroom and also outside classroom. In S2, we followed students of première S (scientific class, 17-year old students). We wanted to start our observations at the very beginning of both the discovery of the calculator and the beginning of scientific studies. Both teachers have a long teaching experience; this choice was done because we wanted to focus on the uses of technology in the class without being distracted by mathematics teaching difficulties. In our methodology, we cross different observations and data:

- Firstly, the TI-Nspire calculator, as previously said, has a functionality which allows uses to structure its contents into directories, files, problems... Hence, we decided to observe the students’ calculators contents; more precisely, we chose representative students and asked them to send us the content of their calculator half-monthly from December to June. We mean by representative, students with different mathematical and technological skills.
• Secondly, we organized observations in the classroom: in the ordinary classroom as well as in the computer laboratory. During these observations, we mainly focused on interactions between students and teacher.

• Thirdly, interviews with teachers before and after the observations give us information about the role teachers give to the calculators in the observed lessons.

• Fourthly, we took advantage of the final examination to observe and to interview students about their personal use of the calculator.

• Finally, we asked students to fill in a questionnaire at the beginning and the end of the year, focusing on one hand on their opinions about the calculator and more generally about technology, and in another hand about their attitudes towards mathematics.

Even if the other observations and data collection enlighten the following results, we particularly focus, in this paper on the study of the content of students’ calculators, in order to draw different types of utilization in relation with the documentary production. These data allow us to follow a part of their documentational genesis and give us information on the calculators’ use outside the classroom. The contents of the small number of calculators (eight the first year, six the second year) allow us to formulate hypotheses that have to be confirmed in a future study. They give us information about the instrumental genesis as well as the evolution of the use of calculators as a part of the students’ individual set of resources. In the next paragraph, we give some results about these genesis seen through the analysis of the calculators’ contents.

**SOME RESULTS**

We lean on the analysis of the contents of the students’ calculators to draw a parallel between the main functions of a documentary production as described below and the actual students’ organization of their calculators. Through the content of the calculators, we assume that we can approach the private domain of mediation and we cross our information with observations in classroom and interviews to reach the collective and public domains.

**Memorization of knowledge and organization of ideas**

From the viewpoint of students, the handheld calculator is a means of data storage, which they perceive as helpful:

> It’s reassuring in the perspective of the exam to have proofs stored, because we have to know very many proofs... and it’s also possible to verify our calculations (Interview, 19\(^{th}\) May, 2009)

The folder structure of this student’s calculator is a good example showing his organization of knowledge, and it is interesting to follow the contents of the folders and their evolution during the year. The figure 1 shows the general organization of
the calculator which doesn’t change during the year and the figure 2 shows the evolution of a particular folder (Maths oblig cours which is an abbreviation for: maths lessons, figure 2a is the content in December and figure 2b is the content in June). We clearly see in this calculator’s organization a complete structure of the maths course. And, looking more deeply into the files, we see that this student uses his calculator as a numerical notebook, giving a summary of the lesson (figure 3) and allowing mathematics experiment: the slider shown on the figure 3 (on the right) changes the value of $a$ and the curve of the function $x^a$.

Figure 1 : Organization of data in a student’s calculator

Figure 2a: Evolution of the content (December 2008)

Figure 2b: Evolution of the content (June 2009)
Depending on the teacher’s conceptions, these properties of memorization and organization of ideas are rejected, ignored or promoted and the resource may stay hidden and private or, in the contrary become collective and shared in the class.

**Property of creation**

Looking at the contents of the students’ calculators, it appears that they very often use them as a draft, using a file or a set of files to do the current calculation. For example, one of the calculator structure is made of different folders called br1, br2, ... br being an abbreviation for the French brouillon, (draft in English). The calculator is seen in this case as a direct creation tool bringing immediate feedback to a given question in a personal domain of mediation. The resource at a particular moment can’t become a document because the dimension of organization of ideas is not present. However, in all the calculators, the dimension of creation exists through specific pages: calculations’ pages, representations of data and draft files linked to mathematical problems. The interviews with students confirm this fundamental aspect of the calculator and its use in the classrooms:

Yes, in maths lessons, for derivative functions, integrals, and so on [...] we really use it (the calculator) during math lessons. (Interview, 19th May)

One very important point during the observation in the classroom was to follow the interactions between teacher and students related to the organization of the calculators. In S1, the first teacher didn’t want to interfere, it appears clearly that this teacher wants to give a private status to this property for her own calculator as well as for the students’ calculators; as a consequence, her students’ calculators are organized around the creation property, and all the data memorization remains private, and somewhere hidden. The second teacher, in the contrary, paid attention to the data organization of the calculators. It is in his class that we find the most organized calculators (see figure 1). In S2, teachers despite their high level of technological skills don’t emphasize the organization of data, and the students’
calculators are organized around particular situations that teachers institutionalize as important in the classroom. For example, a particular lesson about statistics has been stressed, and in all this class’ calculators a folder and files are present and stay present during the year even if there is no visible organization of data.

**Communication**

The calculator allows for the transmission of information between students and between students and teacher. The orchestration (Trouche, 2004) plays a very important role in the transfer from a private to a collective use of the different properties of the calculator. For example, in S1, the teacher used a particular class organization: students worked with their own calculator in a face to face configuration and one student (called Sherpa in reference to Trouche’s work), working under the control of the teacher, calculated and showed through a overhead projector the screen of its calculator. This class organization facilitates the collective communication from an individual question as shown in the next excerpt where students have to search the intersection point of two curves:

Sherpa: Madam, here...
Teacher: Yes, we can see nothing much.
Sherpa: Here, the curve is here and after there is no more curve!
Teacher: There is no more curve?
Another student: They are all at the same place, you can’t see it.
Sherpa: Yes, but you must see the intersection!
A third student: Yes, but, where is your other curve?

The dialogue begins with an individual question and is continued by a dialogue in the class between students. On the other hand, the Sherpa’s calculator appears to be a vector of communication between the teacher and students, when, taking profit of a question of the Sherpa, the teacher transmits information to the whole class. In that case the collective calculator appears to be a generic calculator which allows the teacher to regulate the class work. In other terms, the teacher, through the orchestration, transforms the creation property from the private domain to the collective domain.

**CONCLUSION**

The teacher’s demeanour has a decisive influence, and the transformation of the calculator as an artefact with calculation and representation potentialities into a resource towards a document giving an help to the students’ construction of knowledge depends not only on the teachers’ technological skills but also on their awareness of these possibilities and the pedagogical exploitation of these functionalities, mainly organization of knowledge and memorization. The position of the machine as an element of the system of resources of both teachers and students makes the negotiation of the didactical contract very complex. The availability of the calculator evokes different kinds of tensions:
• tensions between the memorization properties and the teachers’ conceptions of students’ resources,
• tensions between the property of creativity and the teacher’s intentions,
• tensions between the communication property and the teachers’ pedagogical organization.

Trying to explain and describe these tensions offers new perspectives of research that can extend and complete this study.

REFERENCES


