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From computer to instrument system: a developmental perspective

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ABSTRACT

Studies working within an activity theory frame have opened different paths in the HCI field. One of the fundamental points of these approaches focussed on activity is consideration of the constructive dimensions of the user's activity. Several authors have identified the complex relations between usage and design (Winograd and Flores, 1986; Suchman and Trigg, 1991) and beyond this, that design continues in usage (Rabardel, 1995, 2002; Henderson and Kyng, 1991; Vicente, 1999).

The approach that we put forward contributes to the development of this question: the continuation of design in usage. Based on an empirical situation (managing the maintenance of a broadcasting network for radio, television and telecommunications), we define the mediated activity. We look at the mediator and suggest conceptualizing it as a mixed functional entity: the instrument. We examine the emergence and development modalities of instruments during processes of instrumental genesis. We also show that instruments are components in more general systems that integrate and go beyond them: instruments systems.

1. INTRODUCTION

Studies working within an activity theory frame have opened different paths in the HCI field. One of the fundamental points of these approaches is that the main relation is that of the

subject with the object of his/her activity. The tool, whether it be from traditional or digital technology, is in an intermediary mediating position between the subject and the object. Several authors (Bannon and Bodker, 1991; Rabardel, 1995, 2002; Wertsch, 1998; Kaptelinin and Kuuti, 1999; Engeström, 1990) have contributed to this conceptualization. The title of Bodker's study (1991): « Through the interface: a human activity approach to user interface design » sums up the essential characteristics.

We believe that conceptualization in terms of mediated activity is part of a more general evolution of models that aim to account for human behavior. Indeed, a second fundamental point of approaches focussed on activity is consideration of the constructive dimensions of the user's activity. Several authors have identified the complex relations between usage and design (Winograd and Flores, 1986; Suchman and Trigg, 1991) and beyond this, that design continues in usage (Rabardel, 1995, 2002; Henderson and Kyng, 1991; Vicente, 1999). We feel it is necessary to develop a new generation of models allowing the understanding and explanation of these constructive dimensions of the user's activity.

The approach that we will put forward contributes to the development of this new generation of models that we call « generative models ». This name, in taking up Rasmussen's idea[1], seems to us most suited to that which must be described: the continuation of design in usage. It proposes a theoretical frame both to understand what an instrument is for the person using it and how users continue design in usage by processes of individual and collective instrumental geneses. Instruments will thus appear as both private and social entities resulting from their history, used both individually and collectively and shared among work groups and trade communities.

In the first section of this article, we will present the empirical situation on which our study will be based: managing the maintenance of a broadcasting network for radio, television and telecommunications. In the second section, we will define the mediated activity and distinguish different types of mediations. In the third part, we will look at the mediator and suggest conceptualizing it as a mixed functional entity: the instrument. In the fourth part, we will examine the emergence and development modalities of instruments during processes of instrumental genesis. Then in the fifth part, we will show that instruments are components in more general systems that integrate and go beyond them. We will also describe an analysis method of instrument systems and present the main characteristics of these instrument systems.

2. MANAGING THE MAINTENANCE OF THE BROADCASTING NETWORK FOR RADIO, TELEVISION AND TELECOMMUNICATIONS

We will devote this first section to presenting the activity we will use as a support to illustrate our theoretical propositions. The broadcasting company has a national and international network of emitters that it makes available to radio or television companies and telecommunications operators. Maintaining this network is essential: breakdowns lead to interruptions in the broadcasting of programs or services and result in financial penalties that

[1] Rasmussen (1997) gives the following definition: « In several human sciences a common trend is found in modeling behavior. Efforts are moving from normative models of rational behavior, through efforts to model the observed less rational behavior by means of models of the deviation from rational, toward focus on representing directly the actually observed behavior, and ultimately to efforts to model behavior-generating mechanisms ».

may be enormous. Maintenance takes two forms: preventative maintenance operations, which are planned several days or weeks in advance and urgent interventions to get the service working again.

During week N-1, a specialist, the organizer, puts together a provisional schedule of maintenance interventions in the zone for which he/she is responsible for week N (around thirty per day on average) based on the availability of maintenance technicians. During each day of week N, he/she receives several requests for urgent interventions and must assign a technician to each. Occasionally, a maintenance technician is available but usually, they are all out working on pre-planned interventions. The organizer must then modify the schedule in line with the relative priority of the different interventions. He/she can suspend ongoing interventions, postpone planned interventions, etc. for an optimal assignment of maintenance technicians based on emergencies and priorities. These assignment and re-assignment tasks are complex because the solutions must satisfy a range of constraints.

Organizers have developed specific tools to carry out these assignment and re-assignment tasks: « Activity Tables ». Their characteristics vary slightly from one zone to another and can be in paper or computer form (often both are present on the same site).

Activity Table

Semaine 1		6-Jan	7-jan	8-jan	9-jan	10-jan	11-jan	12-jan
MrA	TV	PVT 01563						
MrB	RdC							
MrC	Rad		MDTR Issy					
MrD	TV	VLB OM	~~VLB AM~~		MDTR Maiso			
MrE	TV							
MrF	RdC	BHX 3 05623	BHX 0 04233					
MrG	RdC	BHX 5 05222						
MrH	TV	LE MrD						
MrI	RdC	BHX 6 05553	BHX 6 07945		BHX 4 0477 8			
MrJ	TV							
MrK	Rad							
MrL	TV	MDTR Grisy	MDTR Paris	MDTR Enney				
MrM	Rad	TFL RN3						
				BHX 1 05753		BHX 2 05621		
				MDTR St De				
			LME MrA					

Figure 1

Example of an « Activity Table ».

Figure 1 presents an example of an Activity Table. In spite of differences, all Activity Tables elaborated by organizers have common characteristics. The double-entry table includes the days of the week, technicians' names and the time slots when they are available. The organizer writes in the technicians' assignments to the different interventions and a brief description.

The "Activity Table" tool is essential to the organizers' activity. The company requested identification of the real usage draftsmen made of all their tools and in particular of the activity table from the perspective of its integration into a global computer system. However, this computerization process underway in the company initially brought the activity table into question. We will progressively examine these different evolutions but first, we will focus on the mediated activity.

3. MEDIATED ACTIVITY

We share Wertsch's point of view (Wertsch, 1997, 1998) that mediated activity is an analysis unit that retains the characteristic properties of individuals, cultural tools and contexts. The choice of this unit allows us to avoid two forms of reductionism: ignoring that the action is shaped by cultural tools and ignoring the individual's activity in favor of a mechanical determinism by tools. This is why mediated activity is a good candidate as an analysis unit for interdisciplinary research on human use of tools[2].

It is within approaches born of activity theories that conceptualizations and theory frames first developed allowing the exploration of the question of mediation by artifacts. In the 1930s, Vygotski (1930, 1931) put forward his first theoretical frame conceptualizing activity mediated by tools and signs. He considers mediation as the central fact that transforms psychological functions. In line with this, Léontiev (1975, 1981) also attributes a central role to activity mediated by artifacts in his general theory of activity.

We propose distinguishing three main orientations of mediation in instrument-mediated activity: toward the object of the activity, toward other subjects, and finally toward oneself. Figure 2 is a graphic representation of this.

[2] Wertsch considers that the two terms « cultural tools » and « mediational means » are the same.

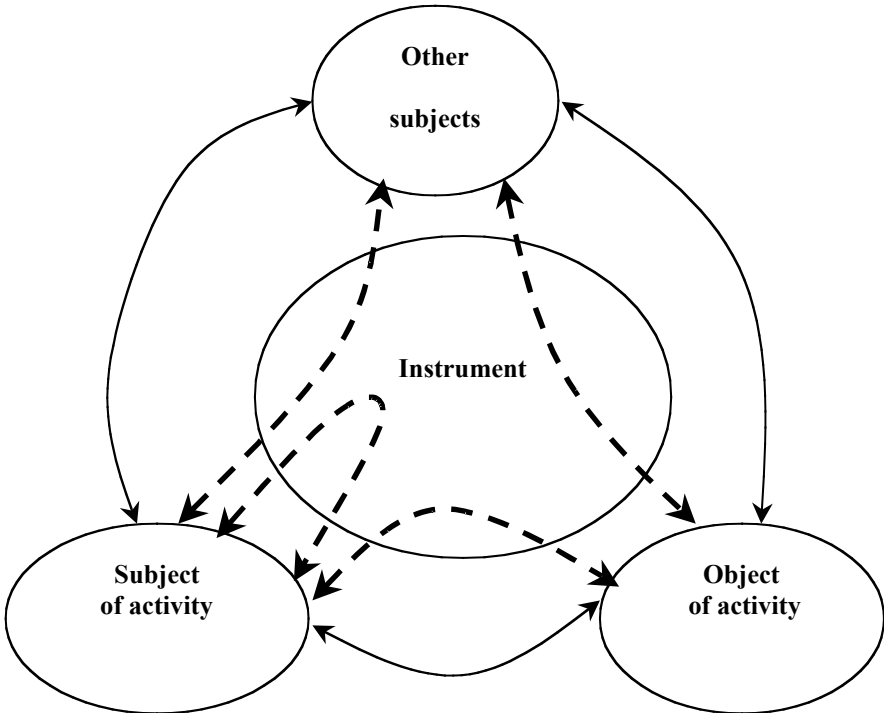

Figure 2
The dotted arrows represent the three orientations of mediation in instrument-mediated activity. The linear arrows represent non-mediated relations.

The main mediation comes from the subject's activity being oriented toward the object of the activity. This « **mediation to the object** » is well identified in the literature. We propose distinguishing two forms of this:

- mediations aiming mainly at getting to know the object (its properties, its evolutions in line with the subject's actions, etc.) that we call **epistemic mediations to the object**. The microscope is a good example of an artifact organized around this type of relation. In the case of the Activity Table, the main epistemic mediation concerns the maintenance intervention assignments already planned. It also concerns the availability of technicians (presence or absence, working hours for those present, etc.);
- mediations concerning action on the object (transformation, regulation management, etc) that we call **pragmatic mediation to the object**. The hammer is an example of an artifact primarily organized around this type of component. In the case of the Activity Table, the main pragmatic mediation concerns the initial assignment or the transformation of already planned assignments.

However, the subject's activity is also oriented toward others. This is obvious in collective activities, yet it is also true for the majority of individual activities (Clot, 1995). This is the second orientation of mediations: « **interpersonal mediations** ». Interpersonal mediations may also be epistemic or pragmatic in nature depending on whether it is a question of knowing others or acting upon them. They can also take on other values in line with the nature of the activity: collaborative mediation in the context of collective work (Béguin, 1994), inter-subjective mediation, social mediation, etc. The Activity Table effectively performs interpersonal mediations: for example, by displaying information to be consulted (or by allowing long distance consultation of a computer file) by technicians, their team managers and planners of non-urgent interventions. These last two categories of managers are also

liable to contribute to assignments and reassignments. In our example, interpersonal mediations are thus epistemic and pragmatic.

During his/her activity, the subject is also in relation with him/herself. He/she knows, manages and transforms him/herself. We must thus take into consideration this third orientation: « **reflexive mediations** »[3] through which the subject's relation to him/herself is mediated by the instrument[4]. Vygotski gave a suggestive example: a knot in a handkerchief is destined to remind us to remember something… In our example of the Activity Table, organizers write in notes for themselves: « They allow me to remember everything about a given intervention, like a summary that brings everything back. In fact they reactivate my knowledge… For me, the Activity Table is also a reminder. I also put in important information that does not fit directly into the boxes and that I have to keep in mind for that day or the following day… I use dashes to indicate interventions for which a work order has already been issued. That way, I can see what remains to be done..."

Vygotski made mediations with oneself and others a characteristic of a particular type of instrument: psychological instruments[5]. We have shown elsewhere (Rabardel, 1999) that these mediations are not specific characteristics of a particular class of instrument. Every instrument is potentially a mediator for the three relations we have just outlined. These three types of relations are liable to be jointly present within each instrument-mediated activity, as we have just demonstrated in the case of the Activity Table.

This does not imply that all instruments must be considered as the same. One or other of the relations is usually dominant (by constitution or depending on the situations). The others are thus less important, generally subordinate to the dominant relation, or sometimes absent.

4. THE MEDIATOR: FROM THE ARTIFACT TO THE INSTRUMENT

Up until this point, we have not distinguished between the instrument and the material artifact: in our example, this is the Activity Table. We will now develop the notion of instrument in considering that the instrument cannot be reduced to the artifact, technological object or machine depending on terminology used. The instrument is a mixed functional unit made up of components born of the artifact and of others born of the subject.

The idea that instruments and more broadly the means of activity are constituted by functional units associating heterogeneous entities has been around for a long time in psychology. Thus, Léontiev (1981), based on studies by Anokin, developed the idea of functional psychic organs resulting from child development. Once formed, they maintain themselves as functional wholes whist remaining liable to adjustments. Other researchers have highlighted the adult's capacity to incorporate artificial extensions (canes, tools, cars) into segments of the body. This is possible because this instrument is included into the hand's coordinate system, as if it becomes one of its organic components (Ananiev, 1959). The condition of this incorporation

[3] Reflexive mediations correspond to heuristic mediations defined in (Rabardel, 1995, 2002; Béguin and Rabardel, 2000).

[4] Relations of the subject with him/herself are not only mediated by instruments but also by other subjects.

[5] Vygotski (1930): « Psychological instruments are artificial elaborations; they are social in nature and not organic or individual; they are destined to control one's own behavioral processes or those of others, just as technique is destined to control the processes of nature ».

is nonetheless that the active experience of handling these extensions can occur (Paillard, 1971, 1987).

The idea of a functional organ was revived and developed in the HCI field by Kaptelinin (Kaptelinin and Kuuti, 1999; Kaptelinin, 1996a, 1996b): « From a mediational perspective there is only one system to be seen: a human already equipped with many kinds of functional organs, developing against a cultural background and situated in a personal history of interactions with the world. Besides this one system there is nothing else to be seen. A place for a computer tool with a set of functionalities is there, but it is totally opaque. There is a possibility that some of the hidden functionality can be used to transform the human system in order to enable it to perform a task, but it is only a potential. To realize the potential, a situation has to be organized where the person interacting with the material can recognize a possibility and create a new functional organ or extend an old one for the new purpose ». For Kaptelinin (Kaptelinin and Kuuti, 1999; Kaptelinin, 1996a, 1996b), there are several kinds of functional organs based on the use of computer tools... One of the most important functions can be defined as an extension of the internal plane of actions. The IPA is a system of mental structures and abilities that makes it possible to perform actions « in mind » before performing actions in reality. We find the same idea of an intrinsic articulation between user skills and the characteristics of the artifacts considered as a cultural tool in studies by Wartofsky (1979) and Wertsch (1998) who gives an enlightening example in the domain of high jumping.

We can see that the idea of a mixed entity is widespread. We feel that in order to give it real operationality in the HCI field, we must further develop conceptualizations of the different components of the mediating instrument of activity.

We suggest defining the instrument as a mixed functional unit born of both the subject and the object (Rabardel, 1991, 1995, 2001, 2002; Béguin and Rabardel, 2000; Rabardel and Vérillon, 1985; Vérillon and Rabardel, 1995). The instrument can be considered as a functional organ made up of an artifact component (an artifact, a fraction of an artifact or a group of artifacts) and a scheme component: the one or more associated utilization schemes. The two components of the instrument, artifact and scheme, are associated with one another but they are also in a relation of relative independence. One utilization scheme[6] can be applied to a range of artifacts belonging to the same class (for example, subjects transpose car driving schemes from one vehicle to another). They are also applicable to neighboring or different classes (not without causing problems at times). On the other hand, an artifact is liable to fit into a range of utilization schemes that will attribute it different significations and sometimes different functions. All of us can think of examples, such as the association of the « striking » scheme with a pair of pliers thus transforming it into an instrument with the same function as a hammer or a blunt instrument.

We will now illustrate this conceptualization of the instrument by returning to the example of the use of the Activity Table in the reassignment task. This is observed when the organizer receives a request for an urgent intervention and the assignment of this new intervention leads to the cancellation of the old assignment, which is reassigned shortly afterwards.

The activity is thus organized by a scheme that we call the « **reassignment scheme** ». It structures the temporal sequencing into five successive steps. So as to facilitate

[6] For a development of the notion of the utilization scheme, see Rabardel (1995, 2002).

comprehension of the organizer's activity, we have added to a description of the steps examples of the spontaneous statements which accompanied them during an organizer's implementation of the reassignment scheme.

1) **Situation analysis** step: the organizer proceeds to analyze all the assignments already carried out and listed on the Activity Table. He spontaneously comments on this activity: « Who can I give this one to?... This one doesn't suit me… I don't know who… »
2) The organizer chooses one of the assignments already listed and decides to cancel it. This is the **decision to cancel an assignment** step: « Okay, I don't have a choice… He'll have to do this intervention… He'll complain… He hates it when I pull him off a job… But I don't have a choice ». This step culminates with the removal of information written in the Activity Table box corresponding to the intervention that the organizer decides to cancel.
3) The organizer proceeds to a **new assignment** by writing information on the urgent assignment in the now empty box: « Okay this one's for him… »
4) « ... so that one's for him »: The organizer then carries out the **reassignment**. He writes into a different box in the Activity Table the information erased or crossed out earlier.
5) The organizer begins the evaluation and checking of the modifications made on the Activity Table: « Okay, that should be fine… It should be fine… Yes, yes… yes, it's okay. » This is the **analysis and checking of the new constructed situation** step.

We note that the first and last steps are devoted to the analysis of the overall situation and they do not include any transformation of the Activity Table. The organizer apparently makes do with consulting it. In reality, on an internal representative level, he tests the cancellation and reassignment possibilities for already planned interventions. On the contrary, in the three intermediary steps, the activity concerns an effective transformation of the table. Thus we can see that the reassignment scheme organizes and coordinates internal and external dimensions of the activity. It constitutes the invariable structure, which is based on the specific properties of the Activity Table artifact and responds to characteristics common to reassignment situations.

The mixed functional unit associates the Activity Table artifact with the reassignment scheme that constitutes the organizer's functional instrument. It is available and mobilizable for implementation at any time in line with the specific characteristics of each reassignment situation, taking into account the result of the activity itself. For example, at the end of step five, the organizer may not be happy with the solution chosen. He/she then throws it into question and may carry out a chain of reassignments. Yet in all cases or variations, the instrument mobilized and implemented by the organizer is the mixed functional unit described above. It is not only the artifact that mediates: the instrument is at the heart of mediated activity.

5. INSTRUMENTAL GENESES: THE DEVELOPMENT OF THE INSTRUMENT

The mediating instrument, the mixed functional unit, is not given to users up front. Several authors have insisted on the necessity of a developmental approach to the appropriation of tools and more generally the mediational means inscribed in culture (Bannon and Bodker, 1991; Wertsch, 1998; Kaptelinin and Kuuti, 1999; Vygotsky, 1931; Léontiev, 1981; Cole, 1996). We will now examine instrument constitution and development processes. We will show that the instrument the users effectively mobilize in their activity is the result of a process of instrumental genesis.

Our first example is a navigation aid system for driving in urban areas. Users were familiar with the use of the system and analyses compared the driving activity with guidance by the aid system and with guidance by a paper map (Forzy, 1999). The car manufacturer wanted to check that the system would not mobilize the driver's attention excessively and thus endanger driving security. Contrary to designers' expectations, use of the system did not significantly improve navigation performances (except for subjects with particular difficulties in reading maps). However, contrary to the manufacturer's fears and the explicit hypotheses of the experimenter, driving quality improved significantly. There was much less risk taking, errors or rule breaking[7]. The process of instrumental genesis thus oriented the usage of the artifact in a direction very different from that planned during the design phase.

Questioning users after experimentation allows us to understand the reasons. The negative consequences of navigation errors are reduced with the system: if a direction cannot be followed, a new route will then be suggested. As a result, users develop usage modalities that favor security to the detriment of possible navigation errors that are much easier to rectify than with a paper map. The main function of the instrument ultimately developed by users during the process of instrumental genesis moves well away from the main function of the artifact developed by designers.

We will now look more carefully at the two dimensions of the process of instrumental genesis that concern the two components of the instrument: utilization scheme and artifact.

The **instrumentation** dimension of instrumental geneses corresponds to the constitution and evolution of utilization and instrument-mediated action schemes.

Instrumental geneses can also manifest themselves as evolutions of the artifact. This is **instrumentalization**.

In returning to the example of the Activity Table, we will show how operators developed this instrument in integrating a new function to manage the class of situations where a cancelled intervention cannot be rescheduled (reassigned) for the same day, usually because of a shortage of available staff. We were able to reconstitute the main stages of the instrumental genesis process based on an organizer's comments on examples of the Activity Table at different moments in the genesis of the new function.

This instrumental genesis occurs in the context of organizational changes in the company. The organizer we interviewed had this to say: « this function came about because we (the organizers) were asked to do as much intervention programming as possible. Suddenly, we had more rescheduling to do than before… At first, I tried to note the cancelled interventions at the bottom of the Activity Table so I wouldn't lose them but it wasn't systematic and we ended up losing a lot of them… » He then systematized these notes at the bottom of the Activity Table: « So I said to myself that to avoid losing anything, it had to be systematic… it had to become automatic… » However, this systematized form was insufficient and in the final phase, he created an area specially devoted to this function in the Activity Table: « Then I realized I had to make a special box in the Activity Table so it would be easier and I wouldn't forget to write them in… It's my Reserve of non-reassigned cancelled interventions » (see figure 3).

[7] Non respect of red lights or overtaking restrictions, refusal to cede priority, lane changing or late breaking, inappropriate speed, deviations from trajectory.

Activity Table

Semaine 1		6-Jan	7-jan	8-jan	9-jan	10-jan	11-jan	12-jan
MrA	TV	PVT 01563						
MrB	RdC							
MrC	Rad		MDTR Issy					
MrD	TV	VLB OM	~~VLB AM~~		MDTR Maiso			
MrE	TV							
MrF	RdC	BHX 3 05623	BHX 0 04233					
MrG	RdC	BHX 5 05222						
MrH	TV	LE MrD						
MrI	RdC	BHX 6 05553	BHX 6 07945		BHX 4 04778			
MrJ	TV							
MrK	Rad							
MrL	TV	MDTR Grisy	MDTR Paris	MDTR Enney				
MrM	Rad	TFL RN3						
				BHX 1 ~~05753~~		BHX 2 05621		
				MDTR St De				
			LME MrA					

Reserve

Figure 3
Example of the instrumentalization of the Activity Table by the creation of a « Reserve of non-reassigned cancelled interventions ».

Above we examined the **instrumentalization** component of instrumental genesis, which culminates, in this example, in the transformation of the artifact and the creation of a new function.

We will now examine the second dimension of the instrumental genesis process, **instrumentation,** which concerns the evolution of the « reassignment scheme » described in the preceding section.

When the organizer cannot reassign a cancelled intervention immediately, he writes it into the new box in the Activity Table: the « Reserve of non-reassigned cancelled interventions ». Initially, we could think he merely resorts to using an external memory to compensate for weaknesses in his internal memory and/or insufficient systematic noting that characterized earlier phases. Yet an attentive analysis of the contents written into the « Reserve » box

indicates that the constitution of this external memory is in fact accompanied by an important evolution in the reassignment scheme.

When an organizer is unable to reassign the intervention that same day, he/she is in fact unable to move on to the key step in the reassignment scheme (step 4: reassignment): he/she cannot write the information concerning the cancelled assignment that has just been erased or crossed out into another box in the Activity Table.

What is this information? There are four closely linked aspects:
- The nature of the maintenance intervention to be performed: (**I**) ;
- The person who is to carry out this intervention: (**P**) ;
- The date the intervention is to be carried out: (**D**) ;
- The time slot during which the intervention is to be carried out (**T**).

The information concerning the cancelled assignment that cannot be written into the table is thus: (**I**) + (**P**) + (**D**) + (**T**).

In the first phase of instrumental genesis, our organizer wrote only one of these aspects at the bottom of the table (in reality in the margins): the nature of the intervention (**I**). In the second phase of instrumental genesis, he invented the « Reserve of non-reassigned cancelled interventions » and the information written into this box is: (**I**) + (**D'**). As before, this concerns the nature of the intervention (**I**), as well as a decision on a possible new date (**D'**) for this intervention.

What the organizer calls the « Reserve » is thus not only a reminder destined to preserve part of the information. It is also a box allowing partial reassignment of the intervention. The reassignment scheme has evolved and is enriched. The fourth step can now occur in two sub-steps that can be separated by several hours or even several days:
- Step **4a**: preservation of the intervention and reassignment to a new date (**I**) + (**D'**).
- Step **4b**: end of the reassignment by nominating the person and the time slot (**P'**) + (**T'**).

This division of step 4 of the scheme into two sub-steps is important in that at each of these sub-steps the organizer can begin part of the reassignment in managing only the constraints known to him at that time. During sub-step 4a, he can thus decide the date without waiting to have all information on the available technicians and time slots to take decisions on who and when.

The new reassignment scheme contains variants (figure 4). One or other of these variants is given preference in line with the characteristics of situations.

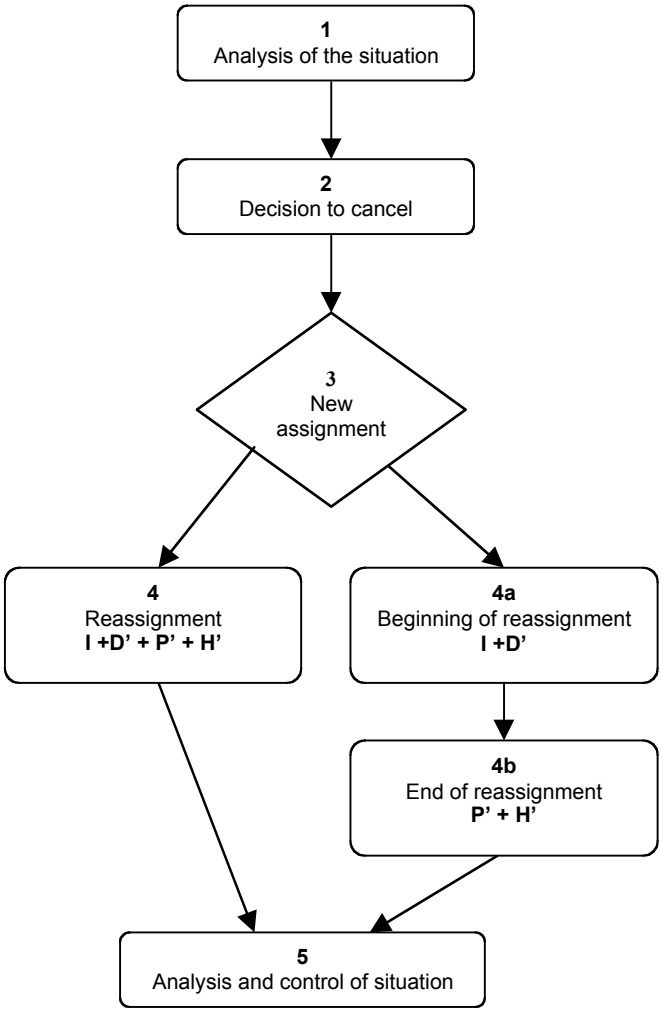

Figure 4
Example of instrumentation: the reassignment scheme enriched during instrumental genesis.

The instrumentalization of the artifact that culminates in the creation of the « Reserve » and the enrichment of the reassignment scheme characteristic of instrumentation jointly participate in the process of instrumental genesis. However, the example of instrumental genesis outlined above is limited to only one phase of the developmental process of the Activity Table as instrument. It does not cover the overall development that began several years earlier[8] and is currently continuing following other modalities in the context of the creation and introduction of a new integrated computer system in the company.

We will take another example of the implementation of a new computer system to illustrate the obstacles that the process of instrumental genesis can confront. A Computerized Maintenance Management System (CMMS) was supposed to help organizers by concentrating all information on the interventions into one tool. It was also supposed to allow follow-up and management by other staff members. In principle, this tool should have

[8] We could not observe the start of the process but reconstituted its main aspects by interviewing those concerned and examining the physical traces preserved (Bourmaud, in preparation).

replaced the organizers' other tools, particularly the Activity Table. After several fruitless attempts, organizers gave up on performing assignment and reassignment tasks directly on the CMMS tool. They returned to the Activity Table and only used the CMMS tool to enter data on the interventions already written into the Activity Table.

What happened and why did organizers give themselves this extra workload? The key to the answer to these questions is in the analysis of mediations that the new tool allows, and more importantly does not allow. Each of the interventions is outlined on several screens. This characteristic encourages data entry intervention by intervention. However, the organizer cannot ever have an overview of the various elements of information that must be treated simultaneously to analyze the situation, take an assignment or reassignment decision and control the potential effects of this decision on the overall situation. In short, the tool allows a good pragmatic mediation when writing in an intervention already decided upon but it prevents epistemic mediation to the overall situation, which is essential to the elaboration of a decision and the control of its effects (i.e. to the implementation of the initial and final phases of the reassignment scheme). It is this constraint that constitutes an obstacle to the process of instrumental genesis and led to dropping the CMMS tool. In the following section, we will return to the probable origins of this « Bug » in the design of the tool.

Finally, to conclude this section on instrumental geneses, we would like to stress their collective dimensions as indicated by Béguin (1994). In the evolution and development process of the Activity Table, we observe both phases of individual geneses and evolutions of the instrument that are partly different from one user to another. We also observe exchange phases in which individual creations are confronted with one another and compromises are reached in order to attain an instrument or at least an artifact that can be shared.

We observed this type of collective construction during the fusion of two maintenance units into one. The two organizers, who had developed their own instrument in their own sector, collaborated so as to construct a new Activity Table for the future unit. Discussions looked at the advantages and disadvantages of each of the existing Activity Tables. A list of functionalities judged positive in each was established and served as a specification chart for the design of the new Activity Table. Compromises had to be reached so as to attain a result acceptable to the two organizers. Hence, the use of color codes suggested by one was bitterly debated before finally being integrated into the new Table.

This evolutionary dynamic of the instrument is social as well as collective. Through this movement, the instrument is gradually inscribed in the organizer community's shared heritage, then more generally in the company's heritage (not without debates and conflicts). The move toward shared heritage is correlative to the development of appropriation processes on an individual and collective level. This appropriation takes place the two levels distinguished by Wertsch (1998): both a movement aiming at mastery in usage and the adoption of the instrument as one's own or as belonging to an entire community. On the limited level of an instrument specific to a particular company, we thus find the more general mechanisms of the social transmission of acquired knowledge analyzed by activity theory and cultural psychology (Engeström, 1990; Vygotsky, 1930; Léontiev, 1981; Cole, 1996; Rubinstein, 1958).

6. INSTRUMENT SYSTEMS

Instruments are not isolated. All of us know this intuitively from experience. For example, writing this text implied that its authors use a range of instruments. They were mobilized during the action in line with operational goals and needs at given times. The logic of our concrete and specific situated activity, in this case, organized functional complementarity relations between instruments and the temporal sequences of their successive or concomitant usage.

But as we have indicated elsewhere (Rabardel, 2001), instruments are not only mobilized in specific situations. They are also structurally linked to invariable dimensions of classes of situations. Instrumental geneses are grounded in these invariants and the instruments developed allow management of their peculiarities. Classes of situations organize themselves into domains of activity (or intervention) for which there are corresponding groups of instruments. We also have (or may have) intuitive experience of this in everyday life: the tool box we keep in the trunk of our car or the sewing kit kept handy, etc. are groups of instruments that allow us to deal with the main situations requiring intervention in these limited everyday domains.
Likewise, groups of inter-linked instruments organized into systems correspond to domains of activities or intervention in the workplace.

Lefort (1982) was the first to our knowledge to have explored the systematic nature of the relation among instruments. He observed work situations to analyze the usage of tools in dismantling activities (in repairs or maintenance) in the mechanics sector. Lefort shows that the operator restructures the tools he/she disposes of in line with his/her experience and skills. Each tool generally performs one or more functions anticipated by designers as well as other functions developed by operators. The operator thus introduces an element of redundancy into his/her tools. This allows greater flexibility in utilization as well as a greater variety of solutions adapted to the particularity of situations. The restructured and organized tools form a homogenous whole in which a better balance between economic objectives and action efficacy is attained for the operator. The new tools and functions, born of instrumental geneses[9] do not develop in isolation. They integrate the operator's tool kit thus ensuring it is globally more balanced. The new functions form an overall system with the functions of instruments developed earlier.

The instrument systems developed by operators can organize vast groups of heterogeneous artifacts and instruments. Vidal-Gomel (Vidal-Gomel, 2001; Vidal-Gomel and Samurçay, in press) demonstrated that in the field of electrical repairs, very different artifacts could be mobilized to carry out a given security function. The choice of the artifact depended on the particular characteristics of situations. The instrument could include a material artifact (such as a padlock preventing maneuvering of a circuit breaker), a semiotic artifact (such as two pieces of tape placed demonstratively as a cross over the circuit breaker not to be used), or more symbolic (for example a security rule). The functional value of these different artifacts thus appears to be the same in terms of the goal (ensuring security), but their specificities differentiate their functional values in line with the particularities of situations.

Finally, we will end this survey by reminding readers of the important results of research undertaken by Minguy (Minguy, 1995, 1997; Minguy and Rabardel, 1993). Minguy undertook a very precise study of the characteristics of an instrument progressively developed by the captain of a fishing boat: his personal map of the fishing zone. Minguy was able to

[9] Lefort does not employ the concept of instrumental genesis which was developed later. Yet the functions and tools level he refers to correspond.

indicate major differences with a computerized tool (a route tracer). These differences explained why the captain made little use of this tool. Above all, he identified the very particular role played by this instrument within the fishing boat captain's instrument system. It allowed the captain to integrate and compare data generated by the many tools at his disposal. For example, for the geographical and topographical data (which only constitutes a fraction of the data on the map), the instrumental origin of data is systematically indicated. The captain had several systems of geographical localizing systems at his disposal (DECCA, LORAN C, GPS) or deep-sea explorers (sounders) that provide results of differing precision and sometimes in different units. The captain thus had the necessary elements to consider them simultaneously. He even incorporated small tools into his map to help with this function of simultaneous integration (graphic miles/kilometers conversion scales, vectors allowing the graphic correction of instrumental errors specific to different instruments, etc.). The fishing map is thus a particular instrument within the instrument system developed by the captain. It plays a pivotal role allowing a range of other instruments to be linked together. This is an essential point we will return to in analyzing the organizer's instrument system and the particular place occupied within it by the Activity Table.

To understand the instrument systems level, concepts used for the unitary instrument are insufficient. We will thus define the concepts that we will mobilize for this level of analysis. They correspond both to the different organization levels of the operator's domain of activity and the dimensions characteristic of instrument systems.

6.1. Analysis of organization levels in the domain of activity

We have explored this question in a text on the articulation between instruments and situations in distinguishing two main organization levels: classes of situations and domains of activity (Rabardel, 2001). Here, we need to add a level of intermediary organization: activity families. Figure 5 represents an example of these different levels of organization.

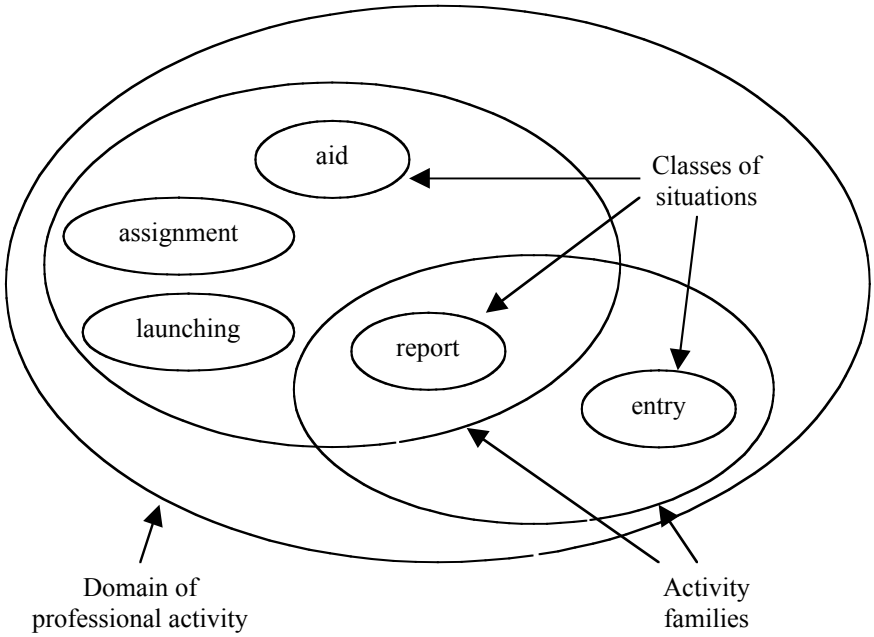

Figure 5
Domain of professional activity, activity families and classes of situations.

Activity situations they must treat professionally are organized by organizers into **classes of situations** that bring together situations with characteristics sufficiently similar (tasks to be performed and situations to be taken into consideration) to give rise to activity modalities that are both relatively stable for the same class of situations and differentiated from one class to another. Operators associate these classes with instrument-mediated activity schemes and instruments adapted to the peculiarities of the class. Classes of situations are sufficiently explicit to be denominated by the operators themselves. In the above sections, we explored one of these: the class of reassignment situations. There are many others for organizers: launching the intervention, aiding technicians from a distance, entering work orders into the CMMS etc.

Classes of situations are themselves organized into a higher level grouping: **activity families**. Thus, for organizers, reassignment, launching and aid to technicians belong to the same activity family: organization of the intervention. Issuing work orders and writing reports belong to another family: administrative activity. Activity families bring together and organize all the classes of situations that correspond to a same type of general finality of action (intervening, managing, etc.). Finally, the group of activity families itself constitutes a level of organization and analysis: the **professional domain of activity**. It includes the group of classes of situations and families of activities liable to spring from operators' professional interventions. In this case the operator is the organizer. Here, we note that classes of situations can be common to several families. For the organizer's domain of activity, we identified 21 classes of situations grouped into three activity families. Each intersection between two families includes a common class. The intersection of the three families is empty.

6.2. Analysis of the functional value of instruments within the system

We have shown elsewhere that instruments are closely linked to situations and to their different structuring levels (Rabardel, 2001). In this section, we will show that this is also true for the organization of groups of instruments into systems corresponding to three organization levels that we analyzed in the above section: class of situation, activity family, domain of activity.

To illustrate this, we will use data collected and analyzed with a specific methodology: the **F**ailure and **S**ubstitution of **R**esources **M**ethod (**FSRM**).

6.2.1. **F**ailure and **S**ubstitution of **R**esources **M**ethod (**FSRM**)

Exploration of the systemic organization of instruments will be based on the failure/substitution test. Data is collected, by observation or interview, on the modalities of performing the activity during the failure of an instrument in a class of situation (e.g. the fax or telephone are not working). Attempts will be made to identify the instruments and more generally the resources that can partially or totally replace the faulty instrument as well as the consequences of this substitution on the activity.

Hence, in writing this article, if the word processor breaks down, theoretically we have several substitution options: writing the article on paper with a pen, recording it on a tape recorder, or dictating it to a shorthand typist[10]... However, there is no strict « **functional equivalence** » among these different possibilities. For example, graphic layout is impossible when recording on a tape recorder. The substitution instrument only fulfills part of the functions of the faulty instrument in that it does not allow one to attain exactly the same goals. We must thus carefully analyze the « **substituted functions** » and those not substituted.

Substitution of functions does not only depend on the nature of the instrument or the resource. It can also depend on conditions: in our example, using a tape recorder is only possible if we are in favorable environmental conditions. While it is fairly easy to use a laptop computer in a train, dictating a long article in the social environment and background noise that characterize this type of environment is more problematic. We must therefore also carefully analyze the conditions in which substitution can occur: the « **substitution conditions** ».

Finally, functional equivalence also depends on criteria and systems that underlie the subject's action. In our example, different pens could have different substitution values: a prestigious pen, whose brand is symbolized by a star on the tip of the cap, will of course fulfill the same functions as a cheap ballpoint pen but its functional value will nonetheless be different in the field of social relations… (at least in the eyes of certain users). Analysis must thus also concern the « **substitution value** » dimension.

When an instrument failure can be compensated for by the mobilization of another instrument or resource, there is at least a partial functional equivalence. This equivalence can be total: instruments have exactly the same possible usage for users, in the same conditions and with exactly the same substitution values. Yet mostly it is only partial: only some functions, or only in some conditions, or with different functional values (e.g. different degrees of speed, ease or comfort, etc) The analysis of functional equivalence among instruments occurs on three dimensions: substitutable functions, substitution conditions and substitution value.

6.2.2. Example of analysis of a sub-system of instruments in a class of situations by the FSRM method.

Our analysis example concerns the sub-system of an organizer's instruments for the reassignment class of situations. We asked an organizer to talk us through a test of different scenarios in which he had to do a reassignment when one of the commonly used artifacts has broken down. The different artifacts were successively presented as out of order and he had to analyze and discuss the possibilities of carrying out the reassignment activity by replacing the defective artifact with other resources. He was also asked to describe how he would proceed in mobilizing the substitution resources. All his comments were recorded and transcribed.[11]

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[10] For readers familiar with researchers' working conditions it will be clear that this example is fictitious.

[11] Here is an example of a verbalization concerning the breakdown of the Activity Table:
« It's getting more difficult… because without the Activity Table, I don't know who I can change or what was planned… If I use the telephone, I can try and call all the guys one by one and eventually, I'd know who to give the intervention to… but it would take much longer… it depends because if I can remember who's doing what maybe I'll work it out... I'd also take the work schedule and try to remember as much as I can that I could use… Yeah, I think I'd use the work schedule because that tells me who's there or who's absent… and you can write directly on it into the boxes… »

Table 1 gives an example of a partial analysis of collected data. The analysis indicates that some functions do not have an equivalent (for example getting the client's request in writing in the case of the fax) and also that the breakdown of other functions can be compensated by several substitution resources (for example, still in the case of the fax, obtaining information).

Usual artifact	Frequency of usage	Functions to be substituted in case of breakdown	Substitution ressources	Substitution value	Substitution conditions
Fax	Always	* obtaining information concerning intervention requests * getting client's request in writing	* Telephone * 'Intervention request' screen in CMMS tool * no substitution artifact	* Less practical * Slower	
Telephone	Always	* being informed of the arrival of a client request	* Fax * 'Intervention request' screen in CMMS tool	* Slower: does not allow anticipation * Does not warn of arrival	
Road maps	Sometimes	* obtaining information on the distance and route between different intervention sites	* organizer's personal memory * calling upon intervention technicians that know the area	* Sometimes less precise * dependent on others' resources	* Availability of remembered knowledge * possibility of contacting intervention technician

Table 1
Example of the exploitation of data by the FSRM method: partial analysis of the instrument sub-system in the « Reassignment » class of situations.

In this example, there is thus no complete functional equivalence among instruments. The substitution possibilities are different depending on functions and are often distributed among several resources. Furthermore, in taking into consideration the substitution conditions and substitution values, we move even further away from a strict functional equivalence among instruments. In other words, among the instruments in our example, there is both a partial functional coverage (redundancy) and equally partial functional complementarities. We feel that this double characteristic contributes simultaneously to the system's robustness (mostly, there is one or more possible alternative solutions in the case of an artifact or function breakdown) and the flexibility and adaptability of its mobilization in relation with the variability of circumstances. Here, in using the systematic analysis of the FSRM method, we find some of the characteristics of the systemic organization of instruments identified by Lefort in his study from 1982.

Table 1 also indicates that the subject's external resources (artifacts as well as other subjects) and internal resources (such as his/her memory and knowledge) can be the object of functional substitutions in certain breakdown cases. In other words, different types of resources participate in the systemic organization of all the subject's instruments. These results are similar to those of Vidal-Gomel (Vidal-Gomel, 2001; Vidal-Gomel and Samurçay, in press) when she highlights the functional equivalence of very different artifacts to ensure

the security function in electrical maintenance. The instrument system organizes resources of a heterogeneous nature into a homogenous system whole.

6.3. Organization of the instrument system in classes of situations

We must now more carefully explore the organizational forms specific to the instrument and resource system and sub-systems. To do so, we will bring together elements from the analysis with the FSRM method and those from the analysis of the instrument as a mixed entity. In the above section, we presented the reassignment scheme associated with the Activity Table. Figure 6 positions the different artifacts identified by the FSRM analysis in terms of each of the scheme phases.

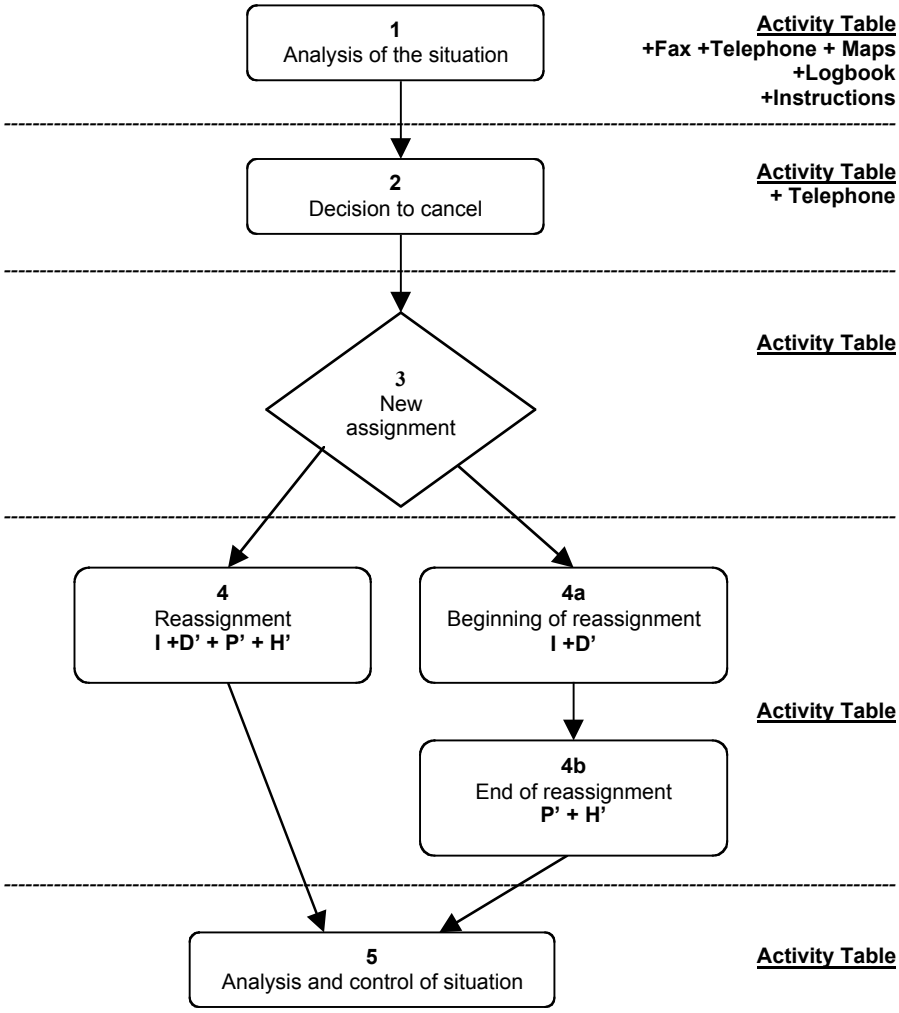

Figure 6
The multi-instrument-mediated reassignment scheme.

An examination of figure 6 casts light on two important points. The first is that the Activity Table artifact intervenes in each phase of the reassignment scheme. The two form a constantly mobilized instrument in the reassignment process. The second point is that the Activity Table is not the only artifact that intervenes in this process. In the first phase, the most enlightening from this point of view, the organizer can use several of them: the fax machine to obtain

information on intervention requests, instructions on their priority rating, the logbook to know their state of advancement and the nature of the intervention underway, maps to examine possible movements for technicians already out in the field, etc. The reassignment scheme thus appears as a multi-instrument-mediated activity scheme and the Activity Table instrument (reassignment scheme + Activity Table artifact) as the central instrument of the instrument sub-system. The Activity Table instrument creates links between them and other instruments and organizes their contribution within different steps of the process. Like the map of the head fisherman analyzed by Minguy (Minguy, 1995, 1997; Minguy and Rabardel, 1993), it constitutes the pivot of the system.

6.4. Organization of the instrument system in families and domains of activity

We will now explore the organization of the instrument and resource system on the level of families of activity and domains of activity. To do so, we will bring together results from the FSRM analysis and organization into families of activity. Let us remember that we have identified 21 classes of situations organized into three activity families: organization of the intervention, technical management of the intervention and administrative activity. Figure 7 presents the organization of instruments in line with classes of situations and activity families[12]. In this example, we limited ourselves to the three main instruments specific to the organizer's job: the Activity Table, the CMMS tool (mentioned earlier) and the logbook, the document on which the organizer progressively notes elements relative to each of the ongoing interventions.

[12] Figure 7 corresponds to a situation in which no instrument is faulty.

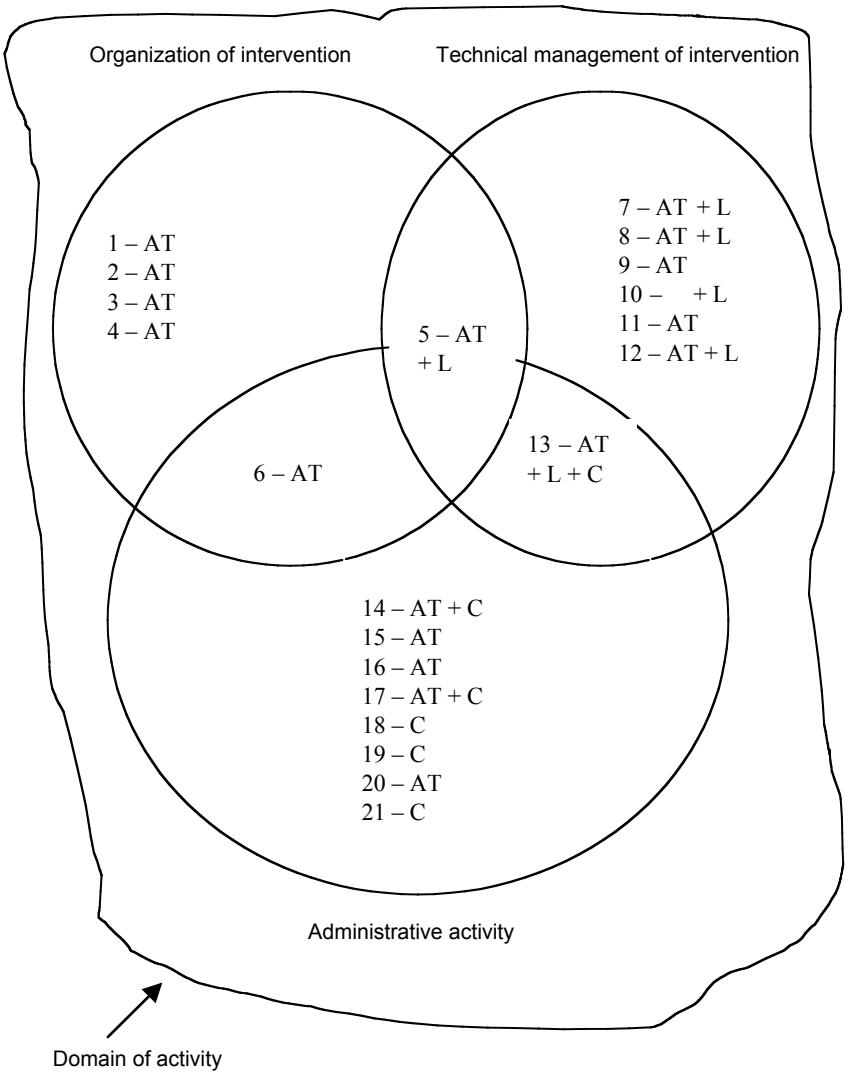

Figure 7
Instruments in line with classes of situations and activity families
(AT = Activity Table; L = Logbook; C = CMMS tool).
The numbers correspond to different classes of situations.

Examination of figure 7 indicates instruments' differentiated membership to different activity families. The CMMS tool, besides one exception, only belongs to the « Administrative Activity » family. The logbook is primarily focussed on the « Technical Management of Interventions » family but is also present to a limited extent in the two other families. Finally, the Activity Table tool, the main tool for the « Intervention Organization » family, is also very present in the two other families. Thus, it is the « pivot » of the system of instruments as a whole in the domain of activity. Figure 8 indicates the particular role of the Activity Table in the instrument system of the domain and the specificity of the sub-systems to each of the families.

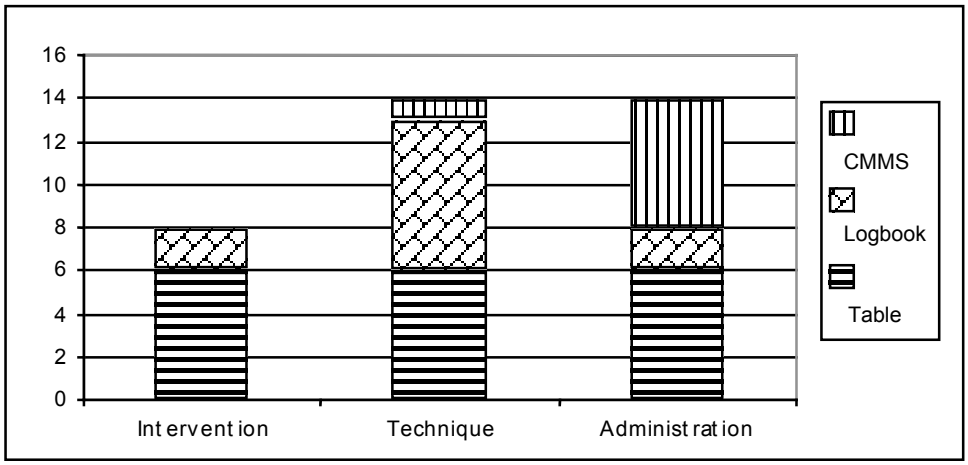

Figure 8
Instruments and activity families.

Figure 9 highlights the weight of the Activity Table in the domain of activity: it is present in three quarters of classes of situations (16 out of 21) whereas the Logbook concerns 8 classes and the CMMS tool only 6.

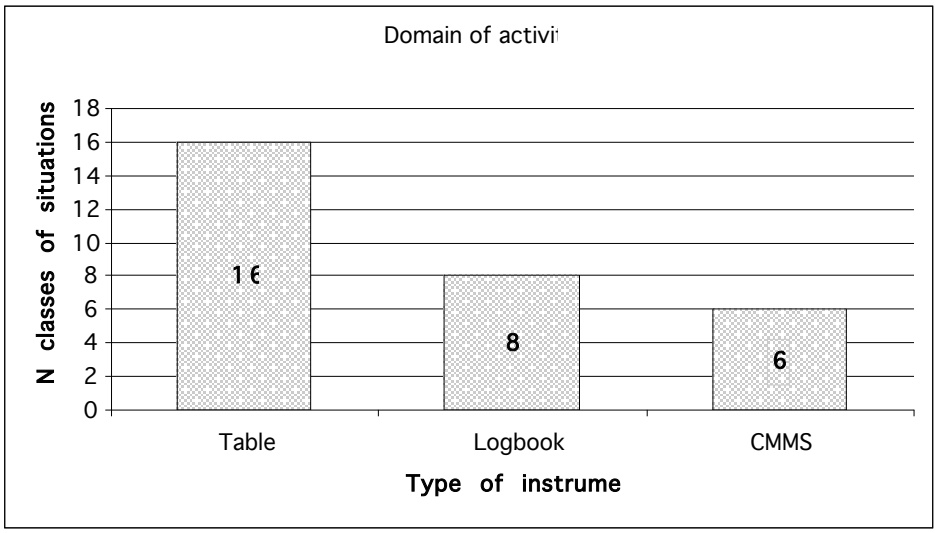

Figure 9
Relative weight of instruments in the domain of activity.

6.5. Systemic artifacts and collision of instrument systems

To conclude this section on instrument systems, we will return to the CMMS tool. Figures 7, 8 and, 9 cast light on two important points. This tool is used a lot in the family of administrative activities. However, it has not found its place in the sub-system of instruments specific to other families of the domain. It has not only been rejected from the reassignment class of situations but also, with one exception, from all the classes of situations of the two families focussed on the intervention (organization and technical management).

The origin of the CMMS tool allows us to put forward a hypothesis to understand both this acceptance for part of the domain and the rejection for the majority.

The CMMS that the company made available to organizers was part of a new information system which was to allow the collection and treatment of all information relative to maintenance at all levels of the company. It is a systemic artifact and organizers were only one of the staff categories the system was to reach. The CMMS was also, and no doubt above all, aimed at other staff, particularly those responsible for management and administration of maintenance nationwide. It seems that for these categories, the CMMS tool was effectively an instrument central to the job and not peripheral as it was for organizers. We hypothesize that organizers' partial rejection of the CMMS was due precisely to the artifact's management orientation. The heart of organizers' job is very different. The design choices that broke information up onto a number of screens did not allow them to have the overview of ongoing interventions that they require. These choices made the integration of the CMMS impossible in the two sub-systems of instruments corresponding to activity families specific to their job: the organization and technical management of interventions. Yet other choices could have been made and the company is currently exploring these options.

Beyond this specific interpretation of the particular situation we have explored, we would like to formulate a much more general hypothesis. The development of information systems and systemic artifacts within companies makes profound changes to the characteristics of work on an individual and communal level in generalizing the transfer of information from one function to another. The result of one group's work tends to become the material for the work of another group: it is taken up and reworked by other categories of staff. The instrument systems of different work communities, hitherto mostly not interdependent, confront one another due to the necessity of working and reworking the same material[13]. In some cases, this confrontation can take the form of a collision or a confrontation. We feel the difficulties encountered by organizers with the CMMS tool result from one of these collisions between instrument systems. Its outcome is not yet known and one of us is working on the systemic artifact so it can be instrumentalizable and integrated into the instrument systems of the different communities concerned. A local solution will probably be found but this problem is not local or specific to maintenance. It is representative of new types of problems thrown up by the general move towards processing in companies and the accompanying development of systemic artifacts. In order to analyze and treat these problems they must be apprehended in terms of: people and work communities; instruments and systems of instruments and resources; classes of situations, families and domains of activity.

7. CONCLUSION

We introduced this article with the idea that the historical movement of models aiming to account for human activity tends toward models that allow an understanding of the engendering of behavior and activity. Perspectives opened up by the instrument-mediated activity approach contribute to the development of this new generation of « generative models ».
The instrument is not given to users, or subjects. The artifact they take up or with which they are entrusted is only an instrumental proposition that they will elaborate, if they wish and if it

[13] We had already identified a similar situation in the generalization of CAD in an engineering company (Béguin, 1994; Béguin and Rabardel, 2000).

is possible, as an instrument. This is the function of instrumental geneses. By the instrumentalization of the artifact, subjects adapt and give form to the artifact proposed. By instrumentation, they will develop or adapt utilization schemes. This double development movement concerns the two components of instruments: the artifact and the scheme.

Continuing design in usage, which generative models must account for, is not only linked to deficiencies in the design or the unpredictable nature of the singularity of concrete situations. It is the expression of an ontological characteristic of human activity: activity is both productive, i.e. oriented toward the production of results, and constructive, i.e. oriented toward the development of the subject's instruments and resources.

Activity mediated by instruments is a pertinent analysis unit on the level of usage activity and instrumental geneses but it is not sufficient in itself. Instruments configure themselves into systems and sub-systems linked to characteristics of classes of situations, activity families and domains of activity. Within these systems, particular instruments play a pivotal role. They articulate classes of situations with activity families. In our example in maintenance, one of them, the Activity Table, appears as dominant: it is mobilized in all the activity families and in three-quarters of the classes of situations. The FSRM method allows working on the level of the second analysis unit that makes up instrument systems.

Instrument systems, like instruments, develop. Lefort (1982), Minguy (Minguy, 1995, 1997; Minguy and Rabardel, 1993), Duvenci-Langa (1997), Folcher (1999) and Vidal-Gomel (Vidal-Gomel, 2001; Vidal-Gomel and Samurçay, in press) have shown that they evolve and differentiate themselves depending on operator experience. We put forward the hypothesis that operators' development of instrument systems tends to make them coextensive to their domain of activity as a whole. Their evolution should thus reflect that of the domain of activity itself. Yet it would be a mistake to think that instrument systems' dynamics come only from the subject's need to adapt to the changing characteristics of the domain of activity. The driving force behind the development of instruments and instrument systems is also the search for a more balanced and robust system in relation with the different orientations of mediation that it must make possible and the diversity of criteria and values that orient the subject's activity. It is also in the relations the subject upholds with him/herself and others. These evolving relations give meaning to his/her activity.

We feel that developmental approaches are essential for the analysis of instruments and instrument systems. It is not only a question of understanding their current state but also apprehending their development movement so as to more fully take it into account in the design process. There are several options: follow-up of development among singular subjects; reconstituting development by comparing groups of subjects with different stages of development; archeological type investigation to reconstitute the history of a development based on remaining evidence (see, for example, research by Wertsch (1998) on high jumping).

Evolutions currently underway in companies constitute a specific context for the evolution of instrument systems. Introducing processing into new sectors of the economy and the development of information systems running through every level of companies increases interdependence among actors and leads to collisions between instrument systems of different communities. New types of problems appear throwing up new challenges and issues for design.

We feel that one of these major challenges is taking into account and anticipating design activities in usage within institutional design processes. For this reason, we are convinced that design will need to be more and more clearly considered and managed as a distributed activity among a range of actors and categories of actors who themselves participate in a range of situations and institutions.

BIBLIOGRAPHY

Ananiev, B. G.; (1959); Osyazanie v protsessakh truda i poznaniya (A Sense of Touch in the Processes of Work and Cognition); Russian Academy of Pedagogical Sciences; Moscow.

Bannon, L. J., Bodker, S.; (1991); Beyond the Interface: Encoutering Artifacts in Use; Designing Interaction: Psychology at the Human Computer Interface; Carroll, J. M. (ed.); 227-253; Cambridge University Press.

Beguin, P.; (1994); Travailler avec la CAO en ingénierie industrielle : de l'individuel au collectif dans les activités avec instruments, Doctoral Thesis in Ergonomics; CNAM; Paris,.

Béguin, P., Rabardel, P.; 2000; Designing for Instrument Mediated Activity; Scandinavian Journal of Information Systems; Special Issue: Information Technology in Human Activity; Bertelsen, O., Bodker, S. (eds.); (12); 173-190.

Bodker, S.; (1991); Through the Interface: A Human Activity Approach to User Interface Design; Lawrence Erlbaum Associates Publishers; Hillsdale, NJ.

Bourmaud, G.; (in preparation); Analyse de l'activité des opérateurs : source pour la conception de situations de travail comprenant des outils informatiques; Doctoral Thesis in Psychology-Ergonomics; Université Paris 8; Saint Denis.

Clot, Y.; (1995); Le travail sans l'homme ? Pour une psychologie des milieux de travail et de vie; La Découverte, coll. Textes à l'appui, Paris.

Cole, M.; (1996); Cultural Psychology: Once and Future Discipline?; Harvard University Press.

Duvenci-Langa, S.; (1997); Evolution de l'activité et des compétences en situation d'automatisation : le cas des machines-outils; Doctoral Thesis in Ergonomics; CNAM; Paris.

Engeström, Y.; (1990); Learning, Working and Imagining, Twelve Studies in Activity Theory; Orienta-Konsultit Oy; Helsinki.

Folcher, V.; (1999); Des formes de l'action aux formes des instruments, un exemple dans le champ du travail collectif assisté par ordinateur; Doctoral Thesis in Psychology-Ergonomics; Université Paris 8; Saint Denis.

Forzy, J. F.; 1999; Assessment of a Driver Guidance System: A Multi-level Evaluation; Transportation Human Factors; (1;3); 273-287.

Henderson, H., Kyng, M.; (1991); There's No Place Like Home: Continuing Design in Use; Design at Work: Cooperative Design of Computer Systems; Greenbaum, J., Kyng, M. (eds.); 219-240; Laurence Erlbaum Associates Publishers, Hillsdale, NJ.

Kaptelinin, V.; (1996a); Computer Mediated Activity: Functional Organs and Developmental Contexts; Context and Consciousness: Activity Theory and Human Computer Interaction; Nardi, B. A. (ed.); 45-68; MIT Press; Cambridge.

Kaptelinin, V.; 1996b; Distribution of Cognition between Minds and Artifacts: Augmentation or Mediation?; AI and Society (10); 15-25.

Kaptelinin, V., Kuutti, K.; (1999); Cognitive Tools Reconsidered from Augmentation to Mediation; Human Interfaces, Questions of Method and Practice in Cognitive Technology; Marsh, J. P., Gorayska, J. P., Mey, J. L. (eds.); 145-160; Elsevier Science B. V.; Amsterdam.

Lefort, B.; 1982; L'emploi des outils au cours de tâches d'entretien et la loi de Zipf-Mandelbrot; Le Travail Humain; (45;2); 307-316.

Léontiev, A. N.; (1975); Activité, conscience, personnalité; Editions du progrès ; Moscou.

Léontiev, A. N.; (1981); Problems in the Development of Mind; Progress; Moscow.

Minguy, J. L.; (1995); Concevoir pour aider à l'action située. Le travail en passerelle de navires de pêche : rôle de la carte de pêche comme représentation; Doctoral Thesis in Ergonomics; CNAM; Paris.

Minguy, J. L.; 1997; Concevoir aussi dans le sillage de l'utilisateur; International Journal of Design and Innovation Research; (10); 59-78.

Minguy, J. L., Rabardel, P.; 1993; Control of a Fisching Trawl: A Multi-instrument Process Control Situation, Analysis, Design and Evaluation of Man-Machine Systems; Stassen, H. G. (ed.); 157-162; Pergamon Press; Oxford.

Paillard, J.; 1971; Les déterminants moteurs de l'organisation de l'espace; Cahiers de psychologie (14); 261-316.

Paillard, J.; (1987); Système nerveux et fonction d'organisation; Psychologie, Encyclopédie de la pléiade; Piaget, J., Mounoud, P., Bronkart, J. P. (eds.); 1378-1437.

Rabardel, P.; 1991; Activity with a Training Robot and Formation of Knowledge; Journal of Artificial Intelligence in Education; (2;4); 3-14.

Rabardel, P.; (1995); Les hommes et les technologies, une approche cognitive des instruments contemporains; Armand Colin; Paris.

Rabardel, P.; (1999); Le langage comme instrument, éléments pour une théorie instrumentale élargie; Avec Vygotsky; Clot, Y. (ed.); 241-265; La Dispute; Paris.

Rabardel, P.; (2001); Instrument Mediated Activity in Situations; People and Computers XV - Interaction Without Frontiers; Blandford, A., Vanderdonckt, J., Gray, P. (eds.); 17-30; Springer-Verlag.

Rabardel, P.; (2002); People and Technology: a Cognitive Approach to Contemporary Instruments. This book will soon be available at the following site: http://ergoserv.psy.univ-paris8.fr/

Rabardel, P., Verillon, P.; (1985); Relations aux objets et développement cognitif; Actes des Septièmes Journées Internationales sur l'Education Scientifique; Chamonix.

Rasmussen, J.; (1997); Merging Paradigms: Decision Making, Management, and Cognitive Control; Decision Making under Stress: Emerging Themes and Applications; Flin, R., Salas, E., Strub, M., Martin, L. (eds.); 67-81; Ashgate.

Rubinstein, S. L.; (1958); De la pensée et des voies de son étude; Académie des Sciences de l'URSS; Moscou.

Suchman, L. A., Trigg, R. H.; (1991); Understanding Practice: Video as a Medium for Reflection and Design; Design at Work: Cooperative Design of Computer Systems; Greenbaum, J., Kyng, M. (eds.); 65-89; Laurence Erlbaum Associates Publishers, Hillsdale, NJ.

Vérillon, P., Rabardel, P.; 1995; Artefact and Cognition: A Contribution to the Study of Thought in Relation to Instrumented Activity; European Journal of Psychology in Education; (9;3).

Vicente, K. J.; (1999); Cognitive Work Analysis: Toward Safe Productive and Healthy Computer-based Works; Lawrence Erlbaum Associates Publishers, Hillsdale, NJ.

Vidal-Gomel, C.; (2001); Le développement des compétences pour gérer les risques professionnels. Le domaine de la maintenance des systèmes électriques; Doctoral Thesis in Psychology-Ergonomics; Université Paris 8; Saint Denis.

Vidal-Gomel, C., Samurçay, R.; in press; Qualitative Analysis of Accidents and Incidents to Identify Competencies. The Electrical System Maintenance Case; Safety Science.

Vygotsky, L. S.; (1930-1985); La méthode instrumentale en psychologie; Vygotsky aujourd'hui; Schneuwly, B., Bronckart, J.P. (eds.); Delachaux et Niestlé.

Vygotsky, L. S.; (1931-1978); Mind in Society: The Development of Higher Psychological Processes, Cole, M., John-Steiner, V., Scribner, S., Souberman, E. (eds.); Harvard University Press; Cambridge, Massachussetts.

Wartofsky, M.; (1979); Models: Representations and Scientific Understanding; Dordrecht Reidel.

Wertsch, J. V., (1997); Mediated action; A Companion to Cognitive Science; Bechtel, W., Graham, G. (eds.); Oxford; Blackwell.

Wertsch, J. V.; (1998); Mind as Action; Oxford University Press; New York.

Winograd, T., Flores, C. F.; (1986); Understanding Computers and Cognition: A New Foundation for Design; Ablex, Norwood, NJ.