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Summary : The aim of this chapter is to contribute to the theoretical development of research into mediation by artifacts in learning. We consider the user not only as a physical, cognitive or social entity who interacts with a technical device, but also as a subject intentionally engaged in activities of task performance: "productive activities" and simultaneously engaged in activities of elaborating resources: "constructive activities".

From Artifact to Instrument-Mediated Learning

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Introduction

Research into learning with artifacts is a field that is currently booming. This development is grounded in social questions, in particular those thrown up by technological and organizational changes and the associated evolutions in everyday life, work and training (see Whole). Hence, the arrival of successive generations of technology in the training field has led to the development of research into learning, the development of knowledge and skills and the design of artifacts as well as teaching and learning environments.

Hannafin & al (1997) identify two main paradigms in this field: an "instructionist" approach and a "constructivist" approach. The psychological grounding of the "instructionist learning environments" paradigm was initially inspired by behaviorist theories, then cognitive psychologies of information processing (Gagné & Glaser, 1987; Hannafin & Reiber, 1989). The second "constructivist" paradigm, which appeared later, is grounded in both Piagetian and post-Piagetien approaches (Papert, 1980), situated learning (Browns & al., 1989), socially-shared cognition (Resnick & al., 1991) and activity theories (Jonassen & Robert-Murphy, 1999).

The organization field also led to the development of research into the role of artifacts in learning: organizational learning (Argyris & Schön, 1978; Masino & al., 2000) and innovative organizational learning (Engeström, 1999). We find the same diversity of theoretical foundations as we do in research into training.

Developments in research are also due to internal questioning of scientific theories which postulate that artifacts exercise a decisive influence on activity and on human development. The underlying hypotheses refer to the obvious anthropological fact

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that human beings are born and develop in an environment that is partly artificial and structured by institutional and technological systems: social conventions and rules, but also corporeal and extra-corporeal means of communicating and of processing matter, energy and information. It has been assumed that artifacts could, at least partially, determine man's cognitive relations with the natural environment and with his fellows. For example, they might structure his categories of thought and knowledge or, by developing his ability to act on the environment, they might in turn extend his cognitive capacities.

For example Wallon (1942) states "The universe to which the child has to adapt and on which he models his activity and his impressions... is all the artifacts,... institutions,...techniques of language...which regulate his thoughts by imposing on them, through conceptual or logic frameworks, the breakdown of shapes and objects which the world contains and that are now made available to him through thousands of years of civilization and by material and mental elaboration."

Yet the most profound developments in conceptualizations and theoretical frameworks allowing the exploration the question of mediation by the artifact have occurred within approaches based on activity theories. Vygotski (1978) developed an initial theoretical framework conceptualizing activity mediated by tools and signs. He considers mediation as the central factor that transforms psychological functions: "the use of artificial means, the transition to mediated activity, fundamentally changes all psychological operations, just as the use of tools limitlessly extends the range of activities within which the new psychological functions may operate ". Léontiev (1981) also attributes a central role to activity mediated by artifacts in his general theory of activity. A large number of empirical and theoretical studies have been and continue to be developed within the perspective of mediated activity (eg. Cole, 1996; Engeström, 1990; Kaptelinin, 1996; Rabardel, 1995; Wertsch, 1997, etc.).

Our own research is grounded in constructivist epistemologies, primarily in activity theories but also in the Piagetian and post-Piagetian developmental approach to the cognition-action dialectic.

The aim of this chapter is to contribute to the theoretical development of research into mediation by artifacts in learning. We consider the user not only as a physical, cognitive or social entity who interacts with a technical device, but also as a subject intentionally engaged in activities of task performance: **"productive activities"** and simultaneously engaged in activities of elaborating resources: **"constructive activities"**. These two types of activity are directed (in the Clot sense,1999) toward him/herself, toward collectives and work communities as well as toward his/her working environment in its range of material, artifactual and organizational components. Constructive activity particularly concerns the development of the subject's internal and external resources as a whole, i.e. instruments in terms of their psychological and material components, skills and conceptualizations developed based on and for the productive activity.

We will advance the idea that it is more pertinent when taking on the subject's point of view (Norman's "personal view", 1991) to look at the problem in terms of mediation by instruments and not only by artifacts. We put forward a theoretical framework to define and explore "instruments" and instrument-mediated activity. This implies a

very precise definition of mediations. For this reason, we distinguish between different sorts of mediations.

The subject's activity is oriented toward the object of the activity and mediation by the artifact can include two types of components:

- components of **epistemic mediation**, oriented toward an awareness of the object, its properties and its changes in line with the subject's actions…
- components of **pragmatic mediation**, oriented toward action on the object: transformation, regulation management, etc.

Either the epistemic or pragmatic components of the mediation may dominate. However, they generally interact constantly within the activity.

In his/her activity, the subject does not only relate to the objet. He/she also relates to him/herself: he knows himself, manages and transforms himself. Thus we must take into consideration **reflexive mediations**[2] when the subject's relation to himself is mediated by the instrument[3].

Finally, the subject also relates to other subjects, particularly in situations of collective work. Thus we need to consider **inter-personal mediations** between subjects, which may take on the specific characteristics of collaborative mediation when the work is collective.

All these mediations occur within both the productive activity and the constructive activity.

In the first part of this chapter, we will examine the factors that allow us to identify the educational nature of activity mediated by instruments: the management of constraints and the opening of a space of mediated activity development. We will demonstrate this with an empirical study on competences development in operating blast furnaces.

In the second part, we will look in detail at the development process of the instrument and the mediated activity. We will put forward a second example: the use of a robot to move objects.

In the third part, we will explore the collective dimensions of mediation by instruments in relation to mediation by others. Our example will be a training program on operating a nuclear power plant on a simulator.

These three examples concern artifacts explicitly elaborated or used in a training context to develop competences. In all cases, the subject's activity with the artifacts has a productive dimension that aims to achieve operational objectives. Yet this productive activity only exists as a support for a constructive activity, which constitutes the subject's real finalization.

In the last section, we will summarize the results obtained and develop their implications in a general discussion.

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[2] Reflexive mediations correspond to heuristic mediations as we defined earlier in Rabardel, 1995 and Béguin & Rabardel, 2000.

[3] Relations of the subject to himself are not only mediated by instruments but also by other subjects.

1. Two explanations for the influence of the artifact on competences development

The example that we present here corresponds to a study already published on the design, evaluation and appropriation of a diagnosis assistance tool used in the operation of a blast furnace which produces cast iron from raw materials[4]. Here we reinterpret the data from an instrumental perspective by analyzing a "causal model of the process' operation" that we conceived as an epistemic-oriented artifact. We make it clear that the operators' appropriation of this as an instrument improves the quality of their activity and allows the development of their competences. The main question we will address concerns the impact of an artifact's use in the appropriation of new competences by the reorganization of the activity. This reorganization is linked to the constraints that the artifact imposes on the activity and the opening of a space of mediated activity development that it allows. After a brief look at the artifact's design, we will examine the appropriation process.

The artifact's design basis

The activity studied concerns the supervision and control of this dynamic process (in that many of the transformations occur independently of operator actions and response times are long, i.e. 4 to 8 hours). The blast furnace is like a black box: the operators have information on the entry and exit parameters but very few of these parameters can be measured directly against internal transformations. Thus, they need an operation model allowing them to 1) make inferences on the non-observable internal transformations based on the observables at their disposal; 2) analyze problematic situations and 3) act efficiently on the latter. As a result, operators' activity has two main characteristics: 1) the diagnosis and prognosis finalized by action-related decisions is a central activity; 2) the generation and management of hypotheses on the present and future operation of the process require competences in interpreting non-directly observable phenomena based on combinations of action variables or measured variables. These activities are already instrumented by information and command systems, which are structured in line with the process' topographical logic (for example, entry, exit and intermediate variables).

Based on analyses of operator activity, we highlighted the fact that efficient strategies were characterized by long-term anticipations and the relativization of rules of action according to the context. These strategies are grounded in causal-type schematic representations of the process' operation, which allow operators to apprehend non-directly observable phenomena with the aid of pragmatic conceptualizations. These are schematic (but non-circumstantial) representations of phenomena that are not directly observable. They link the observed variables to action variables and classes of situations[5]. An example is presented below (see Fig. 1): based on measured variables (pressure, descent speed), the operator evaluates the quality of the burden descent (pragmatic concept) allowing him/her to apprehend and treat the class of

[4] For more detailed analyses see Hoc&Samurçay, 1992; Samurçay, 1995; Samurçay&Hoc, 1996.
[5] We will return to these questions in the conclusion

situations linked to burden descent dysfunctions (hanging, falling down, etc) If, for example, the dysfunction is due to the hanging of burden on the shaft walls, the operator then expects to see repercussions on the quality of the reduction of materials. He/she can act on the air blast flow to increase or decrease the descent speed and by modifying the distribution of the burden to improve the quality of reductions.
We have identified 7 to 8 concepts that cover most of the dysfunctions encountered. These concepts are socially shared by professionals and are organized into a network of concepts which reduce the complexity of the system for efficient action as well as for the elaboration of holding systems for supervision. Based on this network of concepts, we have designed[6] an artifact whose use is destined to facilitate the conceptualization process for less experienced operators. In its external form, the artifact can be seen as a

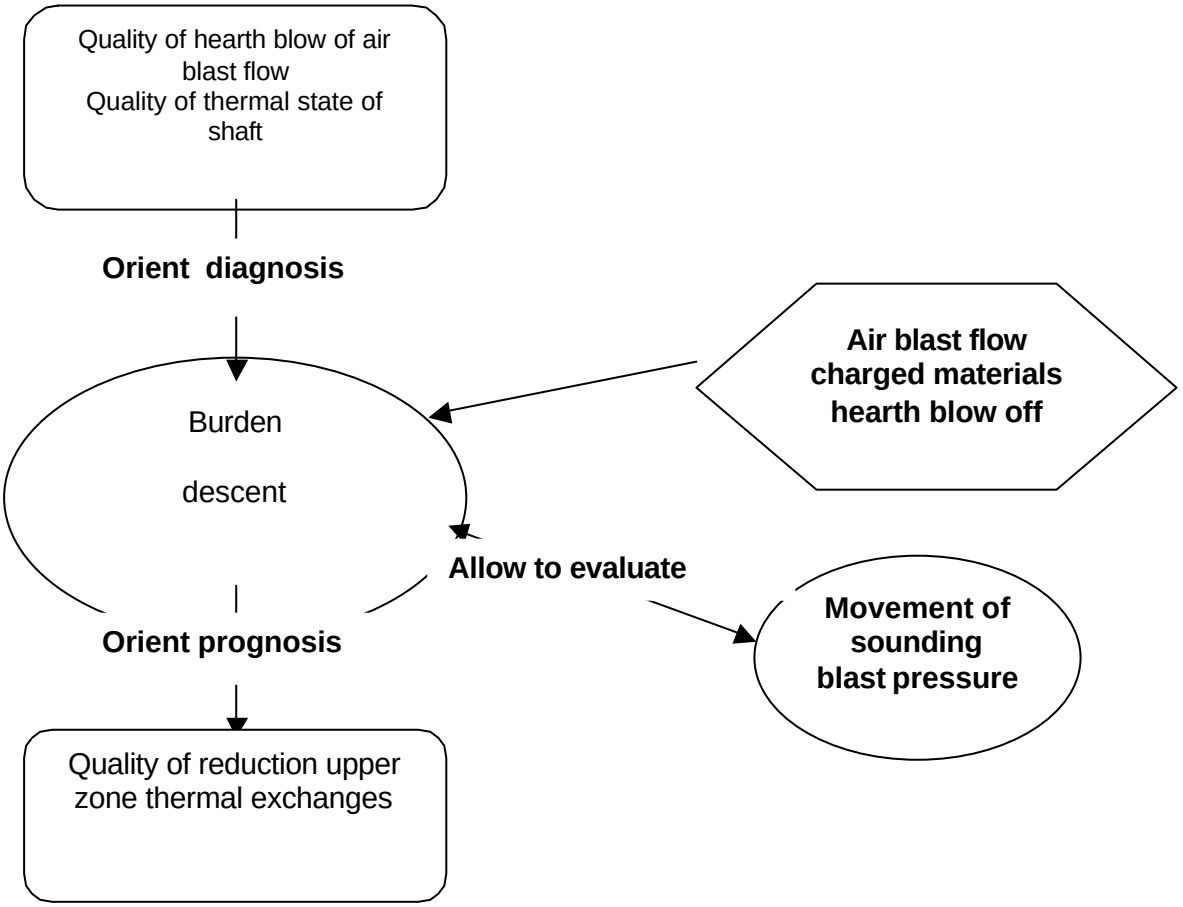


Figure 1: An example of pragmatic conceptualization

new access interface to the system's parameters which restricts the information gathering activity in a causal form (unlike the usual behavior interface which is

[6] The artifact's design was carried out following a participative design cycle and with the participation of the production engineers and operators.

organized topographically) in place of the existing topographical structure. Figure 2 represents the general structure of the new interface.
During an experimental training program, operators worked with the new interface to treat simulated situations. The working hypothesis was that their activities mediated by the new artifact would produce new relations to the object of the activity. Thus the operator would appropriate the model underlying the new artifact. The operators had two work sessions at one-

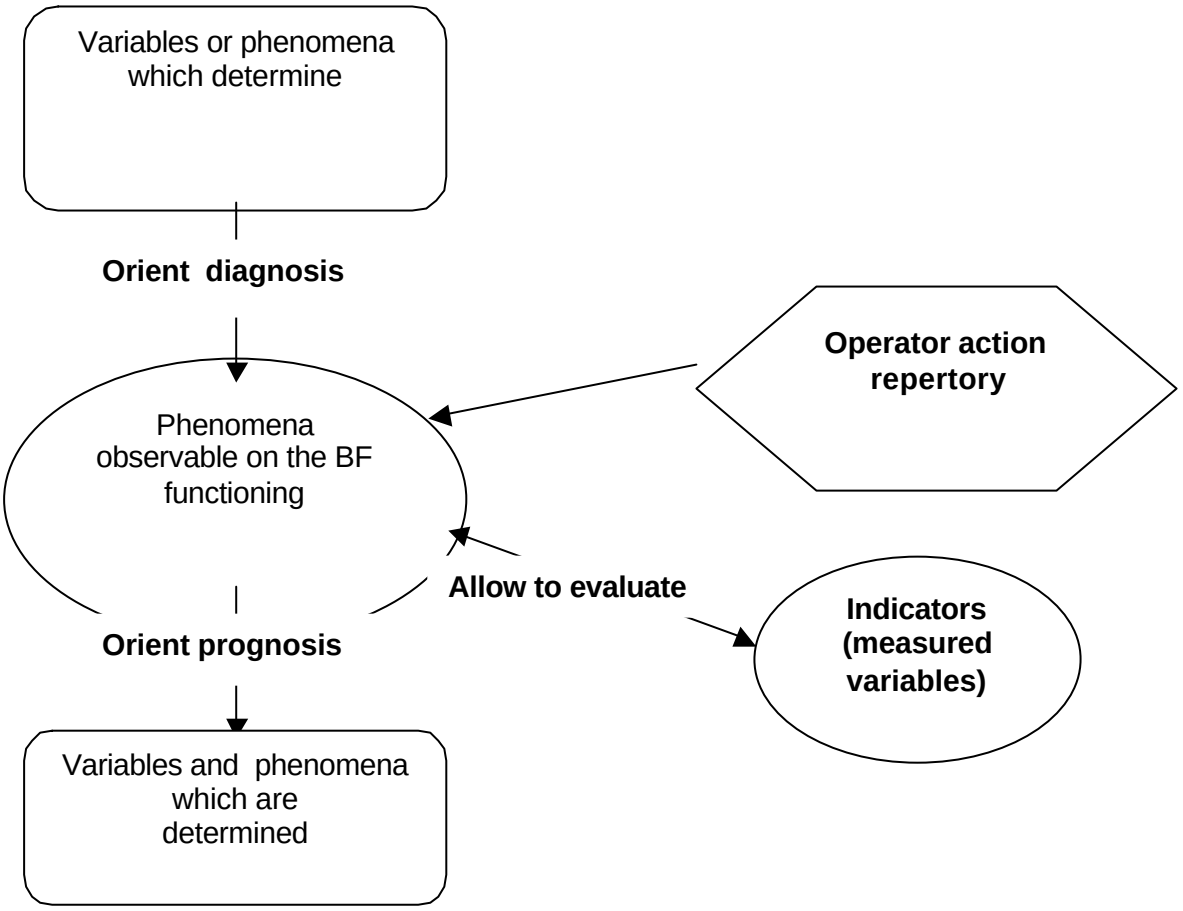


Figure 2. The causal structure

month intervals with the new interface and one free-access session between the two. We analyze the development of competences linked to the use of the artifact on two levels:

- the first level is the development of activities linked to the use of the interface and to the discovery of the artifact's properties (how is it made? How does it work? What can one do with it? Etc.) The subject's activity is oriented by an understanding of and practical experience with the artifact. From one session to the next, the frequency of these activities drops in favor of activities that are thrown up by the realization of the task itself. In the beginning, the information gathering activity is guided by the artifact's surface properties (for example, systematically consulting the variables). Next it is guided by hypotheses linked to causal relations, i.e. the artifact's functional properties.
- The second level is the development of activities linked to the analysis of the situation: the diagnosis, the prognosis and the decisions to act on the process. Development and conceptualization concern both the creation of relations between components of the causal system and the appropriation of the network of concepts:

- a) We observe the development of relations between a pragmatic concept and variables (cause, consequence, indicator and action). From one session to the next, the operators' use of indicators becomes more complete and more varied: they tend to use several indicators to confirm or infirm a hypothesis.

- b) The appropriation of the network of concepts is made manifest by the establishment of causal relations between pragmatic concepts. From one session to the next we can see more concepts being used to analyze operating situations as well as a greater number and improved quality of anticipations requiring cross-referencing of concepts. In other words, the operator appropriates the model as a whole to analyze operating situations, to anticipate consequences and to envisage actions on the process or set him/herself specific surveillance goals.

Thus, we see that the supervision activity, particularly the management of information gathering, is reorganized by the new artifact while at the same time the quality of analysis improves.

Two factors are at the heart of the artifact's reorganization of the activity: the management of constraints it imposes on the activity, and the opening of a space of mediated activity development that it allows (Rabardel 1995, 1999).

Firstly, for the subject the artifact is a collection of imposed constraints, which must be managed in his/her activity in situation. We distinguish three types of constraints linked respectively to the artifact's properties as object, to the objects on which it allows the operator to act and the transformations it allows, as well as the pre-structuration of the user's action. Given these dimensions, the "causal model" tool pre-structures information gathering management activities by obliging operators to generate hypotheses to search for information. Schematically it could be said that it

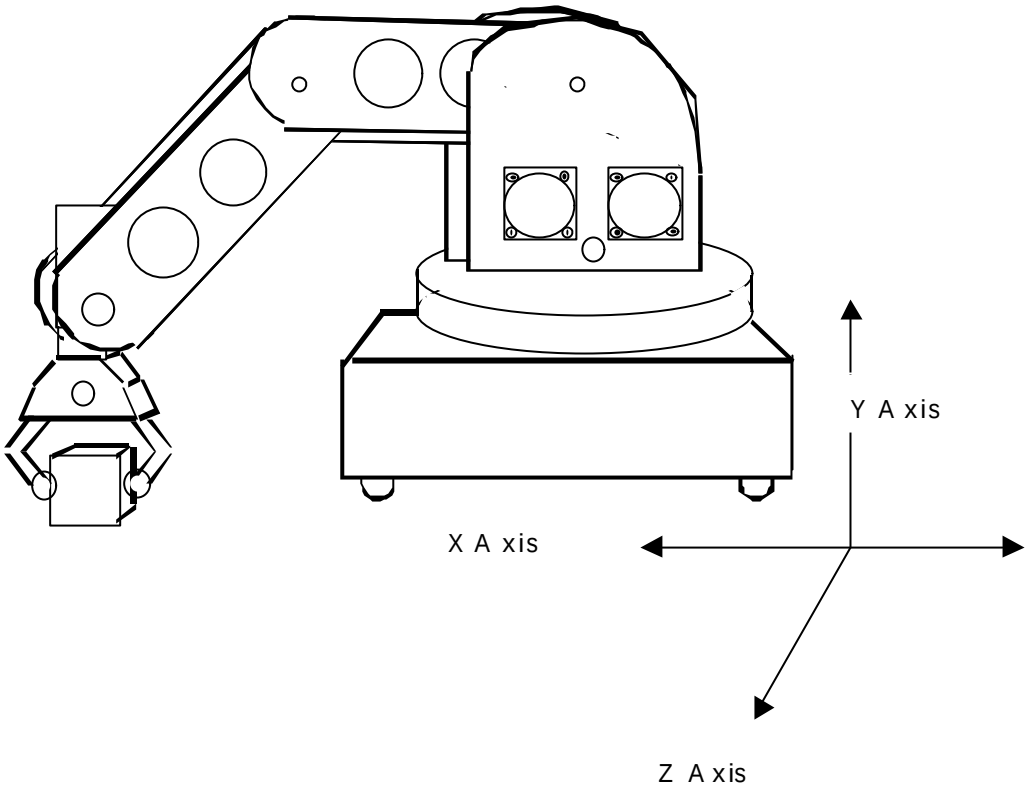
obliges operators to proceed more in a top-down manner compared to the existing tools, which tend to orient the activity from bottom-up.

Secondly, the new interface opens the space of development potential by leading operators to broaden the span of phenomena considered for the analysis of operating situations, to better evaluate possible effects on the process of the observed functioning imbalances, and to better anticipate the consequences of observed phenomena and actions.

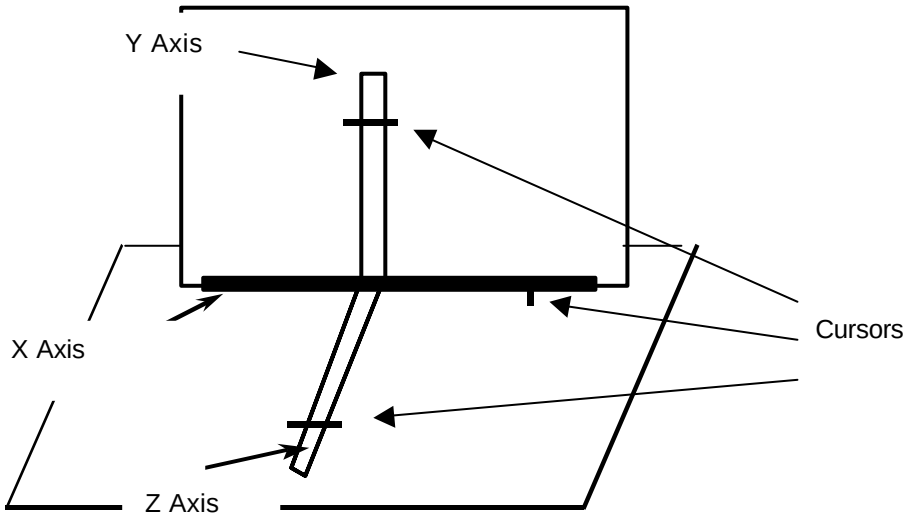
The mediations that occur are of different types. The new interface changes the content of the object to activity mediation. This primarily epistemic mediation moves from a topographic type content to a content in terms of a causal-type pragmatic conceptualization. Yet mediation by the artifact is also a mediation with the community and its inherited knowledge: pragmatic concepts and the network that organizes them. Finally, this knowledge was clarified, then implemented in the new procedure by other subjects. The mediation is thus not only vehiculed by artifacts but also by people: the different actors of the training process. We will come back to this question during the third study.

2. The development process of the instrument

We have seen, with the example of operating blast furnaces, the role played both by constraints and by the opening of a space of mediated activity development in learning mediated by an artifact. We will now examine in greater detail the development process of the instrument and the mediated activity. We will use a second example: a handling arm (robot) which moves objects (figure 3)



Figures 3 the robot



Figures 4 the command device

The commands box has three moveable cursors (figure 4). Each cursor corresponds to one of the axes of the three-dimensional XYZ indicators of the robot's workspace: a vertical axe (Z) and two horizontal axes (X and Y). Thus the position of the three cursors on their respective axes corresponds to the precise position of the extremity

of the claw in the XYZ indicator of the workspace. We put forward the hypothesis that the use of this device would lead the users (pupils from 13 to 15 years of age) to develop a three-dimensional conceptualization of space.

The experiment showed that to reach this objective, pupils required a long process of instrumental genesis.

This genesis developed over several stages. We will use the three main stages to illustrate our position.

- Stage one: the subjects manipulate the cursors and seek to identify the effects of their actions mediated by the cursors through the movements of the different parts of the robot. For example, they will conclude that the axe X cursor allows them to make the robot rotate. The subjects manipulate the cursors one at a time and look to progressively ascertain the effects of their actions on the robot and the movements of the claw in the workspace. The action control scheme is retroactive and the control is not mediated by the artifact. Mediating the action by the artifact occurs on two levels: the cursors allow users to act on the movements of the robot's articulations and segments which, in turn, determine the movements of the claw in the workspace. It is a pragmatic mediation.

- Stage two: the subjects seek to directly control the claw's displacements in the workspace by displacing the cursors in the command space. They will lose interest in the movements of the different parts of the robot. The pragmatic mediation of the action by the artifact now only has one level: the command device. However the cursors are still considered individually. The visual control of the effects of the mediated action focuses on the displacements of the claw in the workspace. The control is not mediated and the control scheme remains retroactive. The content of the mediated action changes. The claw's displacements are initially only seen as being directionally in line with the subject's movements on the cursors. Next the claw's movements are seen as being proportionally in line with the subject's actions on the cursors. Thus we see the progressive conceptualization of a homomorphism between the geometry of the subject's actions and the geometry of the claw's displacements.

- Finally, for the last stage, the action remains mediated by the command device but its content changes again: it is no longer the claw's displacements that are checked but its position in the workspace. The three cursors are now seen globally and their coordinated and simultaneous positions in the command space are recognized as determining the claw's position in the workspace. Following instrumental genesis, the claw's positions are defined by referring to a system of three-dimensional axes which characterize both the workspace and the command space. A pro-active control scheme is developed: subjects anticipate the claw's position and visually control the position of the cursors in the command space, which also becomes a representative space. The retroactive control scheme allows fine-tuning of the claw's positions in the workspace. The mediation of the action becomes both epistemic and pragmatic.

Conceptualizations of space change radically throughout the instrumental genesis. To begin with, users conceive space in line with the space of their own motivity. At

the end of the genesis however, most subjects will have attained a conceptualization of three-dimensional space equipped with an indicator. Therefore, as with the situation of operating blast furnaces, the action mediated by the artifact strongly influences conceptualization. Yet the impact of the instrument on conceptualization is not immediately made manifest. The users' appropriation[7] of the artifact results from a progressive process of instrumental genesis.

For the user, the instrument changes throughout the process of genesis, as shown by the summary table 1.

The first point we wish to highlight is that the subject does not confuse the identity of the instrument with the identity of the artifact. Subjects do not apprehend the robot as a whole. At the beginning of the instrumental genesis process, the subjects accord a great deal of importance to the different parts of the arms (articulations, segments) because they think that the commands allow them to act on these parts. From the second stage, the arm is no longer taken into consideration. The only part of the artifact mobilized as a tool is the command device, which allows them to act on the displacements, then on the positions of the claw. Thus it is not the entirety of the artifact that constitutes the subject's instrument, but only a fraction of this which he/she selects and whose properties he/she evaluates for their pertinence to the action (interdependent cursors, representative properties of the command space). There is no confusion between the instrument and the artifact: the subject's real instrument results from a gradual elaboration[8].

Stages	**Type of control**	**Control scheme**	**Artifact mediator**	**Type of mediation**	**Content of mediated action**
Stage 1	Direct control	Retroactive control scheme	- command device with independent cursors - Robot segments	Pragmatic mediation on two levels	Claw movements
Stage 2	Direct control	Retroactive control scheme	- command device with independent cursors	Pragmatic mediation at one level	Claw displacements
Stage 3	Mediated and direct control	Proactive and retroactive control scheme	Command device: - representative space - interdependent cursors	Pragmatic and epistemic mediation	Claw positions

Table 1
Main changes during instrumental genesis

The second point is that the fraction of the artifact elaborated as a means of action does not constitute the entirety of the instrument. We have seen that the artifact appropriation process is accompanied by the subject's conceptualization of the properties of the reality on which it allows him/her to act (the

[7] Our use of the term 'appropriation' corresponds to what Wertch 1998 calls 'mastery'.

[8] In many situations, this elaboration is not restricted to the selection of a part of the artifact. The artifact is often diverted from its initial functions and used in ways not planned for by its designers. It may even be transformed. All of these activities are part of instrumental genesis.

movements space becomes a displacement space, then a positions space). The appropriation of the artifact is also accompanied by the mobilization or elaboration of the subject's activity organizing schemes. In our example the control schemes are initially only retroactive. They then become proactive.

This double construction which takes place in the instrumental genesis allows a change in the content of the mediated action and in the nature of mediations (pragmatic then pragmatic and epistemic). The subject's instrument can thus be seen as a mixed entity made up of both artifact-type components and schematic components that we call utilization schemes. This mixed entity is born of both the subject and the object. It is this entity which constitutes the instrument which has a functional value for the subject.

Utilization schemes have a "private" dimension in that they are the schemes of an individual subject. Yet they also have an essential "social" dimension. This is because their emergence results from a collective process that both the users and designers of artifacts contribute to. It is also because they undergo a process of social transmission (from written instructions through to training). Thus utilization schemes (US) should be considered not only in terms of their private dimensions but also as social utilization schemes (SUS). This dimension is particularly important in education and learning.

The subject's instrument is not a "given", but is elaborated by the subject during the instrumental genesis process. This process concerns both the artifact and social utilization schemes. As a result, it has two dimensions:

- **instrumentalization** which corresponds to the emergence and evolution of the instrument's artifact components: selection of functionally pertinent parts of the artifact, choice, grouping together, elaborations of functions, transformations of the artifact's function or structure, etc.
- **instrumentation** which corresponds to the appropriation of social utilization schemes, the emergence and development of private schemes.

Using the instrument means mobilizing this mixed entity, while appropriating it means constructing it through a process of instrumental genesis. This allows us to better understand the impact of instruments' use on users' cognitive activity and the fact that they cannot be considered neutral in any way.

3. Mediations in training on a simulator: training for the collective operation of a nuclear power plant

In the two situations we have used as examples, we have deliberately focussed our attention on the subject's activity in relation to the object. The artifact, then the instrument, acted as mediators within this interaction with the object. But it is clear that the other as other subject, or actor, was also constantly present, albeit in the background of our subject's activity (the other being the designer of the artifact, the designer of the situations and tasks the subjects were confronted with, etc.).

It is this collective and social dimension of learning mediated by artifacts that we will now explore based on a third study on learning in a simulated situation in a nuclear power plant. This type of situation differs from the preceding examples in several ways: in the nature of the artifacts (as well as the simulator, there are traces of the activity and an activity analysis method) and in terms of relations which this time are the subjects' direct or mediated relations with their own activities.

Our study looks at initial and ongoing training programs in the operation of an electricity-producing nuclear power plant (Samurçay, 2000). The training takes place

on a simulator. The operators have to develop competences in the four integrated dimensions of the activity:

- planning: the diagnosis/prognosis of the installation's operation and taking decisions (what needs to be done?)
- the temporal dimension: when to intervene? This includes not only mastery of the dynamic of the installation, actions, and the reactions of automatic regulations, but also the management of personnel and collective resources.
- Cooperation: the operators must not only regulate their own activity but also coordinate it with the activity of others. The attribution of tasks and roles only partly guides the efficacy of cooperation.
- Work with tools: here we consider the activity's means as a whole including procedures, automatic regulations and the control command systems. The process of their instrumentalization requires major constructive activities.

These different dimensions are implicated both in initial and ongoing training. It is their respective importance that changes. In initial training, the simulated situations concern normal operation of the installation. Thus cooperation concerns a two-member team. In ongoing training, however, simulated situations are of incidents and accidents: cooperation and training implicate teams made up of at least four members, each with different functions.

Training in a simulated situation as a double mediation process and co-activity

In a training program on a simulator, the transformation of trainees' competences will result from both their productive activity engaged directly in the simulated situation and from the constructive activity mediated by the trainer and the simulator. We distinguish three distinct phases in the design and operation of the simulated situation. The mediations are different in each of the phases:

Phase 1, before the session: this phase consists in preparing the sessions finalized by the construction of knowledge necessary to treat the simulated situation. Here, the main actors are the trainers. For the trainers, the simulator is a tool to create simulated situations, based on scenarios, of a model environment, a model of an operational device[9] and a collection of didactic choices (sometimes implicit) in line with the training program's specific objectives and the target competences. Different constraints weigh on their activity: the specifications defined by the institution, constraints linked to the simulator's possibilities and hypotheses on the interactions they will need to manage between trainees' activity and the situation, as well as constraints linked to the trainers' own activity. In other words, for the trainers, simulated situations are plans that they will seek to realize, or holding systems that will orient the management of the situation in real time. Didactic choices are made based on three elements: trainee characteristics (level and field of competences, needs, etc.), specific modalities of acquisition of target competences and tutorial modalities. We are in a classic tri-polar scheme (fig. 5). The activity of designing simulated situations is mediated by simulators.

[9] By operational device we mean the organization of actors in terms of place and position for the treatment of a work situation. The operational device is also the object of training (Rogalski 1995). Thus, all the actors outside the control room (maintenance, automation specialists, security staff, etc.) are simulated by trainers. Choices concerning their intervention in the situation also constitute situation variables for the trainer.

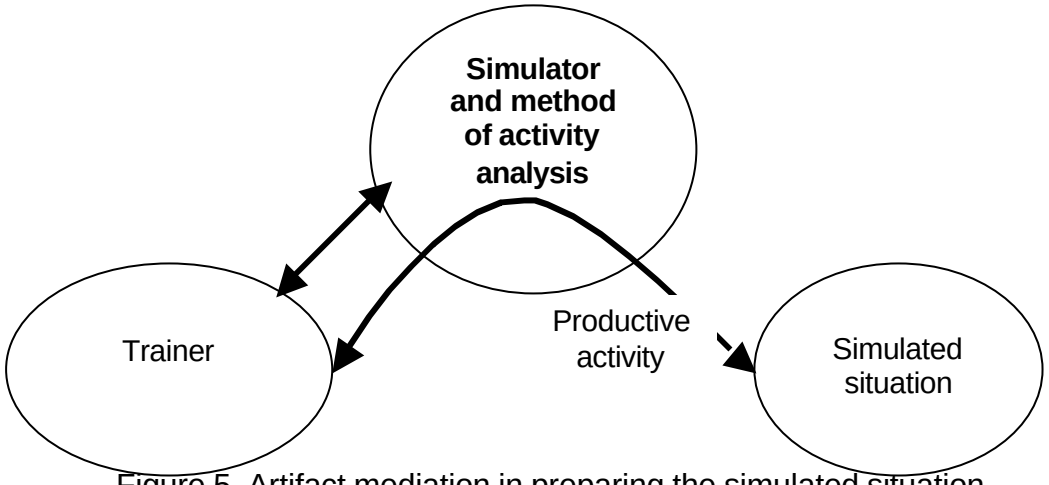


Figure 5. Artifact mediation in preparing the simulated situation

In the study we have undertaken, one of our contributions was giving trainers an extra tool – an analysis method of the operating activity[10]. This allowed, for example, that the choice or construction of situations not depend exclusively on technical criteria (a deregulated sensor or an electrical breakdown). Instead, criteria related to the type of activity necessary in a situation of collective diagnosis or the use of procedures can be applied.

Phase 2, during the session: the trainer manages the training session in real time. The way the simulation is carried out is specific to the situation being simulated. It is a situation of co-activity for the trainee collective and the trainer in which the trainee must construct operational competences.

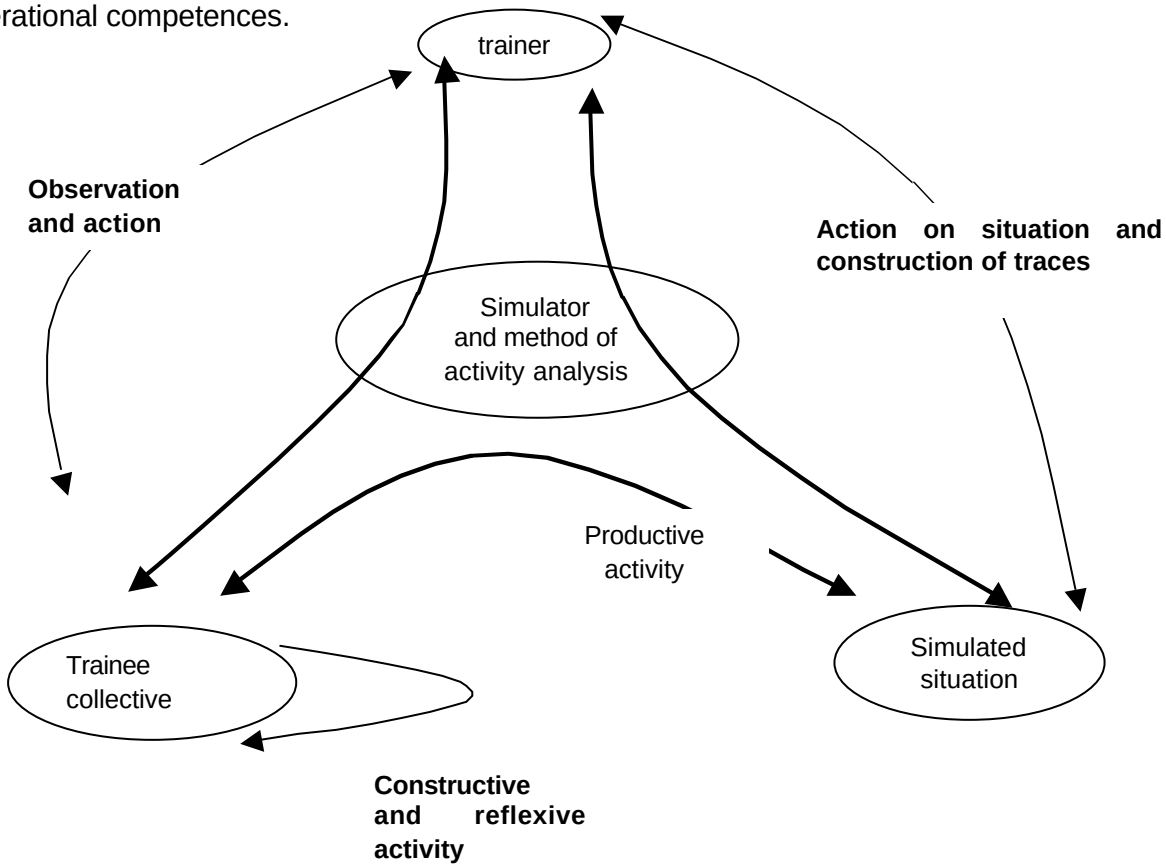


Figure 6 Interactions and mediation during the simulation

[10] The method we have developed is very similar to that constructed by Hukki & Norros (1996).

The trainer has two types of activity: real time management of the situation as it occurs and the construction of indicators and traces of the trainees' activity for the debriefing phase. In both cases, the trainer's activity is either direct or mediated by the simulator[11]. The trainer manages the situation in a more or less adaptive manner depending on the course of events, how he/she evaluates the trainees' activity, the range of options available for modifying the parameters of the situation as well as the specific constraints on his/her work in general (whether it is at the beginning or end of the course, whether it is evaluative or constructive training, amount of time available to design and prepare, etc.). The same simulated situation can generate different realizations depending on the actors, the context, etc. The trainer follows and acts on the trainee collective's productive activity either directly or by modifying the simulator's parameters. He/she also constructs traces of this activity by making recordings on the simulator or directly through observation, with the aim of intervening on the constructive activity either in real or differed time.

The trainees have two activities. The first is productive (the collective treatment of the simulated problem) and is focussed on the object. The second is constructive (the elaboration of new representations and schemes, construction of instruments, etc.). The simulator also mediates the trainee collective's activity but has a different status to the trainer. The simulator is the support for productive activity and its feedback supports reflexive activity.

Our study shows that the trainer's activity needs to be accompanied by a model of the trainee collective's activity, i.e. by significant indicators of this activity. Analysis of the trainee collective's activity indicates that the trainees learn little through the repetition of the action. For example, repeating a simulated sequence does little to reduce errors in reasoning. However, as we will see, they learn better through organized reflexive activity.

Phase 3, debriefing after the session: we observed several spontaneous debriefing practices. We can distinguish two types: i) based on the deficiencies he/she identified, the trainer puts forward technical knowledge: there is little place for analysis in terms of activity; ii) talking about the activity in terms of experience where each of the members of the trainee collective goes back over his/her version. Ideally, the trainer also gives his/her version of events, sometimes including a reminder of the forbidden activity. This going back over the activity exclusively in terms of experience does not favor the conceptualization of the situation. The activity and the situation are analyzed in a circumstantial manner. Their more generic characteristics are not identified in terms of invariant properties and relations[12].

The tools we developed to overcome these difficulties consisted in providing trainee collectives with an activity analysis method so they can work on their activity as an object. This method allows a subsequent analysis of the activity which takes into account both the activity in progress (time, space, specificity) and the traces of changes on the simulated "real" (change trends of the main parameters).

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[11] Obviously the trainer's activity involves other inter-personal mediations that are not explored here.

[12] These two levels of reflexive activity were identified by Piaget (1974a, b) in terms of empirical and reflective abstraction. This distinction is similar to the two levels of experience – habitual and reflexive - identified by Dewey (quoted by Miettinen, 2000).

The trainer and trainees' activities are different in nature. The trainer uses observations and the traces constructed during the preceding phase to create the content and conditions for reflexive activity in the trainees under his/her guidance. He/she mediates this reflexive activity by the way he/she organizes the different stages, reformulates the analyses generated by the collective and institutionalizes certain practices. The trainees on the other hand are in an activity in which they have to analyze their past activities. In other words, the object of the trainee collective's reflexive activity is constructing a conceptualization of situations of action and constructing tools to observe themselves at work by appropriating the activity analysis method The analysis allows them to elaborate and test explicative hypotheses on the activity, identify the invariants of the situation as well as the operational invariants specific to individual and collective levels. Trainer and trainee activities are mediated both by the traces and by the activity analysis method Figure 6 presents the different mediations at play: mediation by the activity's traces, mediation by the activity's analysis method, as well as mediation by the trainer. These different mediations can form chains of mediations of varying lengths. They make up a system of interdependent mediations.

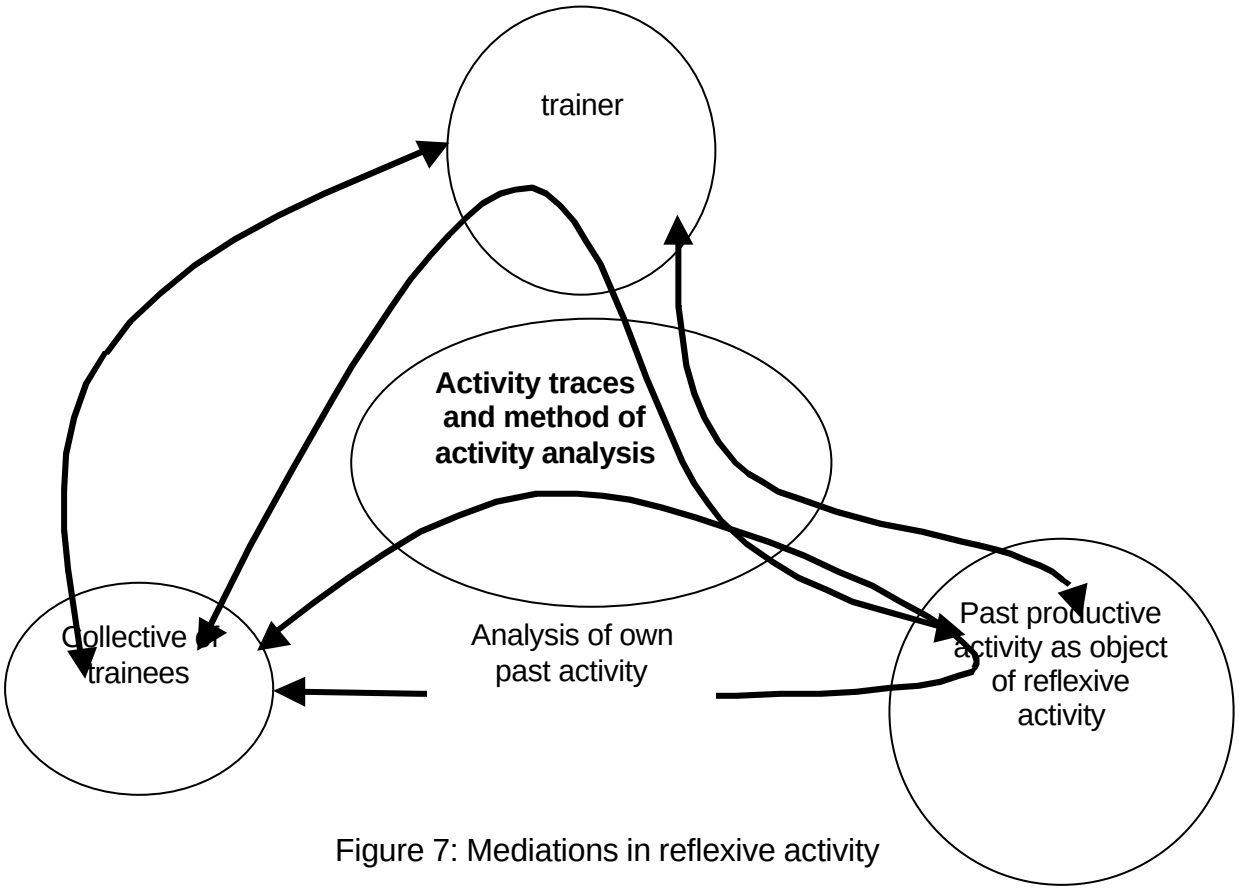

Figure 7: Mediations in reflexive activity

We will now summarize the main elements for the three phases. Table 2 indicates that trainers share with trainees the three artifacts mobilized in mediated activities: the simulator, the activity analysis method and traces of the activity. If we look only at activities mediated by instruments, they appear much more diversified than the artifacts. Furthermore, in most cases, they have specific objects for each of the subjects. It is only in phase 3 that we see shared objects of activity (the collective's

activity analysis in phase two) or partly shared (the collective's reflexive activity). In other words, in this situation of collective learning, if the artifacts are shared (and this sharing may only be partial), the instruments are multi-functional and support mediated activities specific to different subjects and the different phases.

Phases	**Subjects**	**Mediators**	**Objects of the activity**
Phase 1	Trainer	- Simulator -Activity analysis method	- Design of simulated situation - Anticipation of collective's activity in phase 2
Phase 2	Trainer Trainee collective	- Activity analysis method - Simulator	- Trainee collective's activity - Management of situation in real time - Construction of traces - Treatment of problem situation - Construction of experience
Phase 3	Trainee collective Trainer	-Trainer -Traces -Activity analysis method	- Conceptualization - Analysis of collective's activity in phase 2 - Analysis and guidance of trainees' reflexive activity

Table 2 the main elements for the three phases

We also observe the emergence of the trainer's particular status. He/she becomes a mediating subject during phase 3. This is a fundamental characteristic of mediated learning situations: mediations are only ever occasionally supported by artifacts alone. People are always also in the position of mediators. Obviously, this concerns trainers, but also in a much broader sense the subject's peers: other pupils in a class, members of the trainee collective, other actors of a community of practice, etc.

Discussion and conclusion

The studies we referred to all describe situations where the artifact serves as a mediator in a learning situation. Thus, we will not cover situations where learning is a byproduct of the subject's productive activity, nor those centered on learning usage within a usage context (Bodker & Graves Peterson, 2000). We will conclude this chapter with a four-point discussion: the system of mediations, the dialectic of productive and constructive activities, the development of activity mediated by instruments as well as links between approaches thrown up by genetic epistemology and those grounded in activity theories.

A system of mediations

In the situations we explored, a range of mediations by artifacts, or rather, by instruments, contributes to learning. Of course these mediations are epistemic and pragmatic and take place within object-oriented productive activity. They are also reflexive mediations which allow operators to come back to their productive activity: the organized traces of this activity as well as the activity's analysis or self-analysis instruments. Finally, they are mediations with others whether they be other people, actors of a collective I contribute to or people organized into collectivities I may or may not belong to.

However, these mediations by instruments are closely linked to mediations by others with which they form a system of interdependent mediations throughout learning.

Others are present as mediators in several ways: as trainers, organizers of situations and modalities of productive and partly constructive activities; as another actor in training, as a member of a community of practice with which I may or may not identify…

Dialectic of productive and constructive activities

The system of interdependent mediations is part of a complex dialectic of productive and constructive activities. In the situations we have looked at, the subjects' productive activities only exist, as far as the situations' designers are concerned, as supports for constructive activity. They are constructed in terms of learning. Yet a careful look at the productive activity in progress indicates that while the subjects generally appropriate this motive (in the Léontiev sense), their activity also responds to other motives. Thus, in simulated situations, subjects are not only driven by learning objectives. They also test their individual and collective competences and capacities - in the eyes of the institution but also for their colleagues and ultimately for themselves. For operators in ongoing training, being capable of managing a situation becomes a challenge. This means that the productive activity finds its own motivations. This is why in many fields (aviation, nuclear, etc.) subjects react badly to not being able to manage a simulated situation. It is not unusual for failures to strongly influence team cohesion and provoke reorganizations[13]. Thus, there is a complex dialectic both between productive activities and constructive activities in the learning process and between individual and collective motives of designers and trainees.

From mediation by artifacts to the development of activity mediated by instruments

As seen in the robot example, the artifact is not confused with the instrument. The latter has a functional value for the subject. The instrument results from a development process generated by the subject. It concerns, of course, the constitution or transformation of the subject's own utilization schemes. This instrumentation activity is grounded in the schemes the subject has already constituted (part of the "users' background", Bodker & Graves Patersen 2000) and in social schemes available in the community of practices. The development process also concerns the artifact itself. The parts of the robots that have a functional value for the subject change during instrumental genesis. Their functional value also changes. The instrumentalized artifact (i.e. that which has acquired a functional value

[13] Naturally this is less so in initial professional training where the training stakes dominate.

for the subject) cannot replace the "objective" artifact, which can itself undergo transformations in structure or function. Through the process of instrumental genesis, the instrument becomes a mixed unit born of both the person and the artifact. Its nature as a mixed totality has been stressed in both the field of sociocultural research (Wertch 1998) and in the field of activity theories through the concept of the functional organ (Léontiev 1981, Kaptelinin 1996, Kuuti & Kaptelinin 1999). This leads us to reconsider the question of barriers between the subject and the artifact. They break down in favor of the constitution and use of the instrument.

It is not only the instrument in its artifact and scheme components that develops. In a broader sense, there is development of the activity mediated by the instrument. We have seen that the object itself develops. Thus, the conceptualization of space and the transformations that the robot allows the subject to perform change throughout the process of instrumental genesis. The same is true of the conceptualization of the internal process in the blast furnace. These developments of the object correspond to a development of the instrument-mediated activity as a whole. Thus the blast furnace operators supervise a wider range of variables and cross-reference information more systematically while at the same time they increase the span of their anticipations.

Genetic epistemology and activity theories

The theoretical elaborations we have presented in this chapter derive from two movements – genetic epistemology and activity theories – which are sometimes considered irreconcilable given their opposing epistemological positions on the role of culture. Vygotski (1934) strongly questioned Piaget's research. Piaget learnt of this much later and responded well after Vygotski's death in accepting some of the criticisms leveled at him. Yet it would be wrong to leave it there and Davydov (1999) opportunely reminds us that the connection between activity theories and other theories, notably the Piagetian approach, is one of the tasks facing psychology today. He highlights the fact that both approaches share an interest in action. Another important point, in our opinion, is that both of them adopt a constructivist and developmental perspective.

It is precisely on these grounds that we were able to bring together theoretical, Piagetian and post-Piagetian perspectives on the role of action and activity in the genesis of knowledge and conceptualization, with the central role given to the mediation by cultural artifacts in activity theories. The Piagetian concept of the scheme as a structural invariant of the action allows us to identify the replicability of the action and, to a certain extent, the activity in its range of contexts and situations.

For Piaget (1936a), schemes constitute a means which assist subjects in assimilating the situations and objects they are confronted with. They are structures capable of incorporating a reality external to the subject's organization cycle[14]: everything that responds to a need (and we would add, a motive) is liable to assimilation.

The scheme, a means of assimilation, is itself the product of an assimilation activity: psychological assimilation in its simplest form is no more than the self-preservation tendency of all behavior. It is reproductive assimilation that constitutes schemes.

[14]. The evolution in the conceptualization of space during the activity mediated by the robot is a good example of this.

These schemes exist as soon as behavior generates an effort of repetition and thus becomes schematic. An action scheme is the structured whole of the generalizable characteristics of action which allow the repetition of the same action or the application of new contents (Piaget & Beth 1961).

Furthermore, the scheme is an active organization of experience which integrates the past. It is a structure with a history and progressively changes as it adapts to more varied situations and givens. A scheme applies itself to the range of situations and contexts that it assimilates and it comes into general use depending on the contents it is applied to. A scheme's history is that of its ongoing generalization. It is also that of its differentiation. Schemes adapt to situations that they have difficulties assimilating. The evolution of schemes, and the subject, thus precedes two complementary processes: the process of assimilating new situations and the process of adapting to situations that resist assimilation.

The properties of schemes are particularly interesting as a way of identifying the characteristics of the subject's activity and actions in learning and in using artifacts: capacity of assimilating situations which allow generalization; capacity of accommodating sources of differentiation; structure that develops in incorporating experience by integrating the past.

Yet the world that genetic epistemology is interested in is a world of nature, not of culture. We have moved beyond this limitation by giving utilization schemes the characteristics of social schemes: they are elaborated and shared in communities of practice and may give rise to an appropriation by subjects, or even result from explicit training processes.

Schemes are not the only invariants that contribute to the structuring of the action in situation. Representative and conceptual invariants also play a major role. For Piaget and his successors (see Vergnaud, 1990 in particular), the subject's activity also plays a major role in developing conceptual invariants because it is these transformations generated by the subject's actions directed toward the object that allow the construction of the object's invariant properties[15]. The relevance of this approach in understanding relations between conceptualization and action is clear. Conceptualizations born of actions are closely linked to action schemes but are not the same. Pragmatic concepts (Samurçay & Pastré, 1995) correspond to schematic representations of elements of the situation pertinent for action. They are entities which link the variables of the situation both to each other (depending on the nature of the situation, they may be causal, temporal, spatial, etc.) and to those of the action for classes of situations and fields of professional activity. They allow us to read specific work situations as belonging to classes of situations whose properties are already partly identified and constructed. Their elaboration is born of a historic and social construction within communities and work collectives, fueled by but not reducible to technical concepts and artifacts of the field. Their analysis requires the identification of objects, actions and invariants implicated in efficient practices (Samurçay, 1995a). They are constructed in and for the activity and are generally transmitted by trade guilds in the workplace. They can also be the object of specific training programs, possibly mediated by instruments. The notion of the pragmatic concept is situated, like that of the social utilization scheme, both as a descendant of

genetic epistemology in that it upholds the role of action in conceptualization, and of activity theories in that it upholds its social, cultural and motivational dimensions. The notion of pragmatic concepts should be seen as neighboring that of the operative image developed by Ochanine (1978). Vygotsky's notions of everyday and scientific concepts only partially cover the distinction we introduce between pragmatic concepts and scientific and technical concepts. They clearly feed each other, yet we recognize an epistemology specific to pragmatic concepts whose validity should not be evaluated in terms of truth but in terms of pertinence for the action and the activity.

The three levels of artifacts

The development of instrument-mediated learning activity is based on different types of artifacts in the Wartofskian sense (1983), later developed by Engeström (1990) and Cole (1995).

The level of primary artifacts which corresponds to the concept of the tool as it is commonly used, includes a great number of different artifacts, computers, robots, interfaces and simulators, as well as traces of the activity in the situations we presented.

The social utilization schemes and pragmatic concepts are schematic invariants and are representative of the action and the activity. They can be considered as secondary artifacts, which consist of representations both of primary artifacts and of modes of action using primary artifacts.

Finally, the level of tertiary artifacts – in the sense Cole intended (1995): artifacts for use in designing activities that will promote social and cognitive development – is represented, for trained subjects in particular, by simulated situations as well as by reflexive methods of self-analysis of their own or the collective activity.

Each of these artifact levels contributes to the development of the learning activity mediated by instruments. This development, conducted by subjects and collectives, is a necessary prerequisite to learning itself. Without this development of instruments and mediated activity, learning would not occur.

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