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COGNITION AND ARTIFACTS: A CONTRIBUTION TO THE STUDY OF THOUGHT IN RELATION TO INSTRUMENTED ACTIVITY

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Introduction

Epistemology, notably genetic epistemology, has shown that only a controlled transformation of reality enables the intellect to elaborate its invariant and variational properties.

In the real world, persons perform transformations in a variety of contexts and in view of different goals. Consequently, the resulting generation of knowledge occurs in different situations and through different processes.

For example, the construction of reality and of its properties may, in itself, constitute the finality of systematic investigative and experimental approaches. Scientific research and science education provide institutionalized and paradigmatic instances of this scholarly relationship with the environment. Guided by hypotheses or simple curiosity, transformations are designed and performed in order to infer regularities and "laws" from the responses of reality to these stimulations. This constitutes what could be termed an "epistemic" process of knowledge construction, aimed at the elaboration of descriptors, categories, relationships, conceptual objects, models, theories, etc., and characterized by a tendency towards generalization and decontextualization.

On the other hand, knowledge may also be elaborated in situations where action by the subject on the world is not directed by an epistemic intention but finalized by a practical and functional project. Here, transformations aim at obtaining a desired conformation of reality (particularly in order to meet demands of the bio-economic sphere). In reference to Cellérier (1979), this second process may be characterized as "pragmatic": it is concerned with the detection and constitution of problems posed in the course of practical situated interaction with the environment, as well as with the elaboration and implementation of solutions (procedures, methodologies, material and semiotic artifacts, etc.).

The "epistemic" approach has been well covered by research in both the fields of philosophy and of the history of science, for which there is a long tradition of work. Areas such as physics or mathematics, which come under this approach, have thus been able to benefit from available epistemological frameworks through which they can consider and elaborate their objects of study. In addition, psychology has furthered general understanding of individual cognitive processing in these areas, and workers can rely on coherent psychological models, notably those derived from genetic epistemology (Matthews, 1992).

Such is not the case, however, with the "pragmatic" approach. Evidence shows that this domain suffers from insufficient scholarship and has yet to design its own epistemological and cognitive models.

This theoretical and conceptual deficit concerning the nature of technical action and the conditions under which it engages cognition particularly affects the field of education. In France as in other countries, it accounts for some of the difficulties raised by the introduction of technology education within compulsory schooling as well as the delays currently encountered in developing didactics specific to this curriculum.

In effect, due to the lack of a conceptual framework specific to the field, teachers and didacticians tend to resort, in pedagogical practice, to epistemological and psychological models associated with the "epistemic" approach. Similarly, models of learning and development proposed in educational literature to technology teachers are often undifferentiated from those designed for the didactics of science (cf. for example, INRP, 1975, 1980). As Frey (1991) has pointed out, such a situation breeds "misconceptions about the nature of science and technology and about the relationship between them (which) can be misleading at best and fatal at worst for technology education". It probably also occults many of the potentialities for cognitive development that proponents of technology education hypothesize as inherent to this subject.

Obviously, there is a need for conceptualization consistent with the specific nature of the domain. The aim of this paper is to contribute to such theoretical construction by focusing on one very specific aspect of pragmatic activity: the fact that it most often involves interaction with artifacts which intervene as mediators between the subject and the object of his action.

In the first section, instrumentation of activity through artifacts is discussed in the light of past and present conceptions of human cognition and development. In the second section, new concepts and a model are advanced through which to analyze instrumented activity. In the third section, examples of microgenetic evolution in the course of chidren's interaction with artifacts are analyzed. The conclusion attempts to generalize the problematic and to sketch out areas for future research.

Artifacts and cognition

Towards a psychological approach to an anthropological issue

In a way, the hypotheses underlying this approach are not new. They refer to the obvious anthropological fact 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. Since these artificial systems extend and amplify man's natural means of action on the environment, it has been assumed that they could, at least partially, determine his cognitive relations with the natural environment and with his congeners. For example, they might structure his categories of thought and knowledge or, by developing his ability to act on the environment, they might in return extend his cognitive capacities.

To date, these essentially psychological questions have been more documented by work in prehistory or anthropology than by psychology, although in some areas, interest in how artifacts relate to cognition has been growing (for example: Scribner (1986), Lave (1988), Norman (1988, 1991), Bruner (1991), or Inhelder & Céllerier (1992). As pointed out by Norman (1991), most of our scientific knowledge of human cognition is based on the study of psychic functions in the "single, unaided individual, studied almost entirely within the university laboratory." The work of authors - Norman cites the Vygotskian school, but we could also add Wallon, Meyerson, etc.. - who, in the past, tried to link cognitive development and cultural environment (ideal and material), has been obscured by psychological paradigms seeking their coherence in biology and/or cybernetics (i.e. reflexology, interactionism, behaviourism and artificial intelligence).

However, these now dominant paradigms encounter increasing difficulty in explaining the interaction of the subject with complex tasks - and objects - like those found in the fields of work or education.

For example, in regard to the cognitive conditions of the acquisition of sensorimotor skills in work, Leplat and Pailhous (1975) question the pertinence of the Piagetian concept of equilibration as a model of the process of appropriation of technical objects. Similarly, Norman (op. cit.), considering the design of user interfaces in computer technologies, notes the difficulties of "integrating artifacts into the existing theory of human cognition." In particular, their approach through psychology cannot solely be limited, as the tendency has been, to the subject-artifact relationship. For example, he shows that, in order to be understood, the "amplifying" effects linked to the implementation of new technologies must be interpreted in terms of the in-depth transformations they introduce in the relationship between the subject and the task and also within the task itself. He concludes that the appropriate unit of analysis of situations involving artifacts is that of the "total system of human, task and artifact".

Anthropological approaches highlight some of the far-reaching consequences of technological change on the nature of tasks and of associated human activity (Leroi-Gourhan, 1964; Havelock, 1963, 1991; Olson, 1976; Goody 1979). Consider, for example, Havelock's study of the impact of the evolution of writing systems on thought modes. He showed that precursory writing codes, such as syllabic writing, did not constitute effective means of communication. The high level of homography in texts implied that users be familiar with their content. In effect, writing was limited to discursive forms still mainly structured for, and by, the constraints of oral tradition, in particular those linked to memorization: rhythm and linearity of the epic poem, fables and aphorisms, etc.

The advent of alphabetical means of writing considerably changed both the nature of admissible content and that of the task itself. In the first place, due to phonography, messages not known nor anticipated by the addressee could be recorded and read without difficulty and, secondly, the reader was freed from the cognitive burden constituted by memorization. Other potentialities combined with these effects: the visualization and spatialization of conservable texts greatly facilitated the adoption of "meta" positions in regard to them (metalinguistic - in regard to form -

and metacognitive - in regard to content). Although most likely unanticipated, a personal and generative use of written discourse became possible, opening the way to new textual forms and content such as philosophical dialogue in prose, for example.

Viewing writing, mathematical computing, graphic representation, etc., as technology raises interesting problems for the psychology of education. It highlights properties they share with material scientific and technical artifacts and which distinguished them considerably from those objects which the psychology of learning has been able to study in the laboratory.

First of all, they intervene as mediators between the subject and the object of his action. This leads to question the adequacy of the traditional, dualistic, subject-object interaction framework for modelling interaction with artifacts in psychology.

Secondly, due to the "generative" or "amplifying" character which these technologies confer on the subject's action, the appropriation of such objects at school age raises new questions concerning the relations between learning, functioning and development. For instance, their appropriation could determine specific "potentializing" effects on development in the manner of what Stanovich (1986) sees as underlying certain "Matthew effects" in learning to read. More radically, the question is raised of the legitimacy of dissociating cognition from its technological context of functioning, development and manifestation. Olson (1976, 1986) argues, for example, that the criteria of abstraction and rationality which are used to characterize and evaluate intellectual development are far from being autonomous and general categories of thought. On the contrary, they are intimately and functionally linked to writing, and to the discursive techniques to which it leads in literate societies, and, consequently, refer to the extent to which these techniques are mastered by the individual.

In order to better account for these particularities, certain authors (Bullinger, 1987; Netchine-Grynberg & Netchine, 1989; Rabardel & Verillon, 1985) resort to the concept of instrumentation. In doing so, they revive ideas from that tradition of psychology, mentioned by Norman, which endeavoured to link learning, cognitive development and the cultural transmission of means of knowledge and action. In this perspective, it may be interesting to examine the concepts of artifact, instrument and instrumentation as they appear in the seminal work of theorists who were intent on not disconnecting psychogenesis from anthropogenesis.

The theoretical status of artifacts in anthropologically orientated psychology.

Inside the paradigms currently dominant in the field of psychology, the opposition between natural objects and artificial or manufactured objects is not relevant. For example, the object submitted to the Piagetian subject is fundamentally non-historical and non-social: its main property is that it is structured by physical laws. Whether these are determined in the object by nature (plasticine) or per artificial construction (sling, scale, etc.) does not constitute a pertinent difference under this model. The introduction of artifacts in classic[1] Piagetian experiments is mainly due to their convenience for highlighting the invariant properties of reality: having been implemented through artifice, they are often more transparent. On the other hand, the artifact is never taken into account

[1] As shall be seen, this critique does not concern current genevan research which has come to focus more on cognitive functioning than on cognitive structure (Inhelder, 1987).

in its instrumental dimension, as a finalized and functional form designed to act on reality, since these properties are reserved exclusively for the assimilatory structures of the subject.

In fact, in Piagetian epistemology, as in that of behaviourist inspiration, it would appear that there is no fundamental break between the adaptive processes observed in the lower levels of the animal kingdom and the cognitive development of the human being. Over and above their radical differences, they link up in the evolutionist idea of a continuity "from the vital to the rational" (Piaget, 1967) or "from the actinia to man" (Pieron, 1959).

On the other hand, for an author such as Leontiev (1976), the break is obvious and fundamental. For him, evidence lies in the fact that although animal adaptation to the environment is achieved through anatomical and functional modification, resulting in the evolution of species, human adaptation to its natural environment shows no such biological mutation. Therefore, the explanation for the transmission of attainments within the human species lies outside genetics. Leontiev invokes a process of external fixation and transmission of attainments through material and intellectual culture. For him, development results from the progressive appropriation of these socially formed attainments rather than from a process of equilibration which would be more characteristic of the biological relation with the environment.

Under such a model, the concept of artifact is pertinent. It refers to all the objects of material culture to which an infant has access during his development, and first of all to the tool. Apart from the physical properties of the tool, what is important is "its operating method, elaborated socially during collective work and attached to it (p. 74)". Therefore its appropriation process implies both transmission of the tool and the reproduction by the user of "the practical or cognitive activity adequate to the human purpose it embodies. (p. 263)"

He denies that these actions and operations can "evolve under the influence of the object itself (p. 313)" within a solipsistic process: they are transmitted to the child and, therefore, imply social mediation.

For Wallon (1941, 1942), as for Leontiev, the manufactured environment is opposed to the natural universe, and the tool, which he frequently designates as the instrument, also plays a determining role in development. He insists on the finalization of the instrument and, like Leontiev, on the importance of the operating method, of which he underlines the constraining character: "an instrument is defined by its recognized uses. It is made for them. It imposes its operating method on those who want to use it... It is a constituted object,... often altered through experience, the benefit of which it transmits to the user. (1941, p.165)"

One of the fundamental consequences which Wallon evokes, concerning the interaction between the child and the artificial environment in which he develops, is that this environment plays a role in determining cognitive structure: "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. (1942, p.77)"

Although Leontiev and Wallon allow for the possibility of cognitive development resulting from interaction with material artifacts, particularly in regard to the necessary appropriation of their operating method and to the fact that they provide frameworks for cognition, their theorization remains more rooted in anthropology than in psychology. With Vygotsky (1930), however, there is an attempt to describe the psychological processes through which such a development could be envisaged.

Vygotsky elaborates his theoretical and methodological apparatus on the basis of a radical criticism of conventional psychology which, according to him, illegitimately "reduces complex superior psychic processes to natural processes and disregards the specific characteristics of the cultural development of behaviour (p.27)", notably its two "fundamental forms": the use of instruments and language.

In his view, "alongside the acts and processes of natural behaviour, it is necessary to distinguish the functions and forms of artificial or instrumental behaviour. (p.40)" The characteristic of this behaviour is that it cannot be described within a limited stimulus-response relation. In effect, for Vygotsky, the instrument, whether it is material or "psychological" (i.e., language, computational and mnemotechnic means, symbols, diagrams, maps, etc.), cannot be reduced to a mere stimulus but constitutes "a new intermediary element situated between the object and the psychic operation directed at it.(p.42)"

The introduction and use of instruments, whether material or psychological, brings about far reaching changes, both structural and functional, in the subject's cognition: "it activates a whole series of new functions linked to the use and control of the instrument selected; it replaces and renders useless a whole series of natural processes, the work of which is developed by the instrument; it transforms the development and the particular aspects (intensity, duration, continuation, etc.) of all processes involved in the composition of the instrumental act.(p.42)"

In this perspective, the development of superior functions results from a process of "tooling" of the natural psychic functions: "the control of psychic instruments and, through this, the natural psychic functions themselves, raises a given function to a higher level each time, expands and increases its activity and recreates its structure and its mechanism. But natural processes do not disappear all the same; they are integrated with the instrumental act and, as regards their structures, become functionally dependent on the instrument used.(p.46)"

In this theoretical framework, education logically appears as a determinant factor in development : "It is the artificial control of the natural developmental process. Education not only exercises an influence on a certain evolutionary process; it also fundamentally restructures all the functions of behaviour. The child's capacity to use his own natural specific functions and to control psychological instruments essentially defines his type of development.(p.45)"

Development is therefore seen as the result of a largely artificial process in which the acquisition of instruments plays a leading role. It is not so much the instrument as such which determines evolution but the functional reorganization and redeployment that its acquisition and use impose on the innate mechanisms at different levels: sensori-motor, perceptive, mnemonic, representational, etc.

Vygotsky's hypotheses provide stimulating theoretical guidelines for the study of the impact of artifacts on cognition. Nevertheless, the general macroscopic level at which they are formulated leaves open the question relating to the underlying microscopic processes involved. In the following sections we will address this question from a joint theoretical and empirical point of view.

The knowledge-action relationship in instrumented activities

From the epistemic to the psychological subject

In a recent review of Genevan research on procedures, Inhelder and Cellérier (1992) greatly stressed the need for new focus on the psychological subject. For the authors, genetic psychology has become the scientific instrument of epistemological constructivism and it is vital to elaborate a psychological constructivism constituting a theory of microgenetic innovation, coherent with epistemological constructivism, but also necessarily complementing it.

Genetic psychology studies structural concepts, such as quantity, that are intra and inter-subjectively invariant, both across multiple psychological achievements and under different sensory or cognitive modalities. What is called for is a functional approach of these different achievements, distinct from the categorical approach of genetic psychology, although sharing with it the idea of a constructive subject actively participating in knowledge, not just of the world, but of himself.

Central to genetic psychology is the normative framework of the epistemic subject as a form for the apprehension of reality and for the organization of activity, with behaviour developing narrowly within the cognitive linkage provided by the structures. By way of contrast, the study of the individual psychological subject endeavours to single out the dynamics of his behaviour, his goals, the choice of means and of controls and heuristics which are specific to him. Therefore, in its approach, functional psychology should attempt to preserve the subject as an entity, by taking into account all the aspects which may contribute to the elucidation of cognitive functioning.

This leads to questions such as: how does a child give meaning to a task? How does the subject choose and specify his means of knowledge and action? How does he control the pertinence of his approaches? Are there different representations which are diversely suited to situations?

Approaching the psychological subject in the knowledge-building process implies taking account of his intentions and values. The object of functional psychology being finalized activity, attention must be paid to the teleonomic and axiological dimensions of cognitive activity, i.e. to the finalities and evaluations produced by the subject himself.

The multiple dimensions of the situated action

But, as underlined by Bruner (1991), beyond behaviour, psychology must also take an interest in action, its counterpart based on intentionality, or, to be more specific, in action, in terms of activity situated both in a cultural perspective and within the reciprocal interaction of the intentions of actors involved in the complexity of the "real world".

Habermas (1968 & 1981), extending the reflection of Weber and other theorists of social critique, characterizes the constituent dimensions of situated action[2], i.e. action performed in a complex environment. He distinguishes four modes of action, with any singular action resulting from a combination of these different dimensions:

- the "teleological" dimension: the actor pursues a pre-defined goal implying the use of means; his rationality is instrumental and the criterion of his activity is efficiency;
- the "axiological" dimension: behaviour is governed by ethico-legal norms in a social world. The criterion of the activity is exactness in regard to these norms;
- the "dramatic" dimension which aims at giving a certain image of oneself and expressing one's own subjectivity. The criterion of this dimension of activity is authenticity.
- finally, the author distinguishes communicational action involving a process of intersubjective dialogue aimed at establishing consensus. Here, the criterion is the search for the truth.

These modalities are interesting in that they go beyond the cognitive dimension of activity. But their limits reside in their consideration of subjects solely as social actors with no real psychological dimension. Thus, actions with an epistemic purpose, i.e. actions aimed at modifying cognition, are not distinguished.

Focus on the sociological subject has led Habermas to strongly criticize instrumental rationality and utilitarianism which uphold teleological action: utilitarianism leads to negation of the subject as a social subject. Cognitive-instrumental action in society (another term for social teleological action), considers humans as objects, not subjects. Nevertheless, this criticism, however pertinent in sociology, cannot be simply transposed to the psychological level: it would imply denial of the psychological subject as a bearer of pragmatic values corresponding to his own point of view and to his subjective engagement in situated action.

Any approach to instrumented action necessarily allows for teleological activity and, in order to be pertinent, has to be grounded on a specifically psychological conception of this class of activity.

A psychological conception of teleological activity

Cellérier (1979) has suggested ways of articulating theory from genetic psychology, the object of which is "epistemic transformation" (i.e. the construction of knowledge from action), and conceptualizations derived from cognitivism, whose object is the "pragmatic transformation" of knowledge into action. For an action to be adapted, it must satisfy both the external conditions of accomodation to the environment and the organism's internal conditions of assimilation. Consequently, the author proposes a model of adaptive interaction between organism and environment based on three types of knowledge: knowledge of empirical regularities, knowledge of practical or pragmatic regularities and axiological knowledge.

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[2] Habermas himself does not use the term of situated action. We will, however, make use of it since, while remaining faithful to the author's way of thinking, it refers to conceptualizations that are more familiar to psychologists (cf. for example, Suchman, 1987).

More recently[3], Inhelder and Caprona (1992) have been led to distinguish teleonomic, causal and axiological aspects of actions.

* The axiological aspect refers to the attribution of value in problem situations. Evaluation concerns actions and objects in terms of goals. What is thematized under the axiological viewpoint is praxic control related to the pertinence of actions in regard to the situation, both a priori and a posteriori, in a perspective of comparison with the external reality. Praxic control should be distinguished from control relative to the coherence of the knowledge system which plays an essential role in elaborating both operative and empirical invariants.
* The teleonomic aspect is relative to all the end/means relationships and thus refers to the organizing capacity of material or cognitive action. In particular, it concerns temporal planning in terms of goal representation. The teleonomic aspect refers to the organization of precursory approaches and not to the transformation of reality. Teleonomy accounts for psychological intentionality.
* The causal aspect refers first of all to cause-effect relationships, to transformations in the environment as seen from the double viewpoint of the result obtained and the comprehension of the transformation mechanism. It concerns the causality of action and the interpretations which the subject gives of his conduct. Secondly, the causal aspect refers to the causality of phenomena which concern the elements of the situation which are pertinent for action, but of which action is not a causal source (for example, the functioning of a machine).

The teleonomic and causal aspects are two separate points of view of the same situation which are bound to interact: in the same way as the cause precedes and determines the effect produced, the representation of the goal precedes and determines the choice of means.

Thus, for Blanchet (1992), a teleonomic interpretation framework controls the activity of the subject while a causal interpretation framework accounts for the object of that activity. Therefore, the same action may be interpreted subjectively as a means when a subject has to organize his practical activity in terms of an end, and objectively as a cause when he is concerned with its adequation to reality. The causal units comprise all the transformations which the object may undergo from the subject's point of view, while the teleonomic units are defined as correspondences between the successive states of the solution.

Thus, the teleonomic framework of a pragmatic model (in the sense of the subject's representation) consists of the implicative relationships he draws between ends and means. These relationships have been extensively explored in experimental contexts of problem solving, particularly by Genevan researchers. In these experiments, the instruments and the material means used to solve practical problems were provided by the experimenter and consisted of simple artifacts in the sense that they had no functional signification nor any specific and elaborate behaviour.

But what happens when the artifacts and instruments do not have this simplicity which undoubtedly likens them more to balls of plasticine than to present-day technical systems? How are instruments, derived from modern technology, associated by subjects with their actions and, as such, inserted in

[3] For an overall view of the attainments of this line of research, see Inhelder & Cellérier, 1992.

their activity? What influence does this have on activity? How is it modified? Can renewed educative perspectives be based on these transformations?

Instrument and instrumented activity situations (IAS model)

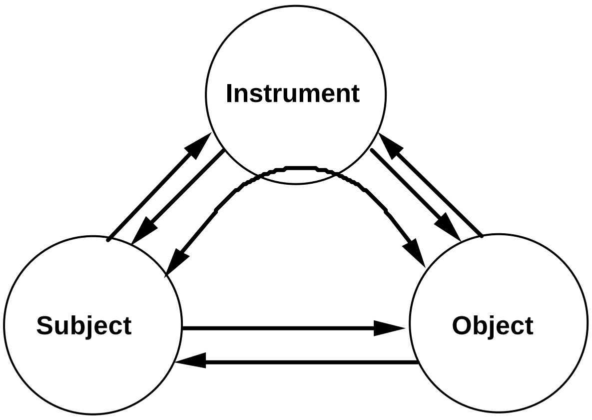
According to Mounoud (1970), an instrument is any object which the subject associates with his action in order to perform a task. It prolongs and/or modifies this action and presents characteristics which simultaneously associate with the operations of the subject and with the objects (and the context of the task) to which it is applied. As such, the instrument constitutes a sort of intermediate universe between subject and object: it is both a content in regard to the subject's actions and a form in regard to the objects to which it is applied.

But it is important to stress the difference between two concepts: the artifact, as a man-made material object, and the instrument, as a psychological construct. The point is that no instrument exists in itself. A machine or a technical system does not immediately constitute a tool for the subject. Even explicitly constructed as a tool, it is not, as such, an instrument for the subject. It becomes so when the subject has been able to appropriate it for himself - has been able to subordinate it as a means to his ends - and, in this respect, has integrated it with his activity. Thus, an instrument results from the establishment, by the subject, of an instrumental relation with an artifact, whether material or not, whether produced by others or by himself.

Despite considerable differences between conceptions of the instrument, most authors explicitly (or more often implicitly) distinguish three poles in situations in which instruments are used:
- the subject (as user, operator, worker, etc.)
- the instrument (as tool, machine, utensil, product, etc.)
-the object towards which the action using the instrument is directed (as matter, environment, object of activity, of work, etc.).

We have proposed the IAS model (figure 1) in order to characterize Instrumented Activity Situations (Rabardel & Verillon, 1985). Unlike the usual bipolar modelling of subject-object interaction, it highlights the intermediary status of instruments and takes into account the multiple relationships which bind together the three elements constitutive of instrumented activity situations. In effect, beyond direct subject-object interactions, other interactions should be noted: interactions between the subject and the instrument, interactions between the instrument and that upon which it enables action to be taken and, finally, the subject-object interactions mediated by the instrument. Consider a (simplified) example of instrumental genesis: a baby learning to use a spoon. Not only does he have to elaborate efficient schemes in order to grasp and manipulate the spoon (subject-instrument interaction), but he has to learn to keep some of the milk in the spoon on the way to his mouth (instrument-object interaction). In the process of this, he acquires some knowledge about the behaviour of liquids as opposed, say, to mashed potatoes (subject-object interaction mediated by the instrument). Eventually this knowledge may lead him to use his spoon differently for milk and mashed potatoes (modifying previous forms of subject-instrument interaction)... etc.

Figure 1
IAS model: the triad characteristic of Instrumented Activity Situations



It is clear that the IAS model does not cover all the characteristics of situations where activity is instrumented: for instance, the fact that a same subject may use several different instruments in the course of complex action, or the fact that contexts of action vary widely and often include a collective dimension. Nevertheless, the use of an instrument is always constitutive of the triad and of the multiple interactions which result from it, forming the common core characteristic of instrumented activity situations as a class.

Concepts for the analysis of instrumented activity

Let us now examine some factors which are liable, in theory, to determine some of the specific features of instrumented activity. They relate, first, to the constraints inherent to artifacts, second, to the resources artifacts afford for action and, finally, to the action schemes linked to the use of artifacts.

Constraints management and required activity. The concept of required activity is correlative to the necessity of taking account of certain constraints specific to instrumented activity situations. For example, each artifact imposes on the subject, a set of constraints which he has to manage in the course of his actions.

These constraints are obviously different according to the type of activity connected with the artifact. For example, in a task involving the assembly of a technical object, the subject must respect constraints (concerning its structure and performance) which are different from those entailed by having to operate the same object.

Thus, like any constituent of the environment, artifacts confront the subject with a set of constraints which he has to identify, understand and manage. As such, they partake in the resistance that the objective world, in the philosophical sense, opposes to human action.

However, an artifact also exerts constraints related to the transformations it enables and to the way they are produced. For example, a lathe, by its very construction, performs only a limited set of transformations. All machines determine classes of allowable transformations, of attainable object states and conditions relative to state change. These constraints are linked to the specific functional features of artifacts as designed to produce transformations, and no longer just to their general material characteristics which are common to all material objects.

Finally, artifacts introduce constraints in as much as they imply, more or less explicitly, a prestructuration of the action of users[4], allowing, naturally, for the possibility that users may deliberately not comply with this prestructuration.

This leads to required activity being considered as a relative concept, a tension between two poles: the constraints resulting from the association of the artifact with action and the psychological subject himself, as a singular and intentional actor.

Expansion of the field of possible actions. The reorganization and recomposition of activity due to the introduction of instruments does not only depend on the different types of constraints just examined. It is also results from the new possibilities of action which are afforded to the user.

The transformations which may be imparted to matter through the use of a lathe, for example, are certainly limited and this limitation itself is a constraint which hampers the subject's action; but, at the same time, they enable the emergence of new types and new forms of action. Novel changes of state in objects are accessible, for example, under conditions of amplitude, speed and cost that are novel in themselves; also new classes of object may be open to transformation. In this sense, the use of an instrument increases the assimilatory capacities of the subject and contributes to expanding the field of his possible actions.

Similarly, artifacts may provide the subject with new conditions for organizing his action: for example, renewing the conditions of reciprocal implication of ends and means, or the chaining of goals and sub-goals, or the control of action, etc. Thus, associating artifacts with one's action, leads to a complete reorganization of activity linked both to the expansion of the field of possible action and to the required management of constraints. It is in this sense that Vygotsky (1930) postulated an overall transformation of the psychic processes during what he called the instrumental act.

Social schemes of artifact utilization. Reorganization of activity leads to the emergence of instrument utilization schemes (US) (Rabardel & Verillon, 1985; Rabardel, 1991a). These could be defined, in the Piagetian tradition, as the structured set of the generalizable characteristics of artifact utilization activities. They enable the subject to develop the activity necessary to perform the functions he expects from the association of the artifact with his action. They thus form a stable basis for his activity. The USs may be considered as representative and operative invariants, corresponding to classes of instrumented activity situations.

Representations can concern the types of transformation which can be performed, the conditions and technical modalities specific to these transformations and to the operation of the artifact, the properties of the user-interface zone, the conditions of intervention in this zone, etc. The operative aspects pertain in particular to goals, elementary or composite operations, procedures, to the organization, planning and management of action during its development, etc.

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[4] The idea of operating method, taken up by Wallon and Léontiev, corresponds to this dimension.

The USs have assimilatory capacities: they enable repeatability of action by ensuring its adaptation to intra-class variations of objects and situations. They have accommodating capacities enabling their application to different classes of objects and situations. Like all familiar schemes, the USs confer signification to the situations in which they are mobilized.

Utilization schemes have a "private" dimension in the sense that they are the schemes of a singular subject. But they also have an essential "social" dimension. This is due to the fact that their emergence results in part from a collective process to which not only the users, but also the designers of the artifacts, contribute. It also results from the fact that they are the object of social transmission processes (through operating instructions or technical training, for instance). More fundamentally, it is due to the fact that USs concern the coordination of action, not only within the subject, but also inter-subjects in collective activities, whether in everyday life, in training or in work. That is why the USs should not only be considered in their private dimension, but also as social utilization schemes (SUS), particularly important in an educational perspective.

A psychological definition of the instrument concept. These considerations lead us to formulate a broader definition of instruments. An instrument is formed from two sub-systems:
- first of all, from an artifact, either material or symbolic, produced by the subject or by others,
- secondly, from one or more associated utilization schemes resulting either from the subject's own construction or from the appropriation of SUSs.

Thus, the instrument, as such, is not a "given" but must be elaborated by the subject. The instrumental relation with the artifact results from the constitution of the SUS-artifact association. The instrument constituted is not ephemeral. It has a permanent character and is conserved as a whole, available for future actions. Naturally, this is a dynamic whole which will evolve according to the situations with which the instrument will be associated.

Microgenetic approaches to instrumented activities

In order to provide initial data concerning both the nature of microgenetic processes, and the conditions under which they occur in problem-solving situations involving instrumental interaction with artifacts, three tasks were submitted to secondary school pupils (girls and boys, aged 11 to 15). They were designed to enable focus on two classes of invariants: spatial and physical. Two of the problems entailed modifying the shape of an object, while the third consisted in displacing an object. In all three situations, solving the problem implied either designing or using a mechanical artifact. As such, the artifacts were considered in their instrumental dimension: as constituent elements of the solutions to the problems posed. It was therefore expected that the microgeneses occuring in the course of the elaboration of the solution would be relatively dependent on the role and the functional signification attached to the instrument by the subjects.

For this reason, in analysing these situations, special attention was paid to the representational aspects of activity:
- the genesis of the problem space for the child, its evolution during the task and the elaboration of the solution (decisive moments, obstacles, back-tracking, etc.);

- the teleonomic and causal dimensions of the activity: type of goals which the subject sets himself, the transformations which he anticipates, etc.;
- the role played by the artifact in problem-solving: if it has to be designed, how does it originate? If it is available, how does it fit into the problem-solving process? In particular, what role does it play in the teleonomic and causal referencing of the problem?
- the reciprocal determinations between representations and processing: their evolution during the task. In particular, during elaboration of the instrument (conception or discovery), how do the functions anticipated relate to the properties (mechanical, geometrical, etc.) of the solutions proposed?
- the type of knowledge used: schemes, knowledge "in action", implicit or explicit invariants (Vergnaud, 1985), etc.

Designing means of producing ruled surfaces

The task (Verillon, 1988, 1991) consisted of asking a group of 10 pupils (5 girls, 5 boys), to individually devise, in imagination, ways of producing plane and revolution (cylindrical and conical) surfaces on pieces of wood. The aim was to identify, through an analysis of the technical means conceived by the pupils, the physical and geometrical solutions they anticipated in order to carry out the surface generation process.

In effect, solving the problem implies taking into account transformations along both a mechanical dimension (elaborating a system for structuring the material) and a spatial dimension (giving this system geometrical properties through which it would be possible to generate the desired shape). The instrumental solution (the artifact and its utilization scheme) should articulate these two dimensions in a satisfactory way, particularly in view of the fact that the material used did not tolerate just any transformation.

The pupils were asked to imagine the means necessary to transform a prismatic piece of wood into a cylinder (or, inversely, from a cylinder into a parallelepiped, or again a parallelepiped into a cone, etc.). In order to minimize language bias, the question actually asked was: "How would you make an object with this shape here from an object like that one there?". The pieces (representing both the initial workpiece and the end-product) shown to the subjects, and which they could handle at will, were in solid wood, approximately 100 x 30 x 30 mm. The interviews were videorecorded and the analyses concerned the verbalizations and the drawings produced by the students during the interview.

The first procedure invariably mentioned by the subjects in order to obtain the desired shape consisted of roughly eliminating the excess material from the wooden workpiece, most often by means of a cutting tool (knife or cutter) or with a saw, then finishing it through abrasion: file, sanding machine, sandpaper, etc.

Some pupils suggested making reference marks on the workpiece in order to guide their action. For example, to produce a cone from a parallelepiped, they would draw a circle on the base and a point in the centre of the opposite base. Thanks to these marks, they would be able to check "when they looked at the object" while removing the material "that it was straight" and that "it did not go off to the side" (the "it" designates a line of sight - therefore projective - which, in Euclidian conceptualization, obviously not used here, would correspond to the generatrix of the cone).

In short, the transformation technique proposed by all the pupils consisted of removing the material in two phases: rough-cutting then finishing through abrasion. These two classes of action were associated with two classes of instrument: knives, cutters and saws (even a power-saw!) for rough cutting; files, abrasives, etc. for finishing.

As regards management of the spatial aspects of the transformation, during the operation, the desired shape seems, so to speak, projected by the subject on to the "uncut" workpiece. This projection, which is mental, though it may take the form of lines drawn on the piece, guides the step by step removal of matter from the workpiece, until, through successive approximations, it "matches" the desired shape as much as possible.

The lack of particular constraints in the procedure to be used enabled the subjects to build and solve the problem solely using instruments and technical and spatial schemes which were familiar to them. Nevertheless, none of the pupils thought that the process that they suggested was the same as that used in industry to produce the desired shapes. "That's done with machines, otherwise it would take time ... and then, anyway, a machine is more accurate!"

We therefore asked them subsequently how they imagined such machines.

An examination of their answers shows a relative diversity of the mechanized solutions suggested, in contrast to the procedure anticipated for manual manufacture, which is practically identical from one subject to another. Leaving aside one subject's initial proposal consisting of a sort of remote manipulating device capable of reproducing the manual procedure through a system of rods with terminal clamps, they may be grouped into three categories according to the technical solution anticipated to produce the desired transformation:

- moulding or deformation

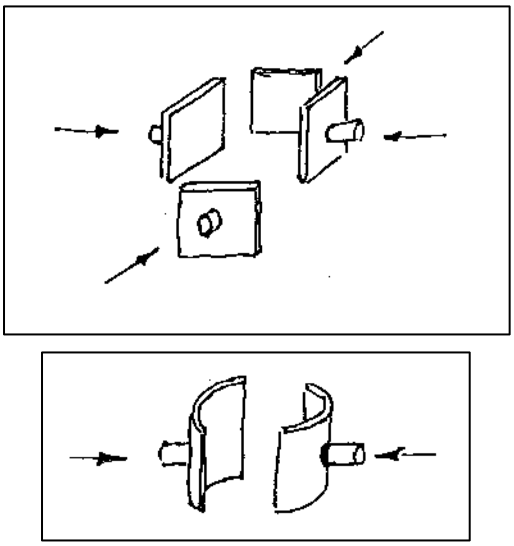
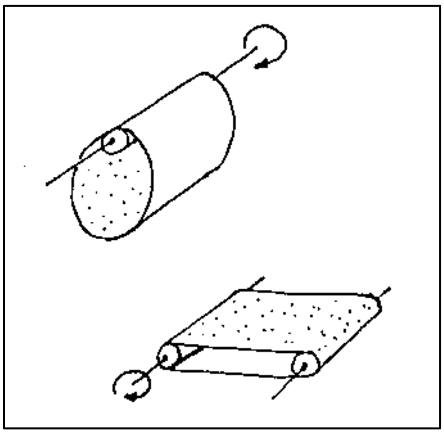


Figure 2 : « Presses »

- removal of matter through abrasion

figure 3



- removal of matter by cutting

figures 4 to 8

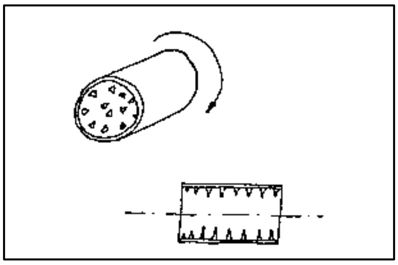


Figure 4 Rotating « tube », lined with « teeth »

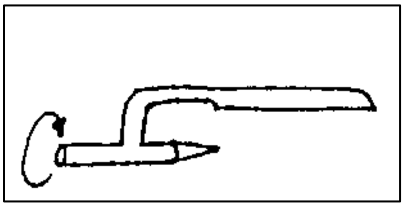


Figure 5 : « Compas with a blade for cylenders »

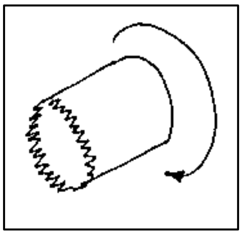


Figure 6 « Cylindrical saw »

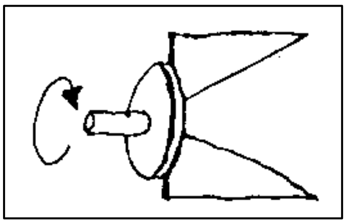


Figure 7 « Slanted blades for making cones »

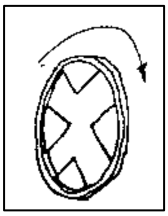


Figure 8 « Rotating circle with four blades for making cylinders »

The constraint of mechanizing their manufacturing process considerably transforms the task for the subjects. The main element at stake and the principal difficulty introduced by this constraint concerns the management of the spatial and temporal aspects of transformation.

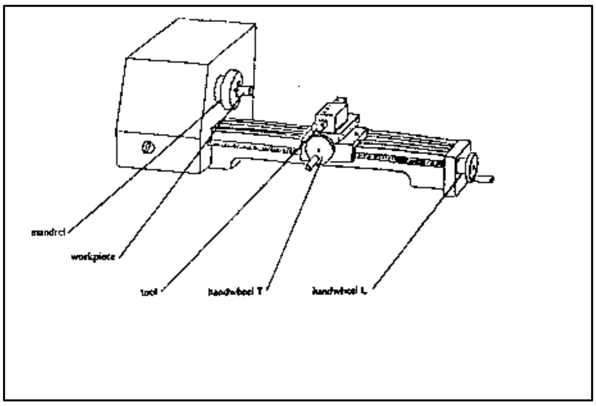
In the non-mechanized procedures, it is the hand holding the tool which controls the amplitude and direction of the transforming action. Similarly, as regards the planning of action, the deviation from the anticipated final state is managed in a retroactive way, step by step, under the control of successive sightings, possibly facilitated by the reference marks drawn on the workpiece. What characterizes the manual procedures is a lack of a general spatial coordination of action (which, for example, could take into account properties of axial symmetry or revolution). The reason why they are spontaneously proposed is mainly just because they do not require an overall geometrization or synchronization of the entire transformation process.

On the other hand, the instruction to mechanize the task is interpreted as leading to attributing to the machine the management of the energetic and spatial aspects of the transformation. Hence the need to equip the device (to exteriorize into it, in a non-homomorphic form of the manual procedure) with the physical and geometrical operators enabling it to produce the desired shape in a definite and proactive way. The remote manipulator solution, which conserves retroactive adjustment and the ability to operate the removal of matter on a step by step basis, appears to be an attempt to get round the difficulty which the conception of such operators constitutes for the pupils. In effect, their elaboration requires addressing multiple and complementary problems concerning the physical aspects of the transformation, the spatial analysis of the desired final form, as well as, correlatively, the geometry of the generating organ, the locus of its successive positions, etc.

In this sense, the devices imagined by the pupils - other than remote manipulators - demonstrate, to a variable extent, a geometric dissociation (or breaking down) of the desired form and, at the same time, a relative abstraction of the means of its production. Thus, moulding devices (fig. 2) enable the shape to be conserved fully (i.e. without having to be broken down) within the geometry of the press simply by reversing it: as one pupil asserts: "to get that shape, the machine has to have the same shape". On the other hand, transformation by machining does not enable the desired shape to be conserved in the tool. Thus, production using abrasive strips in translation, while still partially conserving the shape, implies an analysis in terms of surface. Pushing geometric abstraction a step further, other systems using cutting edges and points, actuated by controlled movements, within different spatial arrangements, reveal their designer's capacity, at least "in action", to dissociate the initial shape into generator points or lines in liaison with revolution axes and directors.

Learning to operate a lathe

Unlike the preceding experiment, this task (Verillon, 1988, 1991) did not involve designing an artifact but discovering, through exploration, how to operate one: in this case an EMCO Compact5 mini-lathe (figure 9).



- Figure 9: a lathe

The experimenter first gave a brief presentation of the machine consisting of designating the workpiece to be machined (in place on the mandrel), the switch which starts its rotation, the tool (presented as operating through removal of matter from the workpiece) and the transversal (T) and longitudinal (L) handwheels which control its movements. Thereafter, each subject (the same as in the previous experiment) was asked to suggest and, where possible, execute a procedure for reproducing a model part - comprising cylindrical and conical surfaces - but without taking dimensions into account. The tool assembled (figure 10) was a turning tool, consequently designed for surface generation by a point: the tip of the tool.
The tool assembled (figure 10) was a turning tool, consequently designed for surface generation by a point: the tip of the tool.

- Figure 10 : The tool

The aim was to try to follow, in its evolution, the subjects' construction of a functional representation of this artifact, notably in the light of the insights gained from the previous experiment. Here again, the analysis concerned the videorecording of the behaviour and verbalizations of the pupils.

Leaving aside certain initial answers guided by the conviction of a sort of hyper-automation of the machine (the tool has only to be brought into contact with the part for the lathe to take charge of the entire transformation process), the initial spontaneous strategies of the pupils appear to be directed by two general conceptions of how the lathe operates.

An initial procedure leads the subject to bring the tool into contact with the part, using handwheel T, thus provoking a light cut. Removal of the material is then extended over a certain length of the part using handwheel L determining, as such, a slight cylindrical stroke.

However, in the course of the interviews, it was noted that, in the pupils' mind, the shape obtained was not necessarily cylindrical and that the same procedure could be used to obtain a conical shape. In effect, it turned out that in this conception, the tool is thought to exercise continuous force directed at the workpiece. Consequently, the action of removal of matter, qualified as "wear" by the subjects, may be spread relatively unevenly over the length of the part according to the rotation speed given to handwheel L.

Since the amount of matter removed at a point of the part is seen as dependent on the time the tool is in contact with this point, different shapes can actually be anticipated. They are attributed either to lack of skill: the pupil has doubts about the cylindricality of the part because he has "slowed down" during the stroke, or to a deliberate strategy: a cone is obtained by gradually "wearing away" more matter towards the end of the part.

Under the second conception, the desired cylindrical shape is planned and produced through a series of cuts - the pupils talk about "cutting" - done with the help of handwheel T and repeated successively along the part by moving the tool one increment each time using handwheel L.

The problematic result, often anticipated by the pupils considering the shape and orientation of the tool, is that of the conical shape of the groove obtained with each transversal passage (figure 11a).

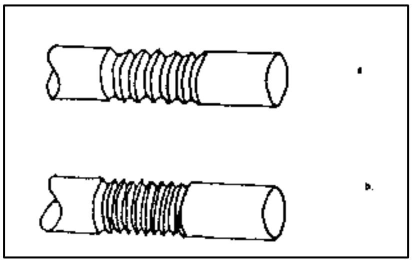


figure 11a,b

For this reason they often asked for a modification - which they considered necessary - of the tool's orientation in order to be able to machine either with its concave cup (figure 10): "it has the same shape", or with the rectilinear edge placed parallel to the part. Failing this, they suggested reaching the cylindrical shape progressively by "attacking" the tops of the grooves with the tip of the tool, considering that they would disappear after a several cycles (figure 11b).

For most of the pupils, the idea of being able to produce a cylindrical surface using a single rectilinear longitudinal stroke only appears at a late stage (and, a fortiori, later still for the cone, since its generatrix is slanted in regard to the rotation axis). To achieve such a notion, it is necessary to become aware of certain invariant spatial properties of the lathe, imparted to it by its very design: for example, the distance between the tool and the rotational axis of the workpiece remains invariant across action on handwheel L.

But, at the same time, this means that the subject has to decenter himself from his own actions so that he can resituate and coordinate them in an overall space. In effect, only the conscious discovery, or the discovery "in action" of the spatial structures underlying his procedures - often linked to failure of these procedures - enables the subject to recompose them and, for instance, to become aware of the relations of equivalence between a cutting edge of a given shape and a generator point with a suitable trajectory, or again between the iteration of elementary operations and their composed form.

Genesis of the properties of a robot

Like the previous one, this experiment (Rabardel, 1991b, 1993a, 1993b), consisted of learning - through discovery - to operate an artifact: a YOUPI type handling arm (figure 12). This artifact may be characterized as a machine for moving objects in space. The robot operating system consists of a control box with three mobile cursors (figure 13). Each cursor, in a different colour, corresponds to a 3-D XYZ reference axis of the robot's work space in such a way that each relative position of the three cursors determines a position of the end of its clamp in this space. The opening and closing of the clamp is controlled via the computer keyboard.

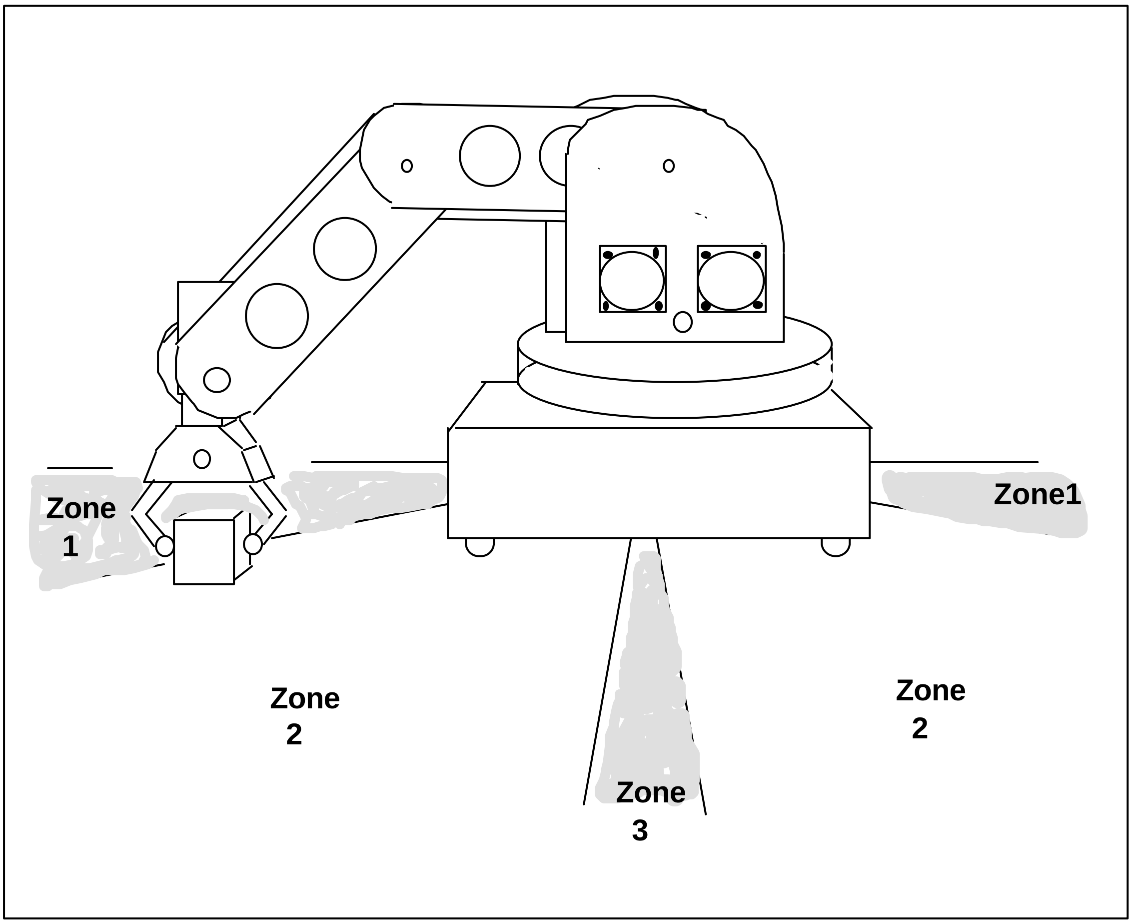


Figure 12
The handling robot
The shaded zones are not shown on the experimental system

The coordinates control system

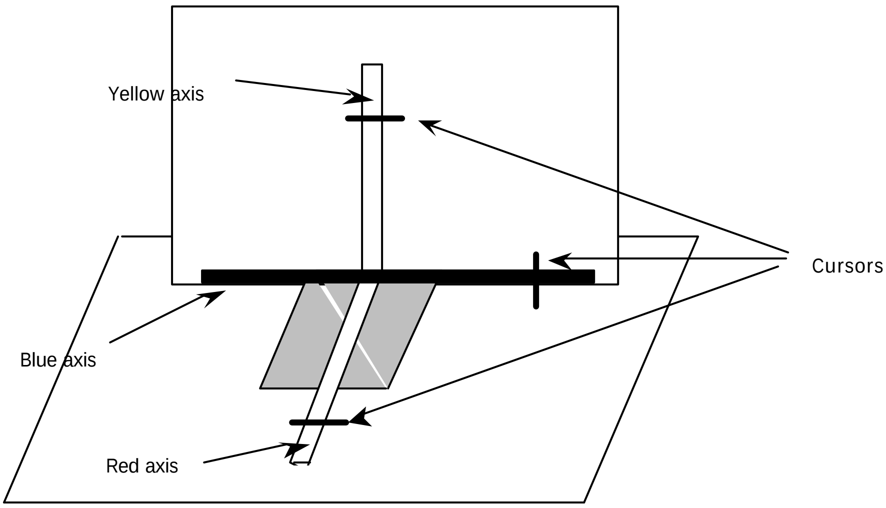


Figure 13
The control box

Since the cursor slide-rails are orthogonal to each other and are located on the control box in relation to a zone representing the place taken up by the base of the robot in its work space (this indication was given to the pupils), it could be considered that the "control space" (i.e. the orthogonal cursors and the representation of the location of the base) constitutes a representation of the robot's work space. In view of this property, it could be thought that learning about the robot would be relatively easy and that it would lead the pupils to conceptualize space in terms of three-dimensional references. In fact, this construction is done in stages, and not without difficulty for the pupils.

The task consisted of moving blocks using the robot. The situations were video taped. The representations and conceptions relative to the system successively elaborated by the pupils were inferred from their drawings and their verbalizations which were spontaneous or provoked by the experimenter.

The microgenesis of the properties of the system and of the corresponding action schemes involved five types of conceptualization. All the microgeneses observed can be described with these types of conceptualization, even if the microgenesis of each subject does not cover all these types of conceptualization.

* Initially, the block is reached and transported through step by step management of the machine movements, under visual-motor control, by manipulating the different cursors. The cursors are considered as associated with movements of the different parts of the arm (joints or segments). For example:

- the blue cursor is linked to rotation of the base;

- the red cursor is linked to movement of the elbow;

- and the yellow cursor is linked to that of the shoulder.

Under this representation, it is considered that the cursors have no relation with each other but that each of them is related to specific parts of the machine. Operating the robot consists of moving the cursors independently from each other leading to movements of the corresponding parts of the machine. Although such a representation is erroneous as regards the properties of the artifact, it is nevertheless functional locally: it enables the effects of the subject's actions on the behaviour of the robot in the front zone (zone 3, figure 12) to be foreseen and justified in an approximate way; therefore, its pertinence is found at the level of the causality of action.

* However, this representation does not enable the pupil to foresee the consequences of actions in the side zones where the effects obtained are very different. It therefore evolves: the cursors still have no relation with each other, but their relation with the parts of the machine varies in terms of the zone where the arm is located. For example, the red cursor is linked to movement of the elbow

but, in addition, in the side zones (zone 1, figure 12) it is also linked to movement of the base. The representation is more complex (although still wrong) since it involves modulating in terms of zones the dependences between parts of the robot and the cursors.

* In the next stage, not only do the relations of the cursors to the movements of the parts of the robot differ according to zones, but in some of them (for example, the border between the side and front zones) the cursors are considered as also interacting together: the blue cursor is still in relation with the movement of the base, but the red cursor amplifies its effect. Thus, new dependences intervene in the representation of the properties of the artifact: dependences between cursors.

* However, these evolutions of the representation are preparing a much more radical change through which the effects of cursor manipulation are no longer considered to be the movements of the joints and segments of the arm but the movement of the clamp in the work space. Causal conception of phenomena has changed: the previous dependences between the cursors and the parts of the robot disappear and are replaced with new dependences between the cursors and the trajectories of the clamp (the blue cursor is linked to the left and right movements and the red cursor is linked to the backward and forward movements). Correlatively, the representation of the causality of action evolves: the movements of the clamp result from the movements which the subject imparts to the cursors. They are conceived as having, initially, the same direction and, later, as having an amplitude proportional to that of the subject's action on the cursors. Progressively, pupils become aware of a homomorphism between the geometry of their actions and the geometry of movements of the clamp. However, the cursors are still considered as independent from each other.

* During the last stage, the representation of the causality of phenomena changes once again. The relations between the control space and the work space are no longer conceived in terms of movement but in terms of positions. Due to this, the cursors become totally interdependent. It is their coordinated and simultaneous positions which determine the positions of the clamp in the work space.

Initially, the positions of the clamp are refered to the base of the robot in the working space, while the positions of the cursors are relative to the graphic representation of the base on the control box (cf. shaded zone, figure 13). Subsequently, they are refered to a 3 dimensional system of axes which defines all the possible positions of objects in the work space: the robot as well as the clamp and the objects to be moved.

The control system acquires representative properties: the positions of the cursor in regard to the graphic representation of the base are used as indicators of the positions of the clamp relative to the actual base in the work space. Although the signification of this representation was explained by the experimenter during the initial instruction, it is only at this stage that the drawing of the base on the control box really acquires a representative status functional for the subject. This representative status is only achieved at the end of a process of joint elaboration of the causality of phenomena - which enables the cursor-clamp relations to be thought of in terms of positions inside two different though homomorphic spaces - and of the causality of action which enables the actions-events relations to be thought of as transformations of the spatial positions coordinated both within the distinct control and work spaces and between them. Due to this, the action schemes, which were previously movement schemes, become schemes for defining positions inside these two spaces.

Discussion of empirical results

To sum up, an essential stake presented in these three tasks consists of the subject's ability both to conceive the nature and the conditions of the transformation involved and to specify the relative part due to his own actions and those of the artifact in carrying out that transformation. In particular, what these experiments have highlighted are the microgenetic characteristics of this process of partitioning causality and action between the artifact and the user. We have shown that it parallels the joint evolution process of the pupil's representations of the causality of phenomena and of the causality of his own action.

A partial, or wrong (in terms of objectivity criteria) representation of the causality of phenomena interferes with the construction of sufficiently pertinent causal relations between actions and their effects. As a result, it does not enable the development of an action scheme efficient through the different tasks (efficiency criteria). This leads to an evolution of the representation of the causality of phenomena. In return, the representation of the causality of action is transformed, activating new action schemes based on different anticipations. This cycle is repeated as long as the representation of the causality of action has not reached a level of pertinence sufficient in view of the tasks which the subject has to accomplish.

Another important aspect, consistent with the IAS model, is that neither the microgeneses observed in the course of discovering how to use a lathe or a robot, nor the evolutions noted when the pupils moved from an anticipation of manual manufacture to an anticipation of mechanized means, strike us as resulting from a simple process of the subject's assimilation-accommodation of an artifact. On the contrary, they indicate a double elaboration that is both progressive and interdependent: that of the properties of the technical system, and that of the properties of the reality to be transformed, in this case essentially of spatial nature considering the tasks involved. The pupils' data acquisition strategies concerning the artifact, and their representative and operational activity during its operation (subject/instrument interaction) always turned out to be interdependent with their conceptions relative to the nature of the transforming process (instrument/object interaction), with the artifact mediating their action on the environment but, in return, mediating their conceptualization of that environment (subject/object interaction mediated by the instrument).

Conclusion

In this article, we have tried to develop problematics which would better situate technical activities, particularly those involving instruments, in the field of the psychology of acquisitions and of development. The universe of material artifacts, and the practices which are associated with them constitute, in themselves and in several respects, an interesting subject for research. Thus, cognition in instrumented activity, in present day fast changing technological contexts, appears to be a sensitive point - both theoretical and practical - in ergonomics, work organization, initial and continuous professional training, technological training, technology transfers, etc.

But, over and above work situations, there is very little human activity where the mediation of artifacts does not intervene in such a way that, from the earliest age, they constitute contextual factors of cognitive functioning. This leads naturally to questions relative to the genesis, in the subject, of the instrumental competencies linked to these artifacts, to the conditions of their emergence, to their nature and, particularly in the child, to their role in development. Does the instrumental relationship play a structuring role in cognition? Is it a factor of the acquisition of knowledge. If so, how does this knowledge relate to more formalized and scholarly forms of knowledge? Should disjointed, or even contradictory, modes of generation and of existence of knowledge be conceived?

Obviously, this notion of instrumental genesis raises questions in which psychological, didactic and epistemological dimensions closely overlap. The standards and forms of objectivation which govern the production of scientific knowledge (and, through derivation, scholarly knowledge) often constitute the yardstick with which to judge knowledge in general. Thus, in regard to these standards, other forms of thought and knowledge may appear or be designated as uncompleted or "downgraded" forms of erudite knowledge. Examples could be taken from ethnology or in the professional and technical field (Lave, 1988; Scribner, 1986). In these fields, critical voices argue, from epistemological viewpoints, in favour of less "intellectualocentrist" approaches to "practical sense" (P. Bourdieu, 1980) and for the recognition of specific forms of existence and functioning of practical knowledge in relation to technology, irreducibly distinct from an "applied science" conception (J. Staudenmaï er, 1985; J. Perrin, 1991).

These considerations are not only valid for the activities instrumented by material artifacts. Although these artifacts are the ones with which the instrument concept is more immediately associated, the instrumental dimension also concerns the mastery of language, writing and numbers which may be considered as technologies intended to communicate, to represent and conserve information and to calculate. Asking a question, using a check list or giving change all constitute a practical relationship with what Vygotsky termed "psychological instruments", a relationship which differs considerably from the one established with them by the grammarian, the semiologist or the mathematician. Yet, most often, including in didactic situations, this instrumental relation is the subject of real occultation, producing what Y. Chevallard (1991), in mathematics, has called a phenomenon of hypostasiation, through which the artifact is seen as existing in a sort of ideality independently from the concrete practices from which it emerges or which constitute it[5].

This results from the fact that instruments, by nature, whether semic or material, and unlike objects of the natural sciences, justify a double approach. As artifacts, they are suited to an objectivistic approach which may legitimately consider them as independent both from the actual situated conditions of their implementation and from the individual intentions and strategies of their users. By annuling these situational and procedural dimensions, it is then possible to bring to the fore certain objective regularities of artifacts: structures, relational systems, laws of evolution, etc. In the study of language, for example, this has been the approach taken in general linguistics. In the study of manufactured objects such an approach would be that of general technology.

But just as Saussure stressed the fact that "speech is the condition of language", meaning the locus of its actual functioning and of its evolution, we similarly maintain that the instrumental relationship is

[5] Beyond this, the occultation of the role of instrumental devices and practices in the production of mathematical knowledge, has led to overlooking the possibility of an epistemic effect of instrumentation on the learning process. Any tool, in addition to its operative function, may also act like an analyzer of the problem situation, an indicator of its properties - in particular those which are functionally pertinent.

the condition of artifacts, their mode of existence. In effect, although the epistemic break between artifact and instrument (or between language and speech) is legitimate and productive, care should be taken to avoid considering users' behaviour in terms of an application of the technologist's (or the grammarian's) model. Therefore, it is necessary to devise another approach, owing little to the previous one centred on objects, but capable of taking into account the instrumental dimension, that is the condition of artifacts embedded in actual praxis.

In theory, there are three possible approaches of artifacts (whether semiotic or material) according to the focus being placed on the description (syntactics), function (semantics) or pragmatic use. In both the fields of language and of manufactured objects, research has not invested these three levels simultaneously or equally. The pragmatic dimension is the one that was tackled last. In linguistics it has won its place where it maintains close links with psychology, in particular the psychology of development (cf. for example E. Bates, 1976, 1979). Inside the field of technology, however, the scientific elaboration of the equivalent of pragmatics remains be undertaken. Both the psychology of learning and development and didactics feel the need for such work to be carried out. Hopefully, as this article may have shown, they also have some of the keys necessary to contribute to its undertaking.

What are then the perspectives in which future research could be developed?

As recently formulated by science educationist D. Layton (1991): "adopting a cognitive perspective, the primary challenge in relation to technological knowledge, is the nature of the process by which a design concept, interpreted broadly, becomes integrated with the specific constraints of a context to yield a particular outcome, whether an artifact of some kind or a practical action." Unfortunately, as he goes on to say: "although much research has been conducted on problem solving involving science, little of this has been in relation to technological and other problems involving practical action. We lack understanding of the process and its developmental characteristics."

Describing and analyzing this process and elaborating its developmental caracteristics, would effectively appear to be priority themes through which questions for research could be orientated:

- How are the cognitive frameworks of pragmatic activity constituted? What are its primitive forms and forerunners?
- How is the instrumental relation with the artifact constructed: the attribution of finalization, of functionality, the understanding of its functioning?
- In the conduct of instrumented action, how do the respective properties specific to the subject's action, to the artifact and to that upon which it acts become differentiated and articulated?
- How is the representation of a technical problem elaborated: in particular, what role do familiar schemes and artifacts play in the constitution of this representation?
- Regarding activity in technical situations, how are the teleonomic, causal and evaluative aspects constituted, particularly in terms of different types of tasks: artifact design, use, manufacture, repair?
- What are the conditions of the constitution and existence of technical knowledge? How is it structured? Is it organized in conceptual fields (Vergnaud, 1985)? If so, how can pragmatic and conceptual knowledge or scholarly and professional knowledge be articulated?

Although not exhaustive, this list shows some of the empirical and theoretical problems that are raised for psychologists of cognition and development, as well as for didacticians, by the study of instrumented activity and around which a community of interest and work could be formed.

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Key words: Artifacts, Situated cognition, Instrument, Instrumented activity, Microgenesis, Technology and vocational education.

Abstract: This paper addresses from a theoretical point of view a once much debated issue which is brought back to the fore in psychology as a result of a growing attention to the effects of technology and of technological change on the way we live, learn and work. This issue concerns the relationships between cognition and the artifactual nature of many of the objects on which it is brought to bear in everyday, work and school situations.

If cognition evolves, as genetic epistemology has shown, through interaction with the environment, then it can be expected, in the course of its genesis, to have to accomodate to the particular specific functional and structural features which characterize artifacts. Does this have an effect on cognitive development, on knowledge construction and processing, on the nature itself of the knowledge generated? If so, through what macro and microgenetic processes can this effect be thought to be actuated?

These questions are of particular relevance in the fields of technology and vocational education, but, in theory, they concern all situations in which activity is instrumented by some sort of technology - including technology not habitually considered as such: symbols, numbers, graphics, etc. They also constitute an important dimension in the study of situated cognition.

Discussion focuses first on the way past and present models of human cognition have related to instrumented activity and, subsequently, a model and concepts are suggested. These points are then illustrated through observational data relating to situations in which children were confronted with tasks involving designing artifacts and utilizing unfamiliar machines, i.e. a lathe and a robot. Finally areas for future research within this problematic are sketched out.